Study on Project to Grid and Project to Project Interconnection

REPORT

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Abbreviations

AC	Alternating Current
AEPC	Alternative Energy Promotion Centre
ANSI	American National Standards Institute
AVR	Automatic Voltage Regulator
BCR	Benefit to Cost Ratio
CTEVT	Council for Technical Education and Vocational Trainings
DC	Direct current
DG-NREEC (Indonesia)	Directorate General for New Renewable Energy and Energy Conservation
DOED	Department of Electricity Development
ELC	Electronic Load Controller
ERC	Electricity Regulatory Commission
ETAP	Electrical Transient Analyser Program
FIRR	Financial Internal Rate of Return
FIT	Feed-In Tariffs
FNPV	Financial Net Present Value
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
Hz	Hertz
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMAG	Induction Motor As Generator
IPP	Independent Power Producer
JICA	Japan International Cooperation Agency
kA	Kilo Ampere
kV	Kilo Volt
kVAr	Kilovolt-Ampere Reactive
kW	Kilowatt
kWh	Kilowatt Hour
LF	Load Factor
MEG	Monthly Electricity Generated
MEMR	Ministry of Energy and Mineral Resources (Indonesia)
MES	Monthly Electricity Sold
MHFG	Micro Hydro Functional Group
MHP	Micro Hydropower Plant
MoEWRI	Ministry of Energy, Water Resources and Irrigation of Nepal
MLF	Monthly Load Factor

MOU	Memorandum of Understanding
MPPT	Maximum Power Point Tracking
MV	Medium Voltage
MVAr	Megavolt Ampere Of Reactive Power
MW	Megawatt
NEA	Nepal Electricity Authority
NGO	Non-Governmental Organization
ONAF	Oil Natural Air Forced
ONAN	Oil Natural Air Natural
PMG	Permanent Magnet Generator
PPA	Power Purchase Agreement
PPP	Public Private Partnership
R&D	Research and Development
RE	Renewable Energy
RERA-II	Renewable Energy for Rural Areas II
SLD	Single Line Diagram
SWBD	Switchboard
USAID	United States Agency for International Development
USD	United States Dollar
W	Watt

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Executive Summary

Nepal is nearing its electrification target of 100% electrified by 2030, with about 10% of the population remaining to be fully electrified. Majority of it is through the national grid while renewable energy (RE) projects also contributed towards the goal. Among the RE projects, micro hydropower projects are one of the key contributors towards electrifying rural households. The national grid is also expanding its reach in remote locations previously electrified through RE projects. In this scenario, the consumers of RE projects gradually shift towards the national grid seeking lower tariff and reliability. The RE projects, with loss of consumers, will be left defunct. The MHPs, specially, have been constructed through public participation and the government's subsidy. Also, to better the reliability of distribution network in the remote areas, connection of such MHPs to extended nation grid seems logical. Similarly, another way to improve the reliability of the electricity in a local area could be done through interconnection of two or more MHPs in the vicinity. The interconnection not only improves system reliability but also increase availability factor, capacity factor, and power quality, by opening the opportunities to sell excess energy and serve local loads or if possible, to the regional grid.

During the study simulation exercises were carried out for different situations of such interconnections and possible faults arising in the system. The simulations have been carried out for steady state, short circuit condition and transient stability analysis. The Baglung mini-grid was taken as sample for MHP-MHP interconnection while Syaure Bhumi MHP was sampled for MHP-grid connection. The main results of the simulation of MHP-MHP interconnection are:

- At maximum load condition, the excessive reactive power is absorbed by the generators by operating in leading power factor (under-excited) with average power factor of 0.93 (leading). This operation region is still within the generators' tolerance. The average generator loading is 88%.
- At average load condition, the excessive reactive power is absorbed by the generators by operating in leading power factor (under-excited) with average power factor of 0.63 (leading). This operation region is exceeding generators' tolerance. The Average generator loading is 40%.
- The extremely low power factor during average loading condition can be corrected by adding shunt reactor in 11 kV substation to absorb reactive power. The low active power loading of the generators can be solved by switching off several generators, preferably in mid-section of the system.
- Transient stability study on loss of generation of the largest MHP shows that the local load of that MHP was constantly supplied from another source. The frequency fluctuation was out of tolerance limit although the voltage fluctuation remained within the limit.
- Transient stability study on loss of generation of the largest MHP along with load shedding of the local load connected to that MHP resulted in both frequency and voltage fluctuation still within tolerance.

Similarly, the results of MHP-grid connection simulation are:

- At maximum loading condition, there is slight increase in voltage level (0.6 %) at farthest point considering the relatively small size of the MHP compared with total size of the grid. The total losses in the system also decreased.

- In average load conditions and minimum load conditions, the voltage profile was better than that one in maximum load conditions with significant reduction in losses in the system.

- In short circuit analysis, the maximum short circuit current in both 11 kV and 0.4 kV systems is relatively low. The standard design and rating of the 11 kV switchgear with 12.5 or 16 kA short circuit current rating is adequate for the system.

The study also looked into the enabling environment of the interconnection practices. Some of the key recommendations based on the findings are:

- Clear standards, guidelines/code should be developed for MHP-MHP and MHP-Grid interconnection for smooth functioning of the modality and increasing interest of the stakeholders involved.

- The Power Purchase Agreement (PPA) document as well as process for the grid connection of MHPs and mini-grid should be simplified than that for bigger sized hydropower plants. It is better to complete the MHP PPA process through the Provincial office of NEA with some form of consent taking from NEA central PPA department (if necessary).

- The joint initiative of NEA and AEPC should be continued to resolve technical issues as well as pave way for mainstreaming interconnection practices.

- Knowledge and technology transfer along with capacity development activities need to addressed for generating awareness and having capable local manufacturers for scaling-up the practices.

- Viable business models for interconnection, also considering net metering aspects should be developed for investment readiness in the projects. This may include introduction of productive uses of electricity.

1. Introduction

1.1. Purpose and rationale of the assignment

The Renewable Energy for Rural Areas II (RERA-II) project, a follow-up project of its predecessor Renewable Energy for Rural Areas (October 2016-April 2020), aims to strengthen the capacities for the public sector for promotion of Renewable Energy (RE) and using RE on the supply and demand side.

Decentralised RE systems such as micro hydropower plant (MHP), solar photovoltaic, and biogas have been helpful in providing energy services to rural households thereby improving the rural economy. Specifically, MHPs have been serving off-grid rural households in the hilly regions since they were introduced in Nepal in the 1960s. MHPs are contributing to uplift livelihoods of rural people and opening up other avenues for economic activities. With support from the Alternative Energy Promotion Centre (AEPC), more than 30 MW of micro/mini hydropower plants have been providing off-grid electricity to more than 400,000 rural households.

With the target to electrify every household of Nepal within 5 years, the Nepal Electricity Authority (NEA) is also expediting extension of the national grid to rural and remote areas. Unfortunately, as soon as the national grid reaches a MHP jurisdiction, people tend to prefer connecting electricity from grid and they eventually switch from MHP to grid supply, thereby leaving the MHPs idle and ultimately abandoned. The extension of the national grid in MHP areas has already caused shut down of more than 100 MHPs with an accumulated capacity of about 5MW and become stranded assets, while another 100 MHPs are going to be affected soon. There are cases of grid-extension not only in the areas where MHPs have been operating but also in the areas where MHPs are being constructed.

To overcome this situation, connection of MHP to the grid is a possible option and has been piloted in Nepal. However, the technology used is still evolving as well as expensive and thus the progress of connecting MHPs with the grid has been stalled. Additionally, there is a potential for the project to project (MHP-MHP) interconnection in many rural areas in order to exchange energy among the MHPs.

Initiation of studies and discussions has been conducted for scaling up and bolstering partnerships on grid-based approaches in the past, with gradual progress along the way. This is an opportune moment to look at the perspective of grid interconnection as NEA and AEPC both have shown willingness through NEA's board of directors decision about connecting isolated MHPs to the grid provided that: (a) a grid connection of MHPs does not add financial liabilities to the NEA, (b) MHPs are of "grid-ready" quality and do not create safety problems to the grid itself, and (c) only MHPs with synchronous generators (as compared to induction generators) are connected to the national grid to balance the reactive power needs. Recently, AEPC and NEA have have jointly initiated development of standards for interconnection. They are also preparing an integrated masterplan for mini-grids. AEPC has also targeted to conduct feasibility study of MHPs to be connected to the national grid and also allocated budget for grid-connection of viable MHPs.

Considering this situation, RERA-II has initiated a study that seeks for the optimal technology solution for MHP to MHP interconnection and MHP to national grid interconnection backed by a detailed simulation study to understand the transient behaviour of the proposed technology. The simulation study will support in further technology development in the areas of grid and MHP interconnection within the country. Thereby, the study will support in facilitating the integration of 5 MW of clean energy into the national grid as well as identify possible technological options to promote MHP to MHP interconnection for the exchange of surplus energy from one MHP to another MHP.

1.2. Background

Mini-grid definition in this study is an interconnection of several MHPs altogether into a common grid which involve Medium Voltage (MV) distribution line. Often, along with the increasing economic needs of the community, isolated MHP cannot meet the increasing demand for electricity. In such a case, a mini-grid can be a viable option. To form a mini-grid, some standalone MHPs must have excess power and others have a power deficit. By connecting several MHPs to form a mini-grid, the power balance can occur between MHPs that have excess power serving underpowered areas, especially during off-peak and peak hours. In addition, with a mini-grid, if one or two MHPs are turned off, the other MHPs can continue to supply power even under limited loads, thereby increasing system reliability compared to isolated MHP system.

In other words, the main purpose of interconnection is to improve system reliability, availability factor, capacity factor, and power quality, by opening the opportunities to sell excess energy and serve local loads or if possible, to the regional grid. One of the first pilot project was connection of six MHPs into a local mini-grid in Baglung. However, the MHPs are now operating in isolated mode. AEPC has been working on couple of other such projects like such in Taplejung and Jumla, but they are yet to be completed.

Similarly, with extension of the National grid to the MHP serving areas, the MHPs can connect to the grid to either export the power generated or exchange power based on the availability or requirement of power after serving the local energy needs. The power purchase agreement (PPA) is necessary for both cases, while the metering system differs. For power exchange, net metering system has been introduced with addition of bi-directional main meter and check meter.

Till date, four MHPs have been connected to the national grid as pilot projects. They are Midim Khola MHP (100 kW), Chimal MHP (95 kW), Leguwa Khola MHP (40 kW) and Syaure Bhumi MHP (23 kW). Many others are also in the process or are expecting to be connected to the national grid. The development and promotion of RE projects largely falls under the mandate of the local government. However, many local governments are yet to develop and implement policies for RE. They also lack technical capacity to deliver the projects and are seeking supports from the provincial as well as the national institutions. Few of the local government have also reached out to the private sector for supporting them in understanding and work in RE sector.

AEPC in collaboration with NEA has been working to mainstream grid-connection of MHPs and other RE projects. For the upcoming fiscal year, AEPC intends to pave ways for gprid-connected MHPs through conducting feasibility studies and supporting to connect feasible projects to the national grid. NEA has also joined hands with AEPC is preparing a masterplan for years to come.

1.3. Approach and Methodology

The study focuses on MHP-MHP interconnection (mini-grid) and MHP-National grid interconnection (grid-interconnection) in Nepal. The assignment started with the desk study.

Desk study:

The desk study included collection and review of different literature including policies, technical documents, business models and plans and programs. The desk study supported in identifying the policy barriers as well as in confirming the different mandates and modalities in use for the purpose. During the desk study, international best practices were also reviewed. The main activities conducted during the desk study are:

- Assessment of interconnection policies, plans and strategies

- Assessment of electricity and RE related policies of federal and provincial governments
- Assessment of regulations: provision of regulations in electricity regulations, act including power purchase agreement modalities, grid connection agreement
- Identification of barriers that currently exist for grid interconnection
- Provision of mandates of local governments as provided by the constitution
- Review of international best practices, technologies in use and possible knowledge transfer

Mapping of stakeholders and programs:

Identification of major stakeholders of MHP and grid-connection is important to analyse the identified barriers, delve more on the challenges and limitations as well as recommend the optimal solutions to scale-up the activities. The mapping included:

- Identification of key stakeholders
- Their inter linkages and intra linkages with other eco-system stakeholders
- Identification of key challenges and limitations faced by stakeholders
- Preparation of a market map of grid interconnection and MHP-MHP interconnection
- Identify suitable international vendors, local manufacturers and possibility of their interconnectivity

Data Collection:

Data collection from the MHPs and nearest substations was carried out. Local technician from the area were mobilised to collect the required data. The data included project infrastructure, flow control mechanism, load patterns, electrical parameters of both project and grid, distance between the projects and grid, financial parameters, etc. The checklist for data collection in attached in Annex 1.

Secondary data was also collected from NEA. The sites used for data collection are:

- For MHP-grid connection: Syaure Bhumi
- For MHP-MHP connection: Baglung mini-grid

Simulation:

Electrical Transient Analyser Program (ETAP) and DIgSILENT Powerfactory[1] are used for modelling and analysing the power flow, short circuit and transient stability. Simulations are carried out based on existing electrical system data obtained from secondary data and surveys and assuming the addition of MHP. Simulations are carried out for the following analysis:

- Load flow (steady state) analysis to analyse the proper configuration of MHP's (generator) mode of operation in load sharing, changes in direction and magnitude of power flow and change of losses in the system.

[1] DIgSILENT was used in addition to ETAP to provide better load flow characteristics in droop mode with proportional load sharing of each MHP in Baglung mini-grid interconnection study. As for short circuit and transient stability analysis, DIgSILENT model yields similar result as ETAP model.

- Short circuit analysis to analyse the maximum short circuit current that may occur in the system to further determine the appropriate short circuit rating of equipment to be used.
- Transient stability analysis to analyse the impact of disturbances that occur in the MHP on the electrical system. Faults can be in the form of significant load changes, short circuits or a power cut from an existing generator.

Similar information was acquired on the mini-grid network for integrating the MHP operation and connected loads (mapping between MHPs and loads that potential to be interconnected). We also analysed the control and protection scheme of the existing MHPs ensuring proper droop setting and the following conditions:

- The technology proposed for Electronic Load Controller (ELC) will be compatible with MHP to MHP interconnection (mini-grid) and MHP interconnection with National Grid (grid-connected)
- The ELC technology will be capable to operate in constant frequency-controlled mode or shall achieve frequency regulation of +/- 2.5 % of 50 Hz
- The full load rejection frequency stabilization of ELC will be less than 0.5 sec as well as the error response time shall be less than 0.05 Sec.

For mini-grid,

- It shall control the active power injected to the local grid in proportion to the active power generation of each MHP station. The ELC shall be incorporated with frequency/speed droop characteristics.
- All the plant operating parallel in mini-grid mode should have different speed droop characteristics in order to share the load in proportion to their respective kW generation. Moreover, the variation of frequency must in the limit of +/- 2.5% of standard frequency
- Adequate provisions for adjusting speed droop (0-10%) will be provided with ELC to operate in mini-grid mode

For grid-connected,

- The frequency of the overall system is governed by that of the utility system and hence there is no role of ELC after the synchronizing. An automatic mechanism for the disconnection of ELC after synchronization shall be incorporated within ELC.
- When the plant is disconnected from National Grid it should operate in an isolated mode without exceeding standard frequency.
- Auto-grid tracking mechanism for synchronism
- ELC may have a multichannel design and switching pattern for stability and low harmonics. As per IEEE 519, it should not exceed 5% of total harmonic distortion in the voltage waveform and 3% in the current waveform.

Knowledge transfer and capacity building:

Techno-economic viability of mini-grid and grid-connected projects was analysed. This also included human resource capacity required for the interconnection purposes as well as different financial requirements as per PPA modalities. A session for AEPC, private sectors, and practitioners on the results of the simulation is planned for strengthening the capacity of key stakeholders for uptake of this result.

Reporting, Outreach and dissemination:

A final technical report includes design and simulation results.

A virtual sharing workshop will be organised to share the findings, recommendation for scaling up grid interconnection as well as MHP-MHP interconnection in Nepal.

1.5. Assumptions and Limitations

In the simulation of the study, it is assumed that all generators are in droop mode. This means that all generators serve the load proportionally according to their respective nominal power capacities. In this study it is also assumed that all ballast loads at these 6 locations are operating according to their respective capacities.

When the load is low, all generators continue to generate power according to their capacity. The power generated is used to serve existing loads and ballast loads. Because the load for the village is low, most of the power generated by the generator will be absorbed by the Ballast Load.

However, at night, the load on all villages will increase, especially at 19.00 at night. Of course, the power generated by the generator is mostly absorbed by the load and partially absorbed by the Ballast load.

The simulation is only carried out during the peak load, which is at 19.00. This is done to ensure that the existing generator can serve the entire load with a sufficiently voltage.

2. Policy and Institutional Framework for Rural Electrification in Nepal

The rural electrification in Nepal is carried out through either by decentralized renewable energy (RE) systems or through extension of the National grid. The AEPC, under the Ministry of Energy, Water Resources and Irrigation (MoEWRI) is the key government organization for the nation's RE efforts. The NEA is another key government organization which provides mainstream utility-based electricity to the national population and also operates the National grid. The main institutional arrangement is summarised as below:

Local Government

The Constitution of Nepal (2015) has incorporated federalism as the foundation of Nepal's political governance system and established a federal, provincial, and local level governmental structure. The local government can design policies and support programmes, and deliver public goods and services in regards to decentralized RE upto 1 MW and other local level development projects. Most of the local governments are yet to develop individual policies for RE promotion and development. Moreover, the newly established local governments lack capacities (human and technical) and means to take up their new tasks relating to decentralized RE.

Department of Electricity Development (DOED):

DOED has the mandate for providing licenses for study of hydropower/electricity development and generation of electricity from different projects. DOED has updated its guidelines regarding generation licenses of projects including MHP from 100 kW to 1 MW. As per the guidelines, Local Government issues generation license of MHP projects up to 1 MW.

Electricity Regulatory Commission (ERC):

ERC is a recently formed national entity that oversees the regulations, tariff management and protecting consumer interest within the electricity sector. ERC is responsible for Technical regulation (approving grid codes, safety standards), Economic regulation (tariff, wheeling charge, generation and trading PPA, least cost generation plan), Protection of consumer's rights and interests (tariff, public hearing) and other regulatory affairs that includes institutional strengthening (helping establish Integrated Information Management system). ERC has also published new guidelines for conducting PPA titled "PPA and Licence Conditions Bylaws 2076".

Nepal Electricity Authority (NEA):

As the government utility, NEA plans, constructs, operates and maintains generation, transmission, and distribution facilities in Nepal's power system. It also purchases power from private developers and exchanges power with India to meet the nation's needs. NEA signs the Power Purchase Agreement with hydropower developers and has also been signing PPA with MHP developers for projects like Syaure Bhumi MHP (23 kW), Leguwa Khola (40 kW), Midim Khola (100 kW), etc. NEA has also been implementing Community Rural Electrification Programme since 2003 where NEA lease out distribution system and sells bulk electricity for the distribution to community cooperatives.

Alternative Energy Promotion Center (AEPC):

AEPC is the nodal agency for promoting and developing RE systems in Nepal. AEPC has been implementing RE projects with support from the government as well as bilateral and multilateral development partners. AEPC has supported in construction of numerous micro/mini hydropower plants of capacity of generating energy around 30 MW serving more than 400,000 rural households. AEPC has been working to mainstream RE as one of the option for modern energy access. AEPC has supported in piloting MHP-MHP interconnection as well as MHP-grid connection previously.

2.1. Existing Regulations and Gaps

Different policies and technical standards have been developed for connection of MHP with the national grid while implementing the pilot projects as well as paving way for up-scaling the activities. Some of the key highlights of the policies and technical standards that are being implemented are:

- ERC's PPA guidelines[2] have explicitly specified the procedures for fixing tariff of MHP as well. It also specifies documents required for the approval of PPA along with application format, fees as well.
- Model Power Purchase Agreement signed between NEA and Hydropower Project Owner specifies several technical as well as other requirements for grid connection. Several operational guidelines are assumed to be included in Operating Procedures. Validity of PPA, Monthly Energy Generation, Energy Rates, Payment Mechanism, Operation requirement, Insurances, Force Majeure, Dispute resolution, etc. are included in the PPA. Likewise, Grid Connection Agreement signed with NEA explicitly specifies the grid connection requirement and other regulatory provisions.
- NEA Grid Code 2005 is the key document being used for the grid connection requirement of MHP as well. NEA grid code specifies various clauses, conditions, requirements and methodologies for the Grid Users.
- Furthermore, NEA board decision has highlighted the requirement for the Grid Connection of MHPs that include Protection requirement, Generator requirement, Metering requirement, Safety requirement, etc. Likewise, NEA through its Board Decision specified some condition for the T connection of MHP on NEA 11 kV Distribution system also.
- AEPC has prepared a Micro Hydro Projects Interconnection Equipment Standards and Specification which specifies the equipment standards and specification regarding mini-grid formation.

The main activities ongoing based on the above documents for MHP-MHP and MHP-grid Interconnection are:

AEPC's activities for MHP-MHP & MHP-Grid Interconnection

AEPC has prepared a Micro Hydro Projects Interconnection Equipment Standards and Specification which specifies the equipment standards and specification regarding mini-grid formation. AEPC has been practicing its grid-connection efforts using this document. However, the document is being upgraded for the evolving situation before being disseminated. AEPC through its partners provide technical as well as managerial supports for MHP-MHP interconnection and MHP-grid interconnection for community level MHP owner and functional groups. AEPC conducts several studies of MHP-MHP interconnection, MHP–grid interconnection through technical experts, consultants, partners etc. AEPC has initiated process for making policy guidelines for MHP-MHP interconnection and MHP-grid interconnection in collaboration with NEA. AEPC supports community for preparation of feasibility study, technical, financial as well as economic analysis for MHP interconnection. However, the Renewable Energy Subsidy Policy is yet to explicitly mention the Interconnection or Grid-connection subsidies for scaling-up the efforts.

[2] http://erc.gov.np/storage/listies/April2020/ppa-and-license-conditions-bylaws-2076-final.pdf

NEA activities for MHP-Grid Interconnection

NEA Grid Code 2005 is the key document being followed for the grid connection, especially for bigger size generators. Basically, Grid Code specifies grid planning requirement, performance standards, grid connection requirement, grid operation management, grid metering, scheduling and, system test etc. MHP being smaller size and connecting at distribution voltage level, MHP-grid connection requires simplified connection guidelines. As being national utility NEA is facilitating MHP-Grid interconnection through its policy decisions. Basic guidelines and technical requirement has been developed for connection of MHP with the national grid. Some of requirement for Grid-connection of MHP is summarized in the following table:

Description of Features	**Requirement for Grid Connection**	**Source**
Generating Equipment Type	Synchronous Generator	NEA Board Decision
Nominal Generation Voltage & Frequency	3 Phase, 400 V, 50 HZ	Normal Practice
Grid Connection Voltage	11 kV	NEA Board Decision
Connection Scheme	T Connection on 11 kV feeder or Connection at Substation	NEA Board Decision
Generator Power factor at Connection Point (Adjustable Q-V Control)	0.85 lagging to 0.9 leading	Grid Code 2005
Minimum Accuracy of Main & Check Meter	0.2 Class, Bidirectional	Grid Code 2005
Minimum Accuracy of Metering CT and PT	0.5 Class	Grid Code 2005
Metering Voltage	11 kV	NEA Board Decision
Minimum Protection on Grid Side line	50/50N, 51/51N, 27, 59, 51V, 67, 81 O/U, VVS / ROCOV	Normal Practice/Board Decision
Special Requirement	Safe Anti Islanding features in case of Grid Failure	NEA Board Decision
Protection for Generating Equipment	As per relevant standards	
Line Breaking / Making Equipment	VCB	NEA Board Decision/Grid Code 2005
Communication at PH	Dedicated Telephone Line / Mobile Phones	NEA Board Decision/Grid Code 2005
Operational Mode	Grid Connected and Islanded both	Model PPA
Black Start Capability	Required	Model PPA

NEA has already signed agreements with some community owned MHP for purchasing of power through PPA. Some of the key highlights of PPA are summarized below:

- With this model a standard PPA between NEA and MHP is signed for the net export of electricity from MHP to grid.

- PPA specify contract energy on monthly basis, Energy Rates, Payment Mechanism, Operation requirement, Insurances, penalty provisions, Force Majeure with several other regulatory provisions.

- Grid Connection Agreement as being a part of PPA, explicitly specifies the connection / metering point including voltage, grid connection requirement including metering, protection schemes and other mandatory provisions.

- The lowest voltage level for grid connection of MHPs is currently set at 11 kV

2.2. Feed-in-Tariff for RE Systems

The feed-in tariff (FIT) for MHPs is same as the rates for big hydropower projects. The common energy rate practiced for both buying and selling of energy as per PPA is NPR 4.80 per unit for Wet season Months and NPR 8.40 per unit for Dry season months[3]. The net metering system also follows the same rate.

Generic setting for wet and dry season months:

Case 1: Wet Months: Baishakh to Mangsir, Dry months: Poush to Chaitra

Case 2: Wet Months: Jestha 15 to Mangsir 15, Dry Month: Mangsir 16 to Jestha 14

If there is 30% or more dry annual energy then Case 2 will be applicable otherwise Case 1 will be applicable.

The PPA rates are subjected to simple annual escalation conditions commonly 3% for 8 years. However, fixing the PPA rate and giving the consent for signing of PPA is under the jurisdictions of ERC. Multiple departments and agencies are being involved for the completion of PPA process.

In case of other Renewable Energy systems, such as electricity generated from solar photovoltaic, wind and biomass energy generation projects, the tariff set is NPR 7.30 per unit.

All of the grid-connection projects follow the same process for PPA signing. The grid-connection projects need to plan for 3 years regarding the electricity demand, generation and buy and sell planning. The evaluation of technical and financial feasibility is a must for any projects above 100 MW, while only technical feasibility evaluation is required for projects below 100 MW. ERC determines the PPA rate and approval for PPA signing process. For project below 10 MW, the buyer can buy the electricity based on the availability declaration provided by the seller. In case of undelivered electricity due to natural disasters, there is no penalty.

2.3. Challenges and Problems of MHP-MHP and MHP-Grid Interconnection

Mini-grid Operational Modal in Nepal

The Mini-grid is not a single entity but an arrangement of multiple networks and multiple power generation units with multiple operators employing varying levels of communication and coordination, most of which is manually controlled. Management system of mini-grid will be more complicated than the existing standalone operation. Management and technical

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[3] NEA, Model PPA document

aspect are the significant and vital aspect for enhanced operation of the Mini-grid which is entirely new practice in the segment. For a mini-grid power system to sustain and run smoothly, it is significant to determine who invests, develops, owns and operates the system. More importantly, the issue of ownership becomes decisive. The working modality for mini-grid under rural circumstances is specifically dealt with three options. These are

Option A: The whole system, including generation and distribution, is managed by one entity.

Option B: The "business as usual" situation, where the Mini-grid operator will be receiving surplus power only but it coordinates among the seven MHPs.

Option C: The Independent Power Producer (IPP) model where each MHP will be responsible for the generation only and load management and dispatching will be controlled by the Mini-grid operator.

Case: Operational Model of Baglung Mini-grid[4]

This mini-grid at Baglung District, Nepal is funded by RERL/AEPC contributing 90 % of the total investment cost. The remaining is contributed by the community as kind participation, so Community-based IPP cooperative model was adopted. Thus, Urja Upatyaka Mini-Grid Cooperative was formed from the representatives of each Micro Hydro that are connected to the Mini-grid. Rule, regulations and other legal documentation such as *Arthik Niyamawali*, *Bidhut Bitaran Niyamawali*, *Biniyamawali*, *Karmachari Sewa Niyamawali* & Power purchase agreement were developed. This model was chosen to enhance the communal responsibility among the members or the beneficiary households for the project sustainability. The Cooperative is responsible for operating and maintaining the Mini-grid, distribution and consumer services, and individual Micro Hydro Functional Group (MHFG) were restricted to IPPs. The trading arrangement were made in such a way that the Cooperative buys electricity from respective IPP and sells it to consumers that were previously supplied by individual MHFG and new consumers were added by expanding distribution system as well. This executive body of the co-operative has the decisive power for operation, maintenance, expansion of transmission and distribution lines, fixing PPA rate, tariff structure, office management, hiring the staffs and all other related issues. The main objectives of Urja Upatyaka Mini-grid Co-operative are:

- To purchase electrical energy generated by the 6 MHPs situated within the Kalung Khola valley and distribute (sell) the same to consumers.
- To raise financial resources from shareholders to carry out activities for long run sustainability of the organization.
- To promote and assist cooperatives movement in the project area.

Currently, all MHPs forming Baglung mini-grid are operating in isolated mode. This means each MHP is responsible for distribution of village load and operation of MHP. Mini-grid modality was operational for about 1 year after its formation. The main reason behind the unsuccessful operation of Baglung mini-grid are low income for smaller MHPs, complex operation and managerial model, lack of local manufacture, communication, load management, local conflict, etc.

Issues of MHP-MHP Interconnection

Formulation of mini-grid / MHP-MHP interconnection will unite different communities of MHS users but it's equally challenging to bond them without any dispute. This technology is more complex than the isolated MHP management, operation & maintenance as the rural

[4] RERL Reports, Techno-Socio-Economic Study of Baglung Mini-grid

communities have limited resources in term of finance, human resources and technical knowhow. The issues and challenges which may affect the sustainable interconnection are categorized as below:

1. Limited policy guidelines – The NEA and AEPC are yet to fully develop MHP-MHP interconnection policies and guidelines as well as the technical standards. As the sector is quite new and not much has been practiced, it is still being taken as underdeveloped area, hence issues in policy regime are seen.

2. Technical issues – Due to less experience, the interconnection technology is considered as complicated technology in which one MHP can impact operation of other MHPs connected to it. Also, there are issues regarding load sharing, setting of ELC/Automatic Voltage Regulator (AVR), protection coordination, etc. which depicts that proven technology is yet to be widely disseminated, There are only a couple of local manufacturers and suppliers who are readily available to work on the technologies currently. Furthermore, poor existing infrastructures of MHPs lead to higher faults or problems in the interconnection practices.

3. Financial issues – The upfront cost of interconnection is high. Many MHPs may need to change their control panel as well as install newer protections systems and upgrade the distribution lines. Additionally, they will also require more capable human resources to supervise the MHPs, increasing the operating costs. However, for smaller MHPs with low plant factor, the income may be low considering the load connected to the entire system. This may not be viable for few MHPs.

4. Managerial issues – The operation of standalone local mini-grid model may have complexities in managing more than one MHP. It required higher managerial ability, hence more capacity building activities. Limited skilled human resources at MHPs will be an issue which will require skilled Operators to do the task.

5. Mini-grid Operational issues – The operational issues such as Surplus/Deficit Management, Scheduling of MHP, Dispatch of MHP, Load Shedding, Peak load management need to be specifically dealt by the skilled human resources. Proper planning will also be required for the same.

6. Issues in repair and maintenance - Remote locations of MHPs and lack of local technicians for repair and maintenance of the systems make the task difficult. This will require more capacity building activities at local level.

7. Technology transfer – Likewise, not enough knowledge transfer in terms of technology solutions, limited skilled human resources at MHPs also need to be looked after for successful operation of the interconnection projects.

8. Local conflicts – The issues at local level such as political disputes and diverse interest groups need to be looked after for smooth functioning of the modality.

9. Grid interconnection – The connection of the local mini-grid to the national grid for reliability still lacks development of Standards, Policy, Financing, among others and is also subjected to grid availability.

Issues and Challenges in MHP-Grid Interconnection

MHP-grid connection in Nepal is still evolving and there are few issues and challenges faced by multiple actors while implementing the pilot projects. The main issues and the problems associated are summarised as follows:

1. Limited policy guidelines – There is no separate Interconnection Policy and Technical Standard/Guidelines for MHPs. The grid-connection practice of MHPs follows cumbersome Grid Code/Distribution Code used for bigger sized electricity generating projects. Also, limited best practices locally, still shows that much work needs to be done for mainstreaming the practice.

2. Technical issues – The technical issues are mainly attributed to the grid reliability with long feeder length, voltage fluctuation in distribution lines, outages at the point of connection, shutdown problem and utility feeder maintenance. Similarly, upgradation of MHPs for connecting to the national grid is also mandatory for the interconnection to function.

3. Financial issues – The financial issues are almost same as for MHP-MHP interconnection. The upfront cost of grid-connection is high as MHPs will need to change or upgrade their control panel as well as install newer protections systems and upgrade the distribution lines. Additionally, they will also require more capable human resources to supervise the MHPs, increasing the operating costs. Lack of financing institutions is taken as one of the severe problem for managing the costs.

4. Interconnection requirement - Complex Interconnection Scheme, Costlier Interconnection Equipment Circuit Breaker, Metering Scheme, Protection Scheme, Lack of proven & friendly Control Equipment ELC, AVR , Islanding protection

5. Poor existing infrastructure - Control & Protection system is not compatible for grid Interconnection, Lack of proper implementation of Earthing System, Generators/Transformer are not compatible for Grid Connection

6. Repair and maintenance - Remote locations, Lack of local technicians for repair and maintenance of the systems

7. Complex PPA procedure - Involvement of Multiple Department similar as that of Large Projects, Local people unaware of multiple PPA steps, Long steps more time consuming

8. Complex PPA model - Almost same as that for Larger Projects, Difficult to fulfill complex utility requirement

3. Stakeholder Mapping

The stakeholders are defined as the entities and actors directly or indirectly working for and/or supporting the functioning of the MHP development, operation and interconnection systems. The main actors of the system are MHP equipment manufacturers, importers, suppliers, developers and the end users/ consumers. They make up the supply chain of the MHP interconnection market system. Then, there are various government entities and their policies that provide the environment for the market system to function. Some may be enabling while there may be few that could hinder the working process. Also, the support service providers are also the integral part of the market system to operate smoothly.

3.1. Supply Chain Market Map

The following figure depicts a generic market map of the MHP and its interconnection system.

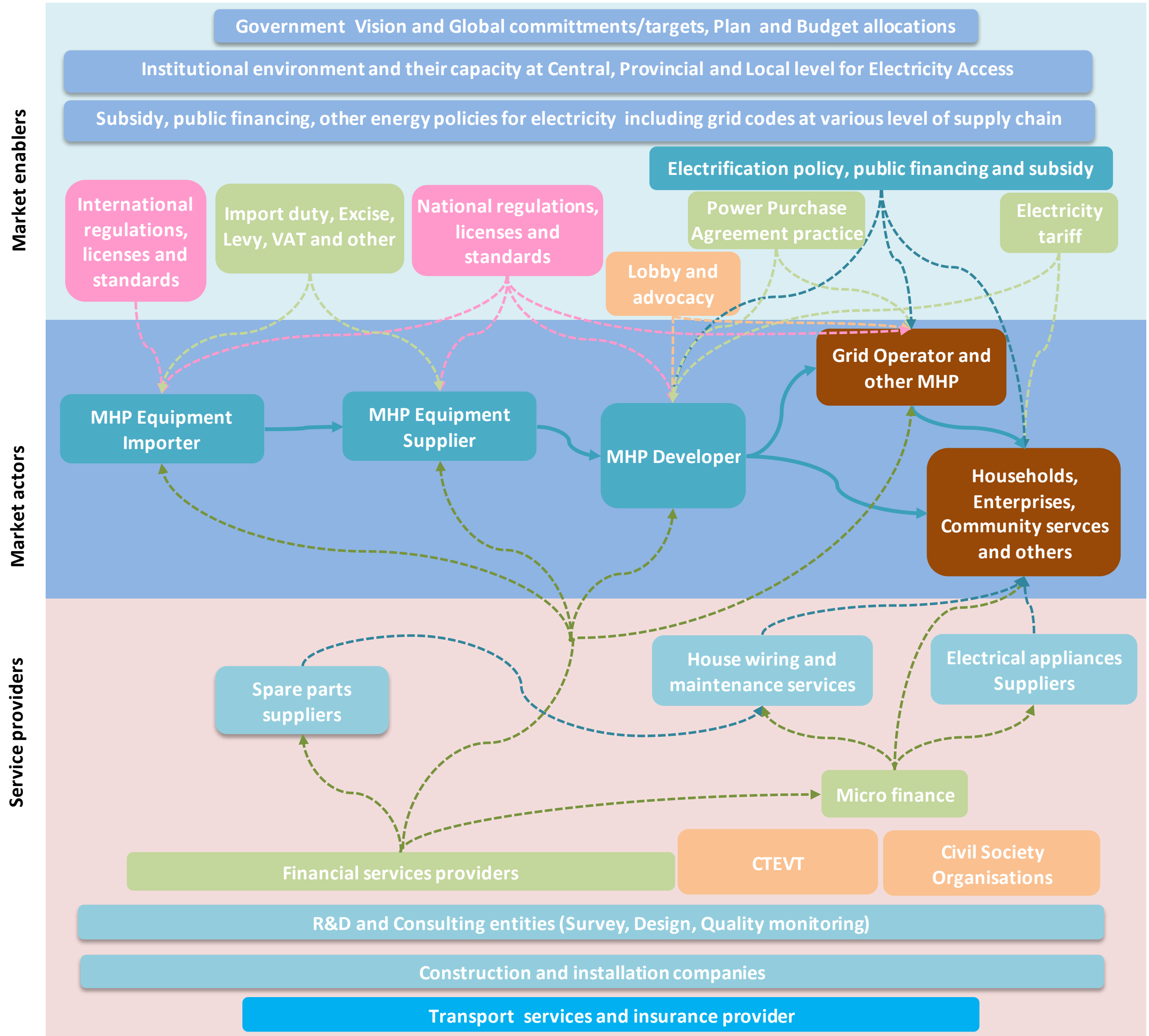


Figure 3-1. Market System Map of MHP interconnection

Observations in the market map for MHP-MHP connection:

- Policies are yet to be developed for interconnection of MHPs, however, the enabling environment is slowly developing
- Pilot projects are implemented but not yet completely successful
- Local manufacturers have are working in couple of interconnection projects but are not quite confident of the practice
- There is presence of banks and financial institutions at local level with credible lending capacity, but yet to be practiced
- Service providers are available at different levels but only few have practiced the works, such as construction/ installation companies, consulting entities, etc.

Observations in the market map for MHP-Grid connection:

- National policies are gradually aligning for enabling grid-connection of MHPs woth two major actors (AEPC and NEA) working together
- Net metering practices have been introduced
- Local manufacturers exist and have piloted few grid-connection projects and are confident in delivering the results
- Presence of banks and financial institutions at local level with credible lending capacity but yet to be practiced
- Service providers are available at different levels, such as construction/ installation companies, consulting entities, etc.

Barriers and Intervention requirements in the market system

The barriers observed in the market systems are grouped as follows:

Barriers	**MHP-MHP interconnection**	**MHP-Grid connection**
Policy and Regulatory Barriers	- No definite PPA agreement model - No clear technical standards for interconnection - No subsidy policy yet - Local government is yet to fully understand and plan for maximum utilization of local rural electrification schemes beyond expansion of the National grid - ERC is yet to include MHPs and their interconnection within its regulatory regime - Perception on viability of MHP interconnection is low	- Lengthy PPA process - Grid connection is mainly guided by NEA based on the grid code for large hydropower plants - No subsidy policy yet - Local government is yet to fully understand and plan for maximum utilization of local rural electrification schemes beyond expansion of the National grid - Public Private Partnership models are not being implemented properly by local government

Market Barriers	- Inadequate local technology suppliers or manufacturers - Inadequate linkages between international manufacturer and local vendor - Limited technical knowledge in MHP operators - High upfront cost for interconnection - Life period of the MHPs - Lack of viable business model	- Inadequate local technology suppliers or manufacturers - Inadequate linkages between international manufacturer and local vendor - Limited technical knowledge in MHP operators - Life period of the MHPs - Lack of viable business model
Barriers in Support Services	- Insufficient R&D for MHP-MHP interconnection - Lack of access to local repair and maintenance after installation of interconnection equipment	- Interests to developed among the private banks to on-lend for grid-connection practice - Insufficient R&D - Lack of access to local repair and maintenance after installation of grid-connection equipment

3.2. Local Manufacturers

There are numerous equipment manufacturers for MHP in Nepal, mostly hydro-mechanical and few in electrical. They are organised into an association named Nepal Micro Hydropower Developers Association (NMHDA). The members of NMHDA are engaged in project identification, survey, design, installation, manufacturing of turbines and accessories, repair and maintenance and research of MHPs. NMHDA is keen in gradual connection of MHPs to the National grid as that will be the ultimate solution for sustainability of MHPs. However, there is limited involvement in MHP-MHP interconnection and MHP-Grid connection projects till date.

Two prominent companies, viz. Preesu Electronics Pvt. Ltd. and Techno Village Pvt. Ltd. are the ones who have been engaged in MHP interconnection projects. They have both jointly worked in grid-connection of Syaure Bhumi, Midim, Leguwa and Chimal MHPs. They have also piloted 5 (five) MHP-MHP interconnection in Taplejung district of Province 1 in Nepal.

The main issues observed by the local manufacturers are mainly technical for mini-grid formation along with some management issues, while policy issues are main concerns for MHP-grid connection. The generator sizing is critical element for interconnection, but due to oversized generator sizing during construction of MHPs, this has given positive support for the purpose. They iterate that generators with compounding AVR and electronic AVR are useful. Some of the key issues highlighted by the local manufacturers for interconnection purposes are:

- MHP-MHP interconnection are technically difficult as complexity in one MHP also impact the others in the network – if Master MHP shuts down, then the network will be down and other MHPs cannot export their generated power
- Load sharing and load shedding among the MHPs is cumbersome process
- Lack of skill human resource for MHP operation leads to synchronisation problems and management difficulties
- Limited communication system due to remote locations also do not help
- Connection of 100 kVA is easier than smaller generators for grid-connection

- 11 kV line in areas with community rural electrification is long and not upto standard, leading to system instability
- The loose connections of the distribution lines at the connection point and beyond also generate faults for synchronizing
- PPA process is long and cumbersome, takes months to get approved

The key recommendations of the local manufacturers are:

- Separate PPA process for MHP-grid connection
- Allowing the use of induction generator for smaller MHPs, instead of synchronous generators
- Optional use of Vacuum Circuit Breaker and Current Transformers/Potential Transformers for 11 kV as they make up the higher cost for interconnection
- Technical training for operators of MHPs as well as a management model for mini-grid
- Knowledge and technology transfer from international companies engaged in MHP interconnection sector

3.3. International Vendors

The local manufacturers are keen to get connected with international vendors. An Indian company, Ytek Controls from Dehradun, was engaged in designing, supply and installation of synchronizing units for Baglung mini-grid. Similarly, an Indonesian company, Renerconsys PT from Bandung, manufactures digital control systems and synchronisers for MHP and interconnection purposes. They are very keen to connect with Nepali manufacturers for knowledge and technology exchange.

Likewise, there are other equipment suppliers relevant to interconnection purposes as follows:

S.N.	Equipment Name	Imported from International Market (Name of National Supplier and/or International Vendor)
e	Current Transformer/ Potential Transformer (For both Energy Meters and Protection)	Mehru Electrical and Mechanical Engineers Limited, India, https://mehru.net Crompton Greaves Limited, India, https://cgglobal.com ABB, https://new.abb.com/indian-subcontinent SkipperSeil Limited, India, https://skipperseil.com/ Pragati Electricals Pvt Ltd, India, https://pragatielectricals.com/ Vishal Electricals, India, https://vishalelectricals.com/
2	Vacuum Circuit Breaker, Relays etc	ABB, India Schneider Electric, India, https://www.se.com/in/en/ Crompton Greeves Limited, India
3	Transformers	Hammond Power Solution, India, https://asia.hammondpowersolutions.com/en/

4	Synchronisers and Controllers	Renerconsys, PT, Indonesia, http://www.renerconsys.com/ Y Tek Controls, Dehradun, India, http://www.ytekcontrols.com/ Protel Multi Energy CV, Indonesia, https://www.pme-bandung.com/
8	Generator	Crompton Greeves Limited, India TD Power System Pvt Limited, India, http://tdps.co.in/
9	AVR	Y Tek Controls Dehradun, India, ABB
10	Other services	Wahana Pengembangan Usaha, PT, Indonesia, https://wpuenergy.co.id/ ENTEC Indonesia, PT, https://entec.co.id/website/index.php/en/

4. International Best Practices of MHP Operation

The successful MHP operation can only be obtained when "the Enabling Environment", particularly with respect to conducive regulation on the implementation of both isolated and grid connected mini-grid, for sustainable operation exists. In some cases, the good written policies and regulations do not necessarily applicable when it comes to the realization. Therefore, it is important to identify which areas or themes on the measures need to be addressed to improve the enabling environment. The regulatory framework (including local government decrees and regulations) must be studied carefully before an MHP scheme is implemented.

When addressing the Enabling Environment for MHP for rural electrification, it is useful to prioritise actions in accordance with importance (some elements of an enabling environment are vital, while others are just useful), and start by supporting the actions with the highest priority.

The following best practice discussions assume that the conducive regulation and policy measures do exist. This chapter draws many experiences from Indonesian landscape with the practices being implemented in Indonesia. However, there are few cases of other countries of Asia that have practiced interconnection of isolated systems to the national grid.

4.1. General Consideration

The development of MHP need clear objectives as to whether it is an investment in social infrastructure (similar like education/school, drinking water supply and health programme), or to create small profit-making enterprises that are financially self-sustaining[5].

However, regardless the objective, the successful MHP operation will be obtained if the following issues are to be taken into consideration:

- Technical aspects: well-designed system, reliable and good quality equipment;
- Financial aspects: security of fund for the operation and maintenance of MHP plant;
- Management aspects: institutional setup and well-prepared management for operation and maintenance.

4.1.1. Technical aspects

The basic consideration on the technical aspects is that the MHP can deliver its services to fulfill the community and/or the user needs. This implies that the quality, reliability and capacity should match with the public expectation. Selecting and acquiring appropriate MHP that meet the location remains a necessary condition for success (wrongly sized plant and inappropriate standards remain a constant threat).

Once the plant could serve and fulfill the public needs, the public trust on the technology will mostly be created. This becomes basic capital which latter make the management easier to encourage the public participation to pay (willingness to pay) for electricity services.

The technical aspects include two elements, i.e.: hardware and software elements. The related hardware for MHP is generally not a big issue. However, it has to be kept in mind that cheaper equipment is not always cheap investment in the long-run. Therefore, the

[5] Smail Khennas and Andrew Barnett; "Best Practices for Sustainable Development of Micro-hydro Power in Developing Countries", In association with London Economics & deLucia Associates, Cambridge Massachusetts, USA for The Department for International Development, UK and The World Bank, March 2000

purchasing criteria have to be carefully prepared. Before implementing the procurement, it is very useful to get an overview over the different guidelines that already exist.

Other institutions or organisations may be implementing similar projects or may have learned valuable technical lessons from previously implemented projects. Local capacities to build micro hydro plants locally appear to substantially reduce costs.

On the software elements, the technical reliability of plant operation is closely relied on the availability of appropriate and reliable resources. Therefore, it is very useful to identify the relevant local service providers that may be needed for repair and maintenance under contract assignment. Alternatively, the routine maintenance and plant operation can be obtained by assigning the best attitude local community with the appropriate preparation through technical training and capacity building. It appears to be no short cuts in developing local capacities. The process takes a long time and is costly, but without such capacities MHP operation can fail. Local capacities to operate MHP are a necessary condition for success and resources will need to be devoted to building this capacity.

4.1.2. Financial Aspects

The financial aspects to be discussed in this section are focussing on the obtaining of fund required to operate and maintain the existing MHP. Most of MHP installation is considered an investment in social infrastructure where the capital funds are normally provided by government or donor institution (or combination of both) as non-returnable grant and, therefore, the cost recovery is mainly calculated to cover costs for operation, maintenance and reserve for spare parts and repairs. It includes, among others: management fee, operator salaries, consumables (e.g.: oil lubricant, grease and electrical fuses) and maintenance (e.g.: electro-mechanical reparation fee, civil rehabilitation cost, and material purchasing like: mechanical bearing, bolts and nuts). However, whenever possible, it is recommended to calculate based on the full cost recovery, to enable reinvestment when the plant reaches the end of its life.

For the off-grid MHP, the revenue of plant is basically relied from selling electricity to the local community that preferably counted based on the kWh consumed. Due to the different capability of community to pay for electricity services, the tariff may be differentiated based on the monthly consumption. The tariffs scheme under which the richer consumers cross subsidises households that can only pay less will spread “the poverty reducing benefits” of MHP, as long as the total revenue is adequate. While there is clear evidence that demand is sensitive to the tariff charged (many potential users would be excluded by full cost covering tariffs in many locations), there is also evidence that the ability of some people to pay is higher than originally thought.

In many MHP installations previously, electricity consumption is not metered, but the households pay for electricity depending on the number of appliances they use. Typically, the lowest tariff is for households that only use electric lighting, for usage of radio, television or further appliances households have to pay extra. At some installation, communities are charged the usage fee according to the size of mini circuit breaker (MCB) used.

The peak load of most off-grid MHP occurred in the evening, when most electricity consumed for lighting. With this scheme the load factor of MHP is basically very low (mostly below 25%). Lighting-only systems will have the greatest difficulty in achieving financial sustainability. Therefore, it is important to look for the productive use electricity to increase the load factor for particularly during the daytime. The common productive uses in the village may include, among others: local shop and restaurant, rice miller, wood carpenter and furniture, ice block making and other cottage/home industries. With additional load of electricity for productive use, the load factor may be increased up-to 40 – 50%.

The grid connected MHP is mostly originated from the off-grid scheme. It became grid connected (on-grid) system when grid arrives or within the proximity of the MHP site. The on-grid MHP will have a better chance to generate profit that allows the MHP management develop other profitable economic activities or provide fund to support community activities in the form of soft-loan provision through the saving and loan businesses. These will also, indirectly, improve the MHP load factor.

The typical obstacle for the transformation from the “off-grid” into “on-grid” scheme, particularly that faced by most developing countries, is the difficulty to obtain permit and PPA which adequate for small power producer like MHP.

The existing regulation for PPA is normally suitable for large IPP which has a capacity to provide necessary or supporting documents like, among others: grid study, commissioning test report, government eligible certificate for grid operation and permit as an IPP (Indonesia: ijin usaha penyediaan listrik – IUPTL). The development on regulation that aim to produce a structure of incentives that result in the needs of consumers being met most cost-effectively is imperatively necessary. It should be technologically neutral, and at costs that are in keeping with the scale of the investment and the ability of the various parties to pay. Regulation should be transparent, stable and free from arbitrary political interference so as to foster competition between suppliers of technology, services and finance.

The following issues may need to be considered within the regulation:

- Set standards that are appropriate to the project cost and the ability of the various actors to pay.
- Quality and safety standards should be enforced to prevent the users being exploited by shoddy equipment and installations.
- Regulations should be designed so that they do not merely increase the opportunities for “rent seeking behaviour" of officials.
- Small IPP can supply power to the grid at ‘realistic’ prices; and connection standards are appropriate for the power to be sold. Rules should be transparent and stable.

4.1.3. Management Aspects

The well-organized management is a vital element for the sustainable operation of MHP. Experience shows that with well-organized management will be able to operate and maintain the MHP for more than 25 years.

The fact that the community itself is responsible for maintenance and operation of the plant is pivotal for both the technical and economic sustainability. The technical knowledge as well as the organizational and financial capacity to sustainably run the plant, does not necessarily exist in the communities. It is part of the intervention to enable the community to sustainably run and maintain the plant by using robust and easy to repair technology, organizing trainings, and implementing rules and regulations that channel community dynamics in support of the MHP plant.

The form of ownership of micro hydro plant is probably less important to success than creating an effective business-like style of management. Regardless of ownership structure, it would appear that the successful management of MHP requires a ‘corporate structure’ that minimises political interference (e.g.: from municipal authorities or powerful community members) by providing clear delegated authority to a management to achieve clearly stated objectives related to profitability, coverage, and the quality of the service to be provided.

Consideration should be given to productive end-uses from the outset, and treat micro hydro investment as a small enterprise (regardless of actual ownership structure). Endeavour to create a business-like management structure, even if co-operative or other forms of joint ownership are used. Attempt to institute rules for tariff setting and for inflation adjustments that are technical and routine rather than arbitrary and politicised (e.g. link the price of electricity to some other freely traded commodity - such as a staple crop, kerosene, or candles).

4.2. Isolated Mini-grid

The isolated mini-grid has been known for more than 100 years ago, when a country (respectively in the developed countries) started with the electrification program. During the early stages of electrification, there was no central or national grid in the country. This isolated mini-grids were embryo that later became the interconnected main grid.

The isolated mini-grids in low-income and/or developing countries, were built particularly to fill the empty, mostly rural, spaces that have not yet been reached by the main grid or to serve areas where it would be too costly to extend the main grid. Local communities and local entrepreneurs typically built and operated these mini-grids.

Most of MHP developments for rural electrification are designed as a stand-alone and isolated system where the electricity is distributed through a mini-grid distribution line. In some cases, the plant powerhouse consists of two or more MHPs operate in parallel. The latter is normally applied for the larger power demand. However, the construction of the individual MHP does not necessarily done at the same time, rather than in it is constructed later to meet the growing power demand. The following table shows some MHP that work in parallel in Indonesia.

Interconnection of standalone MHPs into a mini-grid are very seldom done in the developing countries. However, as the power demand tends to grow, an isolated MHP may unable to meet the growing demand. On the other hand, there might be another MHP which still have excess power and located in the close vicinity to the first MHP. In such a case, a mini-grid interconnection could become an option.

4.3. Grid Interconnected Mini-grid

When the main grid reaches the sites within the vicinity of the isolated mini-grids, there are many possibilities that could happen:

- The isolated grids go out of existence;
- Transform the isolated MHP mini-grids into small power producers;
- Become small power distributors.

In case of Indonesia, when the main grid reaches a village that had been served by the isolated mini-grid, most (not all) isolated mini-grids stop selling self-generated electricity directly to village customers or even totally closed.

Factors that may explain why community-owned mini-grids exit from retail supply business:

- Differences between the electricity tariff, the main grids offer the lower tariffs compared to that of the isolated mini-grids;
- Higher service levels provided by the main grid
- Regulation and/or financing barriers;

There are few MHPs in Indonesia that transformed from the isolated mini-grid schemes into grid interconnected scheme while still serving electricity to the community.

Table 4-1. Eight Isolated MHP mini-grids Transformed into Grid Connected

Year	MHP Site	Operator	Capacity (kW)	Cost in year of interconnection (USD)	FIT (USc/kWh)	Yearly Revenue (USD)
1991/2005	Curug Agung, W. Java	Cooperative	12	12,000	0.84	3,200
1994/2003	Dompyong, E. Java	Cooperative	30	6,700	4.51	-
1994/2003	Kalimaron, E. Java	NGO	30	6,700	4.00	9,700
2004	Santong, Lombok, NTB	Cooperative	40	10,500	no-info	-
2008	Wot Lemah, E. Java	NGO	20	N.A.	4.00	6,700
2010	Krueng Kalla, Aceh	NGO	40	60,000	9.05	27,500
2012	Ciganas, W. Java	NGO	100	29,000	4.93	43,000
2013	Bakuhau, NTT	NGO	35	14,000	3.95	18,000

USD (2017)

In addition to the isolated grid transformation, there are also existing MHPs started as grid interconnected scheme.

Table 4-2. Eight MHPs started as Grid Connected System

Year	MHP Site	Operator	Capacity (kW)	Cost in year of interconnection (USD)	FIT (USc/kWh)	Yearly Revenue (USD)
2000	Waikelosawah, NTT	Community	15	2,400	1.80	12,100
2004	Cinta Mekar, W. Java	NGO	120	30,200	3.91	54,600
2004	Melong, W. Java	Cooperative	100	-	3.20	-
2005	Ulu Danau, S. Sumatera	Cooperative	224	13,300	4.50	43,000
2006/ 2009	Kombongan, W. Java	NGO	65/165	-	no-info	-
2007	Sengkaling, E. Java	NGO	100	-	no-info	-
2008	Wangan Aji, C. Java	Cooperative	140	29,000	4.18	-
2010	Banyu Biru, C. Java	NGO	170	23,900	4.93	80,800

USD (2017)

4.3.1. Case of Seloliman, Indonesia

In addition, some households were connected to the national PLN electricity grid illustrating that many of the communities are located in immediate vicinity of the national grid. Not all of these households are officially connected, but have simply extended the grid from their neighbour. Another small number of households in the EnDev 2 communities were already connected to an MHP in 2010. This happened in communities where neighbouring hamlets already had had an MHP and occasionally households within the access area of the new MHP were able to connect to the existing MHPs.

4.3.2. Case of Cambodia[6]

Cambodia has connected many isolated local grids (running on diesel generators) to the national grid after the expansion of the grid to the local area. They now buy electricity from the utility grid and sell the electricity via the local grid. The generators are not synchornized to the grid but rather used as backup in case of grid failure. The local grids act as distribution utilities at local level. This is not entirely a case of MHP-grid connection, however the upgradation of local distribution grid was necessary for being able to sell the electricity from the grid to the local consumers.

4.3.3. Case of Sri Lanka[7]

Sri Lanka has cases similar to Nepal in terms of connection of MHPs and pico hydro projects to the utility grid. After expansion of the utility grid to the local areas, the local MHPs and pico hydro projects lost their consumers and were forced to close down. Only the ones which were not near to the grid expanded area retained their consumers. Like in some parts of Nepal, two parallel distribution lines also operated for quite a number of years, with some consumers being supportive of the local MHPs and many transitioning to the national grid due to better services and lesser electricity tariff. Transition of management modality from community user groups to cooperatives was not easily accepted by the local grid operators and they rather chose to close down due to diminishing number of consumers than get connected with the national grid. Also, the technical upgradation of the systems was required, which required financing not readily available. The lack of enabling environment for connection of isolated projects to grid contributed to close of small hydro projects after arrival of the grid.

4.4. PPA Legislation of Indonesia

The MHP development for rural electrification services in Indonesia is started already since 1990 as research and development (R&D) activities. These R&D activities are normally funded by the government R&D budget, corporate social responsibility facility, and donor institutions, like: GIZ, JICA, and USAID.

The MHP development can be divided into several phases:

- Technology development (1990 – 1995), system design, control and turbine manufacturing, development of technical standards;
- Social acceptance (1995 – 2000), i.e.: development of pilot, socialization, capacity building, training;
- Policy measures (2000 – 2005), i.e.: policy dialog, technological packages, management practices;
- Dissemination (2005 onward), i.e.: know-how transfer, development of income generating initiatives, networking, facilitation for accessing funding.

Through the above activities, total installed capacity of MHP within 1990 – 2020 is approximately 11 MW.

[6] "Mini-grids and the arrival of the main grid: Lessons from Cambodia, Sri Lanka and Indonesia", ESMAP, Technical Report 013/18, October 18

[7] "Mini-grids and the arrival of the main grid: Lessons from Cambodia, Sri Lanka and Indonesia", ESMAP, Technical Report 013/18, October 18

Table 4-3. Summary of turbine Technology

Turbine type	Quantity	installed Capacity	
Produced Cross flow turbines T12	70	1,750	MW
Produced Cross flow turbines T14/T15	377	19,500	MW
Produced T15 (license out of Indonesia)	250	15,000	MW
local designes Sumatra+Sulawesi	300	7,500	MW
Produced Pelton turbines	20	1,670	MW
Propeller	101	4,400	MW
Total Turbines produced 1991-2018	1,118	49,820	MW

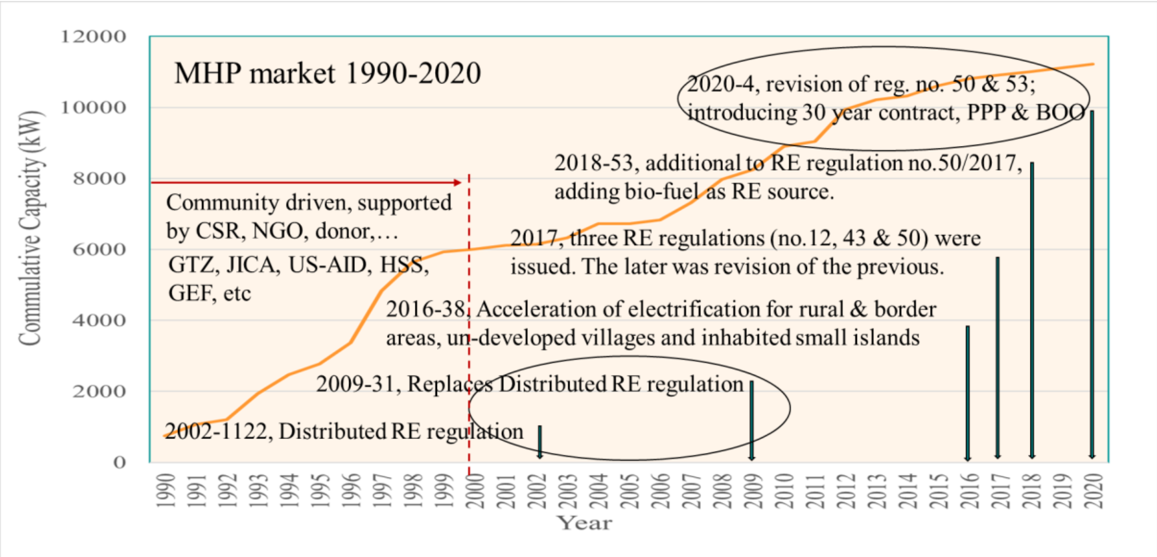
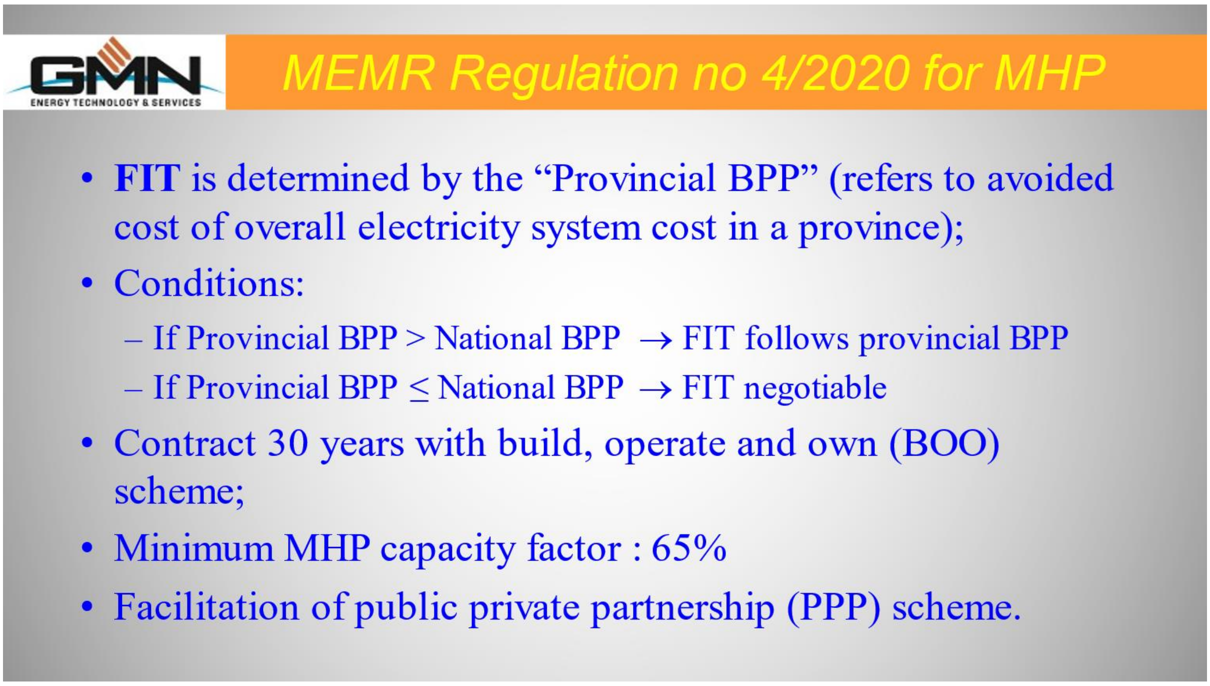
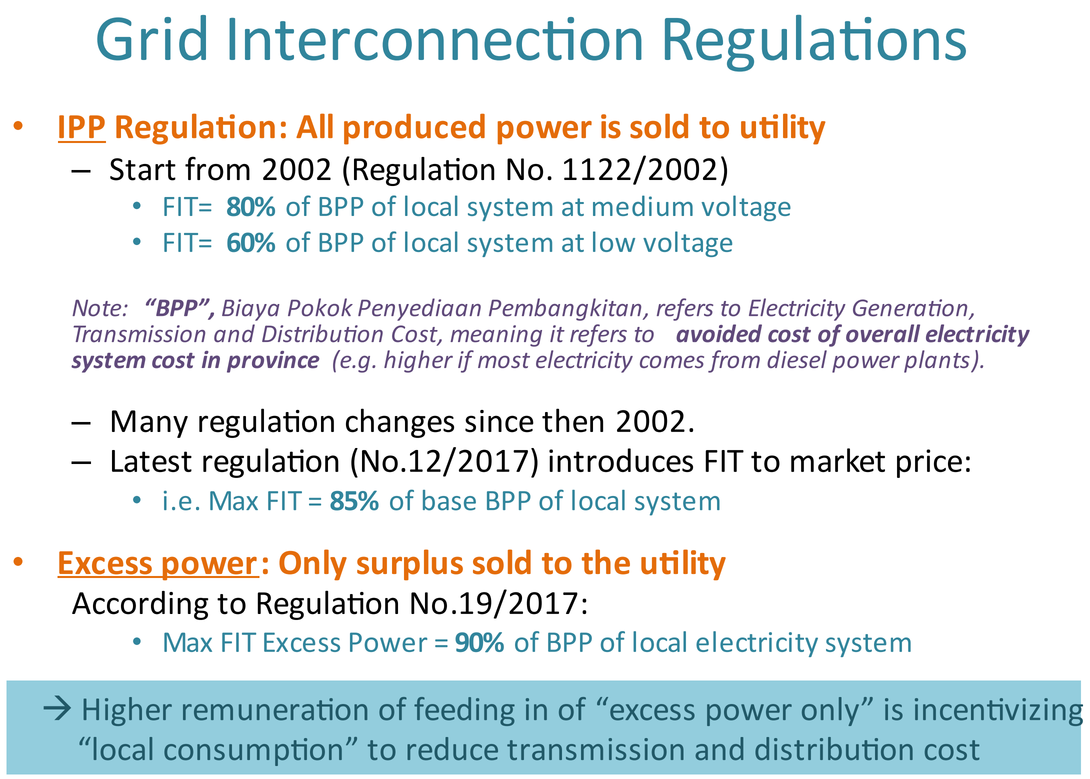


Figure 4-1. MHP Market Progression 1990 - 2020





Government roles:

- Governments need to assign clear responsibilities for micro hydro development and the development of the necessary 'enabling environment'. Best Practice suggests that this would ideally be part of assigning more general responsibilities for the provision of decentralised energy services to rural (or marginalized).
- Governments need to treat all energy supply options equally ('offer the full menu of options') and to favour what best meets the needs of the consumer in different locations.

- Governments need to ensure fair competition between competing supply options and provide equal access to aid and other concessional funds, subsidies, tax breaks and support.
- Plans for the expansion of the electricity grid should be rule based, and in the public domain to reduce the uncertainty about when the grid will reach a particular location. Clear rules should be published regarding the actions the grid supplier must make to compensate micro hydro owners when the grid arrives (either to buy out the plant at written down costs or to buy the hydro electricity produced).
- While government finance tends to favour large scale energy investments (in say power or fossil fuels), micro hydro has the opportunity of utilising local capital (even the creation of capital through direct labour to build civil works) and it is part of the new trend towards 'distributed' power with much reduced costs of transmission.

The institutional framework and the regulations related to RE and grid connection practices of Indonesia are more detailed in Annex 2.

5. Basic Control and Protection Technology for MHP

Before describing the technical aspects linked to control of distribution network parameters (voltage and frequency), a quick review of the major technologies used in electrical energy generation and distribution through electricity grids are:

Synchronous Generators

Most large electricity generating plants have a prime mover that drives a rotating generator. The prime mover may be a hydraulic turbine, a diesel engine, a steam turbine, or any other system that produces mechanical energy through a rotating shaft. This rotating shaft is made to drive a generator that converts energy from mechanical to electrical form. The generator is usually a synchronous machine, rotating at constant speed to deliver an alternative current and voltage at a given standard frequency. Use of synchronous generators with brushless excitation system is recommended standard for MHPs above 10 kW[8].

Induction Generators

In recent years, the use of asynchronous or induction generators for production of energy from rotating machines has developed considerably, especially for relatively small installations such as mini hydroelectric plants or wind power generators. These systems present different characteristics from the synchronous generators as will be explained in the next section on frequency and voltage control. Such generators are considered more rugged, more reliable and cheaper than the equivalent synchronous machines. They are generally used in pico-hydropower projects below 10 kW in Nepal.

Rotating DC Generators

In a few cases, mostly for very low power in the range of a few dozen or hundred Watts, DC generators are used. This is mostly the case for systems built by hobbyist to take energy through a small hydro or wind turbine. As these are not common, we shall not be concerned with such systems.

Electricity grids

As seen above, electricity may be generated in DC or AC generators. There are ways to convert electrical energy from one form to the other.

- Rectifiers convert AC to DC
- Inverters convert DC to AC

By far the most prevalent is the AC grid, available as national grid in all countries. The dispute about the merits and demerit of AC versus DC distribution is not new as it started more than 120 years ago between Edison and Westinghouse, However, with increase in PV sources as well as the appearance on the market of more and more DC operated appliances, the debate is again on the front stage.

For a mini-grid, the choice between a DC or an AC distribution depends on the type of electricity generation, the type of storage if any, the size of the grid and the characteristics of consumers. In relatively small mini-grids based on DC sources such a PV, it is often economical and efficient to remain with a DC distribution. This is however limiting in the type of appliances that may be used by the consumers as most of them are designed to match the norm of the AC national grid.

[8] "Reference Micro Hydropower Standard", AEPC, 2014

At present there is a trend to work on 12V DC as a number of appliances have been developed for such a voltage, usually available for a car battery. However today we see the emergence of a 5V DC standard in the form of the USB connector now being made available on new vehicles and even on board of aircrafts. This in turn encourages the development of small appliances that will operate under such standard.

Basic Control in Electricity grids

In an AC electricity grid or mini-grid, two parameters have to be maintained or controlled:

- Frequency
- Voltage

Each country has standardized the voltage and frequency for its electrical grid. Many national grids are expected to deliver 230 V at 50 Hz at the consumers' premises, which is true for Nepal as well. It is useful to know that, when dealing with large power levels, it is preferable to work at higher voltages to avoid losses, mainly in the transmission lines. Transformers are used to convert the power between different voltage levels and high voltage lines are used for transmission. Even at the generating point, some large generators will directly produce power at higher voltage. However, in the case of relatively small installations characteristic of mini-grids, power is usually generated at the standardized voltage in the case of rotating generators. In any case, the voltage is always brought down to 230V before being supplied to the premises of *"normal"* customers. As per Nepal's Electricity Act 2049 and Electricity Regulation 2050, the standard of supply voltage shall have to be maintained as follows:

a) 230 volt in A.C. single phase and 400 volt in three phase for general consumers.

(b) for those who want a supply of electricity from four wires, the electric service shall be made available in 230/400 volt from A.C. three phases.

(c) The fluctuation shall not be allowed from more than five percent in standard volt

(d) The standard of the frequency shall be maintained as 50 cycles per second (50 hertz).

(e) The fluctuation shall not be allowed more than 2.5 percent in the frequency standard

The frequency is maintained by matching the active power generated (Pg) by all generating units to the active power consumed (Pc) by all consumers (+losses in the system). If we generate more than consumed ($Pg > Pc$), the frequency will tend to increase beyond 50 Hz till $Pg = Pc$, while if we generate less power than required ($Pg < Pc$), the frequency will drop below 50Hz.

In conventional generating station using synchronous generator the active power generated is regulated by controlling the torque applied to the shaft of the rotating generator. This is done by controlling the water flow in hydro-turbines by means of governing system. There is no difference in governors used for large generating units and small units except for sizes, operating pressure and control features as per requirement of individual project. Also, for smaller units, hydro-mechanical part of governor is built on the sump of oil pressure plant for compactness. Governing system may be in the form of flow control or electronic load controller which depends on appropriate designation described in the table below.

Table 5-1. Governing System Classification Based on Hydro Power Capacity

No	Hydro Plant	Governing System
1	Micro Hydro – Up to 100 kW	Digital speed control system with load actuator (Electronic Load Controller) is used.
2	Small Hydro – Up to 3 MW	Flow control governing system with hydraulic actuator and digital PID speed and power control system. Mechanical motor type actuator has also been used up to 1000 kW unit size with microprocessor-based level control PI Controller.
3	Small Hydro – Above 3 MW	Flow control PID governor with hydraulic actuator

The voltage is maintained by matching what is known as reactive power[2] generated (Qg) to the reactive power required by the load (Qc). Reactive power is required by inductive loads such as motors or any appliance using magnetic coils and can be produced by a generator or by capacitive loads. As this form of power generates losses in the transmission network without resulting in useful energy, utilities require large users to compensate as much as possible their reactive power by installing suitably dimensioned capacitors to match their requirements. However there always remains some mismatch between generated and consumed reactive power.

In conventional generating station using synchronous generator the reactive power generated is regulated by controlling the excitation current in the generator. In generating plants using induction generator, the reactive power (and therefore the voltage) has to be controlled by switching capacitor banks as the induction generator itself is not able to produce the required reactive power

Protection system

Protection system in MHP can be divided into mechanical and electrical protection. Mechanical protection is usually related with the turbine such as overspeed protection and pressure/flow related protection.

Electrical protection is the protection system which covers the generator, switchgear, transformer and transmission/distribution line. It usually achieved by the use of protective relays. Protective relays detect abnormal conditions, including short circuits and overloads, and operate circuit breakers to isolate the malfunctioning system components, preventing damage to the generator and to transmission and distribution system components. Relays measure current via current transformers, which step down the high currents in the power system to levels that the relays can handle. Similarly, relays in high- or medium-voltage systems require voltage transformers (also called potential transformers) for voltage measurement; however, some relays can measure low voltages (common in small power systems) directly without voltage transformers. Once a fault condition that caused a relay to interrupt a circuit has been resolved, the relay will automatically either re-close the circuit or return to a state that allows an operator to manually re-enable the circuit.

In power system diagrams, the functions of protective relays, circuit breakers, and other devices are indicated using device numbers given in parentheses, defined in the ANSI/IEEE C37.2 standard which are:

1. Instantaneous/time overcurrent (50/51)
2. Synchronizing check (25)
3. Undervoltage (27)
4. Overvoltage (59)

5. Over/underfrequency (81 O/U)
6. Voltage-restrained overcurrent (51V)

While solid-state discrete relays are available, a major advantage of the microprocessor-based design is that a single relay can incorporate the functions of many discrete relays, potentially allowing a single device to provide all necessary protection functions for a small generator. Programmable multi-function relays, also known as numerical (or numeric) relays, can result in a significant decrease in system complexity and cost.

Though many protection devices are required in the protection system of hydropower plant during operation as mentioned above, the following protection system may be furnished as the minimum requirement for micro-hydropower plant in rural electrification:

1. Over speed of turbine and generator (detected by frequency) (15)
2. Synchronizing (25)
3. Undervoltage (27)
4. Directional power relay (32)
5. Phase balance current relay (46)
6. AC Inverse over current relay (51)
7. Overvoltage (59)
8. Frequency Relay (81)
9. Over current by NFB (No Fuse Breaker) or MCCB (Moulded Case Circuit Breaker) for low voltage circuit.

For system with MV distribution line, normal protection system of line (Pole-mounted type Lighting Arresters and Fuses or Fuse Switches) is to be provided throughout the line which are:

1. MV Fuse Switches with fuse, hand operated type (3-phase)
2. MV Lightning Arrester
3. MV line connection materials (Insulators, support structure, wires)

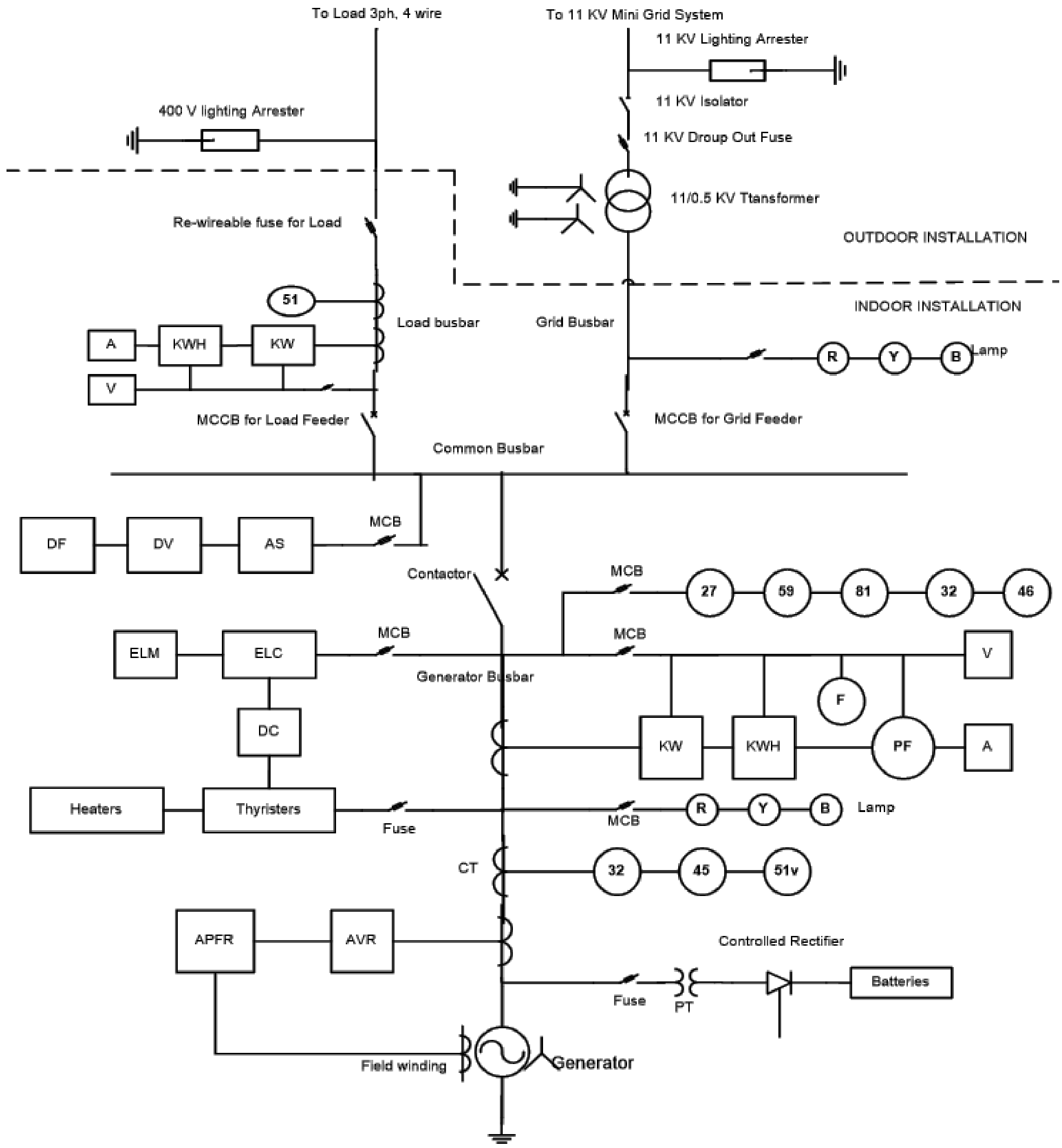


Figure 5-1. Common Electrical Protection System Scheme on MHP

Guidelines for Connecting Renewable Energy Power Plants to the PLN Distribution System (Indonesia) provide several technical function/protections required for interconnection shown in table below.

Table 5-2. Technical Functions for Interconnection Required by PLN Guideline (Indonesia)

Technical Functions Required for Interconnection of Renewable Energy Plants	Guidelines for Connecting Renewable Energy Generators to Distribution Systems
Maximum size of Renewable Energy Plants that can be connected to a Distribution System	Not bigger than 10 MW
Renewable Energy Generation Technology	Applicable for synchronous generators, induction generators, and inverter-based PLTS Photovoltaic
Trip settings and over and lower voltage clearing time	Set the maximum clearing time from -50% to + 135% of normal voltage
Trip settings and clearing time of higher and lower frequencies	Set the maximum clearing time from 47.5 Hz to 51.0 Hz specifically for PLTB and PLTS in the frequency range of 49.0 to 51.0 Hz.
Network Interference Detection	Stops energize to network within 2 seconds.
Anti-islanding	Stop energizing to the network within 2 seconds of forming Unintended! Standing.
Synchronization	Does not cause voltage fluctuation at the connection point> + 15%.
Reconnection to the network	At least 5 minutes after the network voltage and frequency return to normal
Parallel equipment	220% resistance of the rated voltage of the connection system
Manual, visible disconnect	Required
Harmonic Distortion	Same as the requirements in the Electric Power Distribution Rules
Flicker	IEC Standard (P_{st} = 1.0, P_{lt} = 0.8)
Power factor	between 0.90 leading and 0.85 lagging
Inrush current limit (for Induction Generators)	Maximum voltage drop of 5% at the Connection Point
DC injection limit (for inverter)	+ 0.5% limit and nominal output of the inverter
DC isolation (for inverters)	Required

As for voltage and frequency regulation, detailed requirements are as follows:

Table 5-3. Voltage Regulation Requirement by PLN Guideline (Indonesia)

Trip Settings for Over / Undervoltage		
Percentage of the Nominal Voltage at the Connection Point	Maximum Clearing Time	
	Number of cycles (nominal 50 Hz)	Time (seconds)
V <50%	5	0.1
50% ≤ V ≤ 85%	100	2.0

85% ≤ V ≤ 110%	Normal Operation	
110% ≤ V ≤ 135%	100	2.0
V> 135%	5	0.1

Table 5-4. Frequency Regulation Requirement by PLN Guideline (Indonesia)

Renewable Energy Plant Size	Frequency Range (Hz)	Maximum Clearing Times	
		Number of cycles (nominal 50 Hz)	Time (seconds)
≤ 30 kW	≥51.0	10	0.2
	<47.5	10	0.2
> 30 kW	≥51.0	10	0.2
	<47.5	10	0.2

Table 5-5. Synchronization Parameter Requirement Tolerance by PLN Guideline (Indonesia)

Aggregate Unit Size (kVA)	Frequency deviation (Δf, Hz)	Voltage Deviation (ΔV, %)
0 - 500	0.3	10
>500 – 1500	0.2	5
>1500 - 10000	0.1	3

5.1. Standalone MHP

In case of an isolated micro-hydropower plant for rural electrification, the occasional control, manual control and governor control with dummy load is usually adopted because no person can monitor the plant in full time basis and also to save on the cost of control equipment. This means that the operator can visit the plant occasionally to start and stop its operation if it is equipped with governor control and when some trouble occurs, the operator could conveniently inspect the plant to take some necessary measure. Standalone MHP does not need Synchronizing check (25) and anti-islanding protection.

The stand-alone MHP is being the most typical MHP applications. The plant has just one generator, either synchronous or induction type. As mentioned above, frequency has to be controlled by matching the active power produced to the active power consumed (load). This may be done in two ways:

- By controlling the power produce by mean of adjustment of the hydraulic valve position, either manually or automatically (fig. 3).
- By ensuring a constant power consumed, using an Electronic Load Controller (ELC). The ELC is an electronic system which ensures that the excess of power produced by the generator is destroyed in a ballast load (fig. 4).

The ELC is a very fast acting device as it switches on or off the ballast loads using electronic switches. The time-constant of such systems is in milliseconds. On the other hand, if the frequency control is done by activation of the hydraulic valve, this is a slow process with a time constant of a few seconds.

Such a slow correction would normally lead to unacceptably large deviations of the rotating speed and therefore of the network frequency and voltage. To reduce these fluctuations, it is common to have a large flywheel installed on the shaft or the turbine-generator group. This flywheel prevents fast changes in the rotating speed, thus adapting the systems to the time constant of the valve control mechanism and therefore limiting the frequency and voltage excursions.

The voltage has to be controlled by matching the reactive power produced to the one required by the loads. If we have a synchronous generator, this control is taken care of by the AVR, normally an integral part of the generator. When dealing with an induction generator, this control has to be done using switched capacitor banks. If the approach is to use an ELC, such systems are available for induction generators and take care of both voltage and frequency regulation.

We took the example of a micro hydroelectric plant, which is convenient as its output power level can be controlled through the water inlet valve.

5.2. MHP-MHP Interconnection

MHP to MHP interconnection applies for two or more MHP generators connected to the distribution network. The first problem is to synchronise the generators before they can be interconnected. This implies bringing them to the same voltage, frequency and aligning their phase. It may be done manually but is usually achieved with an electronic synchronising unit (fig. 6). Each generator has also its own control of active and reactive power as described above (manual or automatic). It is important to understand here that, for example, we cannot have both generators trying to control the frequency, or they would have to do so in a collaborative manner. The same would apply for the voltage and reactive power.

Let us consider two micro-hydro power (MHP) plants both connected to the same mini-grid. They are at a few kilometres distance and are manually operated. If, after synchronisation, both operators are trying to control the frequency independently of the other, they may end up working *"against"* each other. In such case, it would be advisable to have one operator in charge of maintaining voltage and frequency. The operator would not only make the required adjustments on the plant, but also give instructions to the operator of the second plant to fix the operating point of that plant. This is what would be called a hierarchical control with a master (plant 1) and a slave (plant 2). This requires communication between the two generators, which is very easy if both are in the same location, but may be more complicated the plants are far apart. The concept of hierarchical control, explained here for a manual control, may be applied exactly the same with automatic controllers. But such systems must be designed for master / slave operations and imply the availability of a communication channel (fig. 6).

For systems with an automatic control of both active and reactive power control, it is common to work with the concept of "droop regulation". In a simple way we can state that the control is done in proportion of the error in frequency or error in voltage. To illustrate this let us say that for a mini-hydro plant, the controller is designed to follow a frequency regulation such that the nominal frequency is 50 Hz and the accepted deviation is + or – 4%. This implies that the frequency should remain between 48 Hz and 52 Hz. Towards this the droop controller would act in such a way that, when the frequency drops to 48 Hz, the hydraulic valve would be totally open to produce the maximum power. When the frequency is 50 Hz, the controller would set the valve to produce half the power, and when the frequency touches 52 Hz, the valve would be closed so as to produce no power at all. A similar approach is taken for the voltage control and the reactive power.

Such controllers can work in parallel as long as the droop characteristics of all controllers are matching (same deviation for 0% and 100% power generation). They do not need a separate communication channel as the distribution network itself (mini-grid) carries the required parameters (frequency and voltage).

MHP-MHP Interconnection will need Synchronizing check (25) protection. As individual MHP connected to the mini-grid is usually has local village load, then it is necessary that individual MHP is able to operate in island operation in certain situation.

5.3. MHP Grid Interconnection

Speed regulation of an MHP if grid connected cannot take part in frequency control especially in a very large grid. Accordingly, these should be designed for up to 60% speed rise on full load rejection. Speed control is usually required only during synchronizing. Generator loading will then be controlled by a flow control measure. MHP connected to the grid should have Synchronizing check (25) and anti-islanding protection to prevent MHP from overloading should fault occur in the nearby grid.

5.3.1. Grid connected operation of a single generator mini-grid

When the regional or national grid is available at (or near) the site of a mini-grid, it is often advantageous to interconnect them so that the excess power produced at the mini-grid can be fed to the large regional or national grid. This obviously implies that the mini-gird is functioning at the frequency and voltage of the main grid.

In such a situation, for small installations, the main constrain is to ensure synchronization of the mini-grid to the larger one before interconnecting. This implies adjusting the mini-grid voltage, frequency and phase to be exactly aligned with the main grid before connecting. This is done nowadays mostly through automatic controllers. Once the two girds are interconnected, the frequency will be fixed by the main grid and the generator of the mini-grid can be usually allowed to produce to its maximum power. The reactive power must still be controlled locally by the AVR for synchronous machine, by the ELC for induction machine.

When the system functions in such manner with part or all of the generated power supplied to the main grid, the control unit must be capable of handling critical situations like disconnection when the main grid goes down or the grid parameters go outside the permitted range. These are not only technical issues but very critical issues of safety that have to be taken care of and are integral part of the contract with the main grid operator.

From the above it must be clear that the control systems used for island operation and for grid connected operation are different even if they may be combined in a single controller.

5.3.2. Grid connected operation of a mini-grid with multiple MHPs

The presence of more than one MHP in the mini-grid to be interconnected with a main grid does not change the control strategy. The controller must be able to ensure complete synchronism between mini and main grid before interconnecting them, and it must provide all the features to ensure safe operation including during critical situations.

6. Technological Options for Mini-grid Interconnection in Nepal

Codes, standards, and utility policies regarding grid interconnection vary among countries and regions. In many countries, especially in the developing world, these norms may or may not yet be well defined. In cases where they are not, interconnections are left to be resolved on a case-by-case basis.

Several internationally recognized standards, including several IEC standards and the IEEE 1547 family of standards, guides and recommended practices, are commonly used or referenced as part of interconnection processes in developing countries. However, implementation of such standards without modification in a developing economy may be problematic, given lack of testing facilities, equipment, and trained technicians and engineers familiar with these standards. Regulators may choose to adopt modified standards in accord with available resources, as has been done in some countries.

Shown in table below are several guidelines from different countries regarding interconnection of renewable power plant into the grid.

Table 6-1. Interconnection Guidelines from Various Countries

S.N.	Country	Responsible Agency	Policy Document	Year Adopted	Generating Capacity Limit
1	Indonesia	State-owned Power Company (PLN)	Guidelines for Connecting Renewable Energy Power Plants to the PLN Distribution System	2014 (Rev. 2019)	10 MW
2	Thailand	Energy Regulatory Commission	Regulations for the Purchase of Power from Very Small Power Producers	2002	10 MW (export)
3	Tanzania	Energy and Water Utilities Regulatory Authority	Guidelines for Development of Small Power Projects	2009	10 MW (export)
4	India	Renewables and microgrid working group of the India Smart Grid Forum	Interconnection standards and policy and regulatory aspects of microgrids for India	In progress	To be determined
5	Kenya	Energy Regulatory Commission	Connection Guidelines for Small-Scale Renewables	In progress	10 MW (export)
6	Sri Lanka	Sustainable Energy Authority	A Guide to the Project Approval Process for On- Grid Renewable Energy Development	2011	10 MW

Not all interconnections take place between power systems in top technical condition. In the developing world, many power systems bear the marks of age, poor repair, and insufficient investment, ranging from corroded conductors and deteriorating insulation to leaking transformers, worn out switchgear, and a variety of inoperable equipment. Equipment is often obsolete, and operations that are automated elsewhere may be carried out manually. Systems in poor repair generally perform poorly, have serious reliability problems, and often fail to comply with safety or environmental standards.

Interconnection can improve such systems, by providing emergency reserves and more reliable supplies. However, careful planning must ensure that the interconnection doesn't lead to additional stresses elsewhere in the interconnected system

Distributed generators typically come in three types: induction generators, synchronous generators, or inverters. Each of these has specific characteristics that require consideration if interconnecting to a main grid. Generally, synchronous generators have the most complex protection requirements, since they must be synchronized in frequency and phase before being connected to the grid. Induction generators do not need to be synchronized prior to interconnection; however, they cannot generate electricity without a supply of reactive power from the grid or from capacitor banks. Grid-tie inverters have the simplest protection requirements, with built-in electronics incorporating many or all of the functions traditionally performed by protective relays. However, the correct type of inverter must be selected for the application; most grid tie inverters cannot operate without a grid connection, and most standalone inverters used in off-grid systems cannot export power to the grid.

Grid impacts that need to be carefully reviewed include:

1. Anti-islanding protection
2. Active power dispatch/sharing
3. Reactive power dispatch/sharing
4. Voltage regulation schemes

The fundamental technical differences between isolated and grid-connected systems with local generating assets are the means of control of frequency and voltage. In an isolated mini-grid, the MHP generator must control both frequency and voltage. Frequency is determined by the rotational speed of the generator shaft, while voltage depends on the changing magnetic flux through the generator's stator windings as the generator's rotor spins.

6.1. MHP-MHP Interconnection

There are four possible schemes for MHP-MHP interconnection, namely:

- <u>Common arrangement</u>; MHP-MHP interconnection with synchronous generators;
- <u>Alternative arrangement</u>; using asynchronous generators, utilizing the permanent magnet generator, and combination permanent magnet generator with grid tied inverter.

Synchronous generators are commonly used in isolated mini-grids, since they do not require a supply of reactive power from the grid and can self-start with no external supply of reactive power. Synchronous generators have an advantage over induction generators in that a synchronous generator's AVR can directly control power factor by supplying reactive power to the grid if needed, providing additional voltage support. Before connecting to the grid, the voltage output from a synchronous generator must be synchronized with the grid voltage. The generator frequency and the grid frequency must be the same, and the two waveforms must be in phase (the peaks must exactly line up); if the waveforms are not synchronized, large currents will flow and the generator will be severely damaged. Synchronization can be manual or automatic. Manual synchronization is rarely used with large generators (> 100 kW) and requires a skilled operator, but can at times be used as a backup to an automatic synchronization system. The need for synchronization means that the corresponding protective relays and equipment are required.

In a stand-alone MHP synchronous generator, frequency is kept constant by a regulator (governor) and voltage is varied by increasing or decreasing the strength of the rotor magnetic field. Typically, voltage is controlled by an AVR, which can be configured to maintain either constant voltage (voltage as setpoint) or constant power factor. In an isolated mini-grid, the AVR is configured for constant voltage.

Therefore, synchronous generators in MHP-MHP Interconnection are best interconnected with fixed speed mode MHP systems using electronic load control (conventional AC interconnection).

Conventional hydro electric generators use speed governors/ELC and also excitation controllers to regulate the speed, frequency and voltage generated and fed to the user loads. Since the cost of speed governor is high and comes with associated problems in hydraulic systems, MHP systems generally do not use speed governors. However, the speed may be governed indirectly by maintaining a constant load on the generator and hence on the turbine. Early systems used a binary approach where dump loads were switched in and out using relays. This resulted in step changes in load and for fine adjustment a large number of dump loads of different sizes were required. The use of electronics in later developments allows a continuous load adjustment.

6.1.1. Common scheme of MHP-MHP interconnection

A common configuration of MHP mini-grid is schematically presented in the following figure. The basic configuration of each MHP for mini-grid operation employs: Synchronous generators equipped with AVR with parallel capability, Electronic load controller (ELC) with parallel capability, and synchronizer.

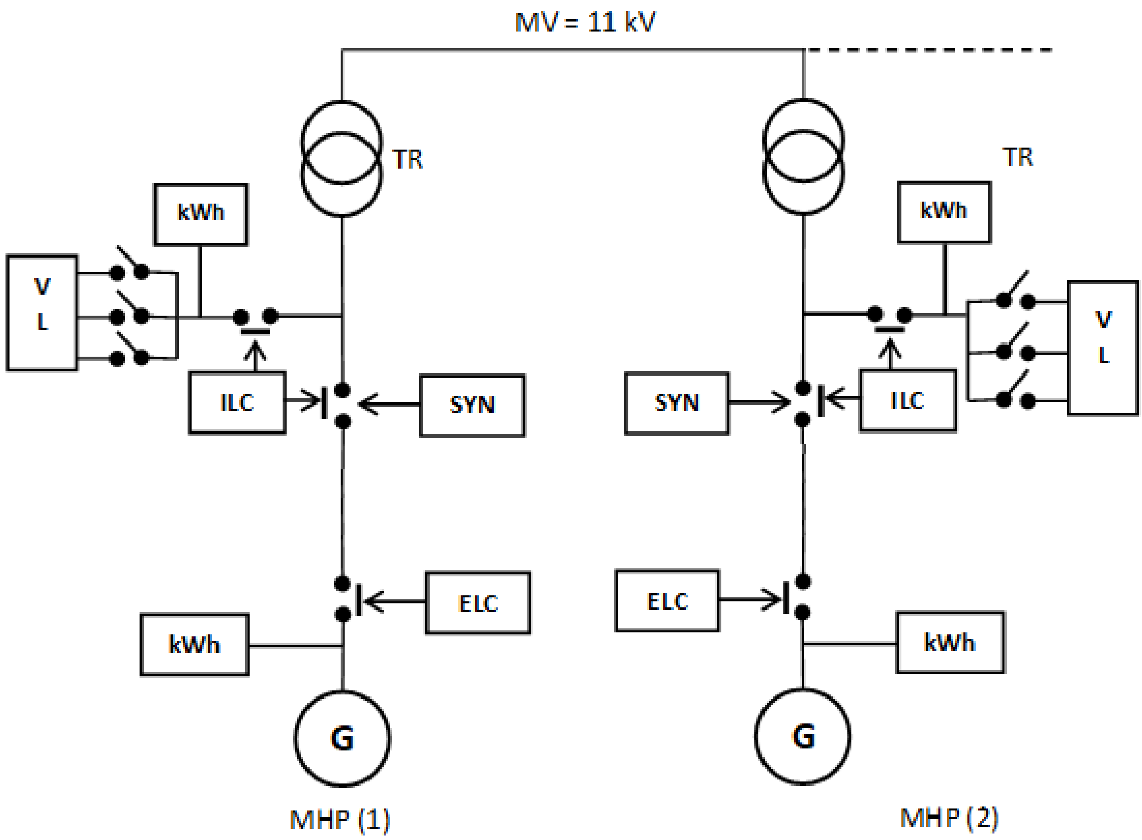


Figure 6-1. Common Arrangement of MHP-MHP Interconnection

VL	:	village (local) load
SYN	:	synchronizer
ELC	:	electronic load controller
ILC	:	inter-lock control
TR	:	step-up/-down transformer

Operating Principles

Under normal condition all MHP plants operate in parallel. If due to any reasons, e.g.: reduction of power out-put of one MHP (because of trash) or increase of village load that caused one MHP fail; the village load of the respective MHP will be automatically disconnected. This is to minimize total blackout of the mini-grid.

After the remedy of the problems, the respective plant operator can start manually the plant. If necessary, the operator can connect the respective village load step-by-step and may also disconnect temporary the non-essential (load shading) consumer of the village.

The advantage of this arrangement is allowing each MHP operate and share the power proportionally to the respective capacity of the MHP. All the MHPs are set to operate in its design or maximum capacities. Mathematically it may be presented as follows:

Total load (VLT) = VL1 + VL2 + ...

Total Generation (GT) = G1 + G2 + ...

Load Factor (LF) = $\frac{VLT}{GT} = \frac{VL1+VL2+\cdots}{G1+G2+\cdots}$

Under a situation that the overall load below its generation capacity, the excess power is proportionally sent to the ballast controlled by ELC. The excess power of the mini-grid:

EP = GT - VLT

Amount of excess power (EP) delivers to each ballast load will be distributed proportionally to the capacity of each MHP, therefore:

ELC-1 = $\frac{\text{EP x G1}}{\text{GT}}$, ELC-2 = $\frac{\text{EP x G2}}{\text{GT}}$, ... ELC-N = $\frac{\text{EP x GN}}{\text{GT}}$

In order to enable proportional load sharing, the droop frequency setting of the ELC of all MHPs must have equal setting, typically as shown in Figure 2.

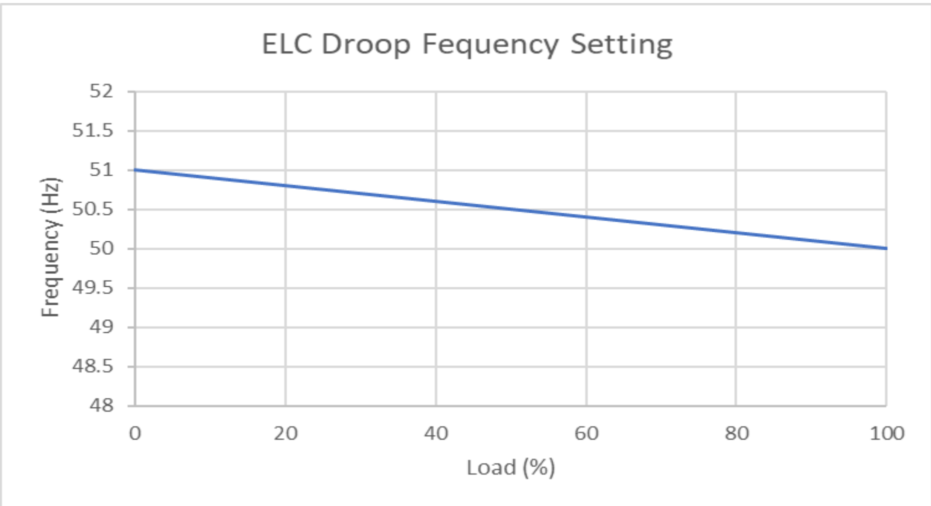


Figure 6-2. Droop Setting for Each MHP

6.1.2. Combination of synchronous- and asynchronous generators

The schematic configuration of combination between synchronous and asynchronous MHP mini-grid is shown in the figure below.

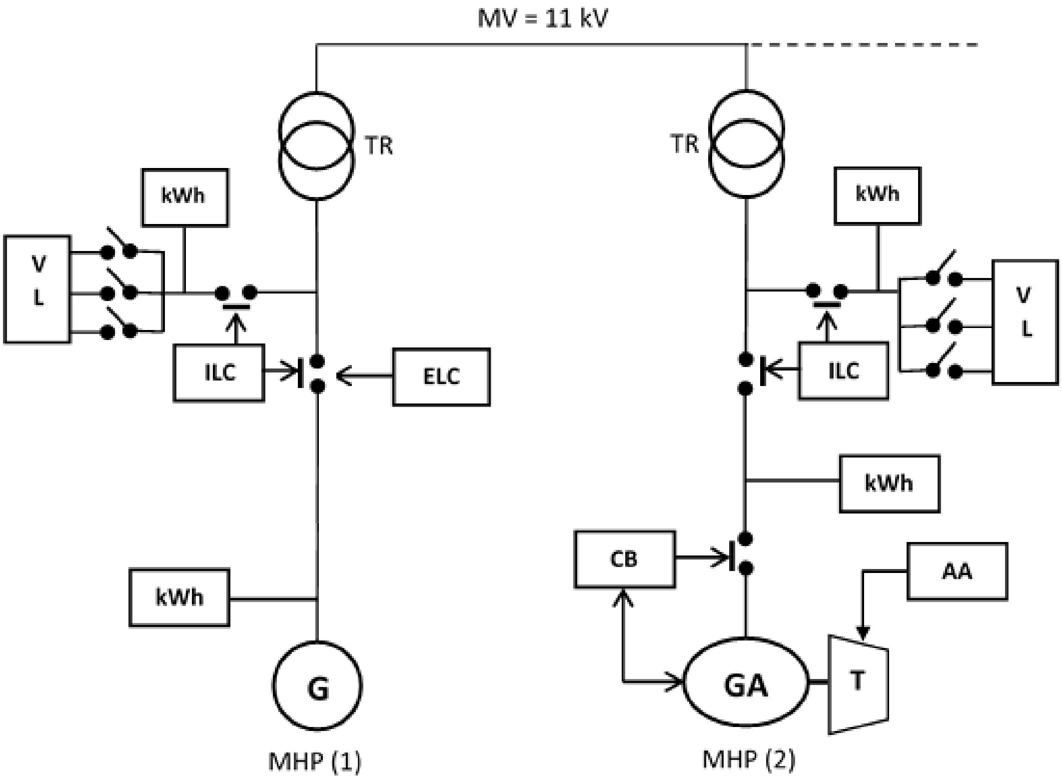


Figure 6-3. Master-Slave using Asynchronous Generator

GA	:	Asynchronous generator
AA	:	automatic actuator
FC	:	flow control
T	:	water turbine

The main principle of this configuration is based on the master-slave operation, in which the synchronous generator acts as the master that responsible to energize the grid. The asynchronous generator acts as the follower. Therefore, the performance of the mini-grid relies on the reliability and availability of the master MHP. This configuration does not employ any synchronizer and use only one ELC connected to the master MHP.

The asynchronous generator is normally a squirrel cage Induction generator as widely applied in electric motors design because of self-starting, reliable and economical. Therefore, this typical generator arrangement is often called an induction motor as generator (IMAG). For MHP operation, this IMAG is connected directly with water turbine.

A capacitor bank is required for reactive power compensation. In case of any problem with the grid (or master MHP), the slaves MHP may enters into free running condition. Therefore, an automatic actuator must be installed.

In case any problem with one or more of the slaves MHP, the local village load of the respective MHP will be automatically disconnected. This is to minimize total blackout that may not be handled by the remaining mini-grid capacity.

After the remedy of the problems, the respective plant operator can start manually the plant. If necessary, operator can connect the respective village load step-by-step and may also disconnect temporary the non-essential (load shading) consumer of the village.

6.1.3. Permanent Magnet Generator

The layout of mini-grid is similar to that of synchronous generator shown in Figure 1. The permanent magnet generator (PMG) replaces the synchronous generator G used in MHP (2) of Figure 1.

Permanent-magnet generators are simple in that they require no system for the provision of field current. Thus, it does not require the AVR. Also, a power factor controller is not required as the power factor can be obtained from slip of the rotors. They are highly reliable. They do not, however, contain any means for controlling the output voltage. Therefore, an ELC is needed to maintain its speed or frequency.

The mini-grid system operation of PMG is similar to that of synchronous generator.

6.1.4. Permanent Magnet Generator (PMG) with Grid Tie Inverter

The mini-grid configuration of combination of using PMG and grid tie inverter is widely applied in wind power plant. The arrangement of the generator and grid-inverter is schematically shown in Figure 4.

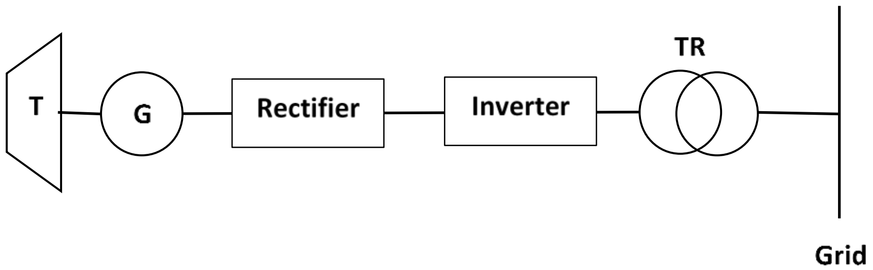


Figure 6-4. PMG with Grid Tie Inverter

The rectifier for this arrangement is simply a full-wave diode rectifier. Like in solar PV application, the inverter should also able to set the maximum power point of the PMG. In case of grid black out the water turbine may enter into free-running condition and it hence generate high voltage at the generator output. Therefore, the inverter must be able to overcome high voltage for a short period before the power is delivered to ballast load of the inverter.

6.1.5. Recommended Option

From the above 4 (four) options, the common option i.e.: the use of synchronous generators that equipped with synchronizer, ELC, and ballast load, is still the most reliable and economical solution for isolated MHP-MHP interconnection within the mini-grid scheme.

With this scheme, each MHP is still able to provide electricity services to the respective village load in case a black out occurred with the mini-grid.

As previously discussed, MHP – MHP interconnection applies for two or more MHP generators connected to the mini-grid. In order to generators work properly, the have to be synchronised before they can be interconnected. This is to bring them to the same voltage, frequency and aligning their phase. It is important to understand here that, for example, each generator cannot try to control the frequency, rather then they would have to do so in a collaborative manner. The same would apply for the voltage and reactive power.

If, after synchronisation, all operators are trying to control the frequency independently of the other, they may end up working “against” each other. In such case, it would be advisable to have one operator in charge as a master to maintain voltage and frequency. This master operator would not only make the required adjustments on the master MHP, but also give instructions to the other MHP operators to fix the operating point of their plants. This is what would be called a hierarchical control of MHP – MHP interconnection. This requires communication among the MHP plants and established standard operating procedure (SOP).

The master plant can be selected from the best sites where it provides stable electricity output over the year and reliable plant operation.

The use of synchronous generator as master and asynchronous generators as slave combination may be suitable in case of each plant does not have village load to be served. If the slave plants have their own village load, these plants will shut down if the mini-grid goes off due to any reasons.

6.1.6. Management for MHP-MHP Interconnection

The MHP-MHP interconnection through mini-grid operation has to be managed into an integrated management system comprises of grid manager and plant operators. Through this management, the monthly energy shared to individual MHP is then calculated based on the sum of the monthly electricity sold (MES) and monthly electricity generated (MEG) by each MHP:

Monthly Electricity Sold (MES) = VL1 (kWh) + VL2 (kWh) + ...

Monthly Electricity Generated (MEG) = G1 (kWh) + G2 (kWh) + ...

$$\text{Monthly Load Factor (MLF)} = \frac{\text{Monthly Electricity Sold}}{\text{Monthly Electricity Generated}} = \frac{\text{VL1 (kWh)} + \text{VL2 (kWh)} + \ldots}{\text{G1 (kWh)} + \text{G2 (kWh)} + \ldots}$$

Accordingly, the monthly energy sold by each MHP is obtained:

MHP-1 = MLF x G1 (kWh)

MHP-2 = MLF x G2 (kWh)

MHP-N = MLF x GN (kWh)

Simple Case:

Let’s consider two MHPs that operate in parallel. Each MHP has the following generating capacity and village load;

MHP-1: Has generating capacity of 10 kW and village peak load of 12 kW

MHP-2: Has generating capacity of 15 kW and village peak load of 9 kW

Using the already discussed approach, the load sharing of the mini-grid can be determined as shown in the following table.

G1	G2	GT	VL1	VL2	VLT	EP	ELC-1	ELC-2
kW								
10	15	25	12	7	21	4	1.6	2.4

During this circumstance, the load factor of the mini-grid is:

Load Factor (LF) = $\frac{VLT}{GT} = \frac{21\ kW}{25\ kW} = 0.84$

For the monthly energy sharing, let's assume the following monthly record.

G1	G2	MEG	VL1	VL2	MES
kWh					
250	400	650	300	220	520

Monthly Load Factor (MLF) = $\frac{\text{MES}}{\text{MEG}} = \frac{520\ \text{kWh}}{650\ \text{kWh}} = 0.8$

Energy sharing distribution for each MHP will be:

MHP-1 = MLF x G1 (kWh) = 0.8 x 250 kWh = 200 kWh

MHP-2 = MLF x G2 (kWh) = 0.8 x 400 kWh = 320 kWh

It is expected that this energy sharing approach can be accepted by plant operators or owners.

6.2. MHP Grid Interconnection

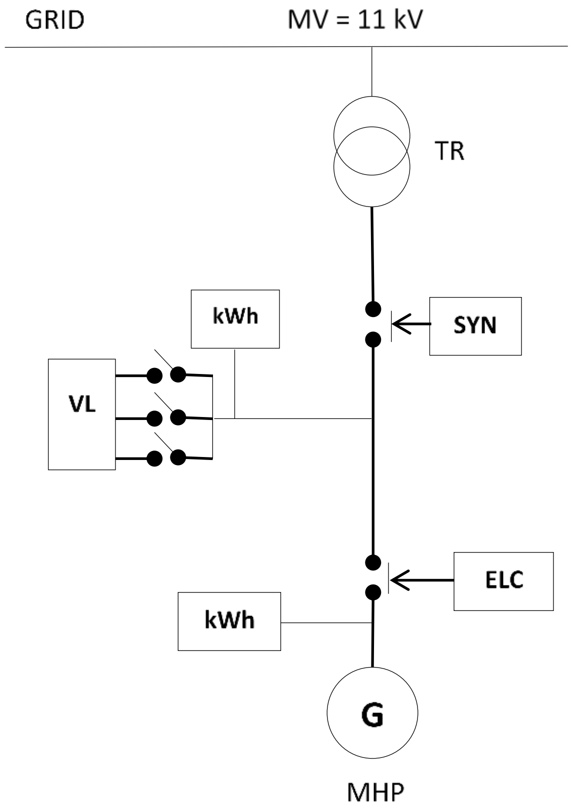
On the main grid, frequency is stabilized by the rotational inertia of very large generators. When connected to the grid, a small MHP generator will spin at the grid frequency. Thus, a grid-connected small MHP generator makes no attempt to regulate frequency. It just injects current in step with the grid's frequency.

Voltage regulation by a grid-connected MHP often depends on local utility company guideline. Voltage varies from node to node throughout the system depending on the distribution of loads, generation, and power factor correcting capacitor banks. In some locations, utilities may prefer that a small power producer regulate its generator to keep a constant power factor. In other cases, particularly in parts of the distribution system where utilities do not have good voltage regulation, the utility may ask the distributed generator to regulate voltage.

In conventional AC MHP-grid interconnection, the main barrier is the cost of both the turbine and the control gear necessary to regulate the speed and keep the frequency within required limits. The grid connection standard makes this requirement even stricter and increases cost. Generally, there are common scheme for conventional MHP-Grid interconnection as follows:

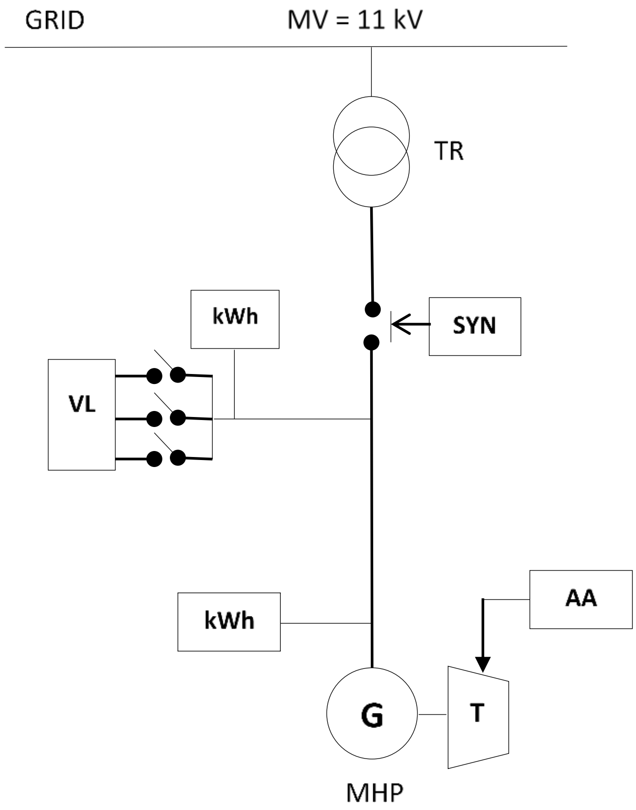
- Synchronous Generator with ELC

For a small MHP (< 100-200 kW) a combination of a synchronous generator with an electronic load controller (ELC), ballast load and synchronizer remain the most preferable solution (see the following Figure). This solution is suitable for the MHP that has local load or village load so, in case of grid failure, the MHP remains able to serve the local or village load.



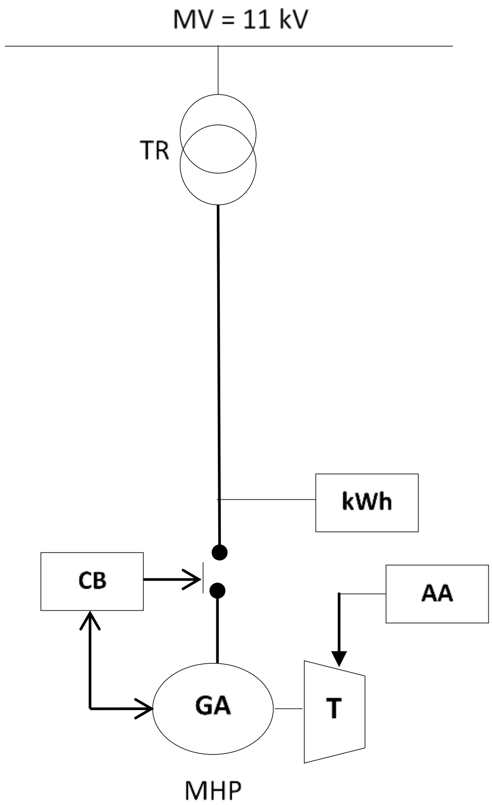
- Synchronous Generator with Flow Control

For a larger MHP (> 100 kW) a combination of the utilization of a synchronous generator in combination with automatic actuator - AA (to control the water flow) and synchronizer is recommended (see the following Figure). Similar to that smaller MHP, this solution is also suitable for the MHP that has local load or village load so, in case of grid failure, the MHP remains able to serve its local or village load.



- Asynchronous Generator

When there is no local or village load to be served by the MHP, the use of asynchronous generator will be possible (see the following Figure). Depending on the local grid regulation, the use of asynchronous generator for gid interconnected system has to be equipped with capacitor bank to compensate the reactive power generated by the generator. In addition, an automatic actuator (to control the water flow and shut-off valve) must also be installed for synchronization process and to avoid a free running of the generator in case of grid failure.



Developments in other renewable energy systems, have led to the availability of electronic converter systems that use techniques from wind, solar PV systems and other renewable energy systems, to allow variable speed operation of MHP system by making the output frequency independent of the speed of rotation of the turbine. A typical adapted technology is the double conversion system used in wind turbines. Maximum power point tracking (MPPT), an adaption of techniques from small grid connected PV systems, uses the variable speed capability to ensure that maximum power is extracted from the water flow under all load conditions.

The widespread use and availability of inverter systems operating over a wide input voltage range make it possible to construct MHP systems with close frequency control, MPPT and grid connection ability at an affordable price.

Variable speed MH systems offer improved control over both output voltage and frequency, while allowing MPPT or maximum efficiency tracking methods to be applied. Techniques include the use of double fed induction generators, electrically excited synchronous generators and permanent magnet synchronous generators with double conversion inverters.

Inverters are solid-state electronic devices that convert DC power to AC. Since solar PV modules produce DC, inverters are an essential component of these systems. Inverters are also used in some wind power systems, in which the generator coupled to the wind turbine generates power at varying frequency (depending on the wind speed), which is then converted to DC and back to AC at the grid frequency. There are two basic types of inverters: grid-interactive (grid-tie or synchronous) and standalone (or offgrid). In grid-interactive inverters, the grid controls both frequency and voltage. These inverters are designed to export power to the utility grid and incorporate many of the functions traditionally performed by protective relays, including synchronization, over/undervoltage protection, and frequency protection. Exporting power to the utility grid requires a grid-interactive inverter; however, most grid-tie inverters cannot operate without a grid connection and will shut down if one is not present.

Variable speed operation is made possible by the use of a double conversion inverter. This principle is similar to that used for large wind turbines, with the hardware scaled down to the power levels involved. In principle the speed of the turbine is controlled within operational limits by means of a simple servomechanism, which allows the output frequency to vary. The output of the generator is converted to DC, which is then converted to AC of the required frequency and voltage by an inverter. Frequency stability is controlled by the inverter and not the turbine rotational speed.

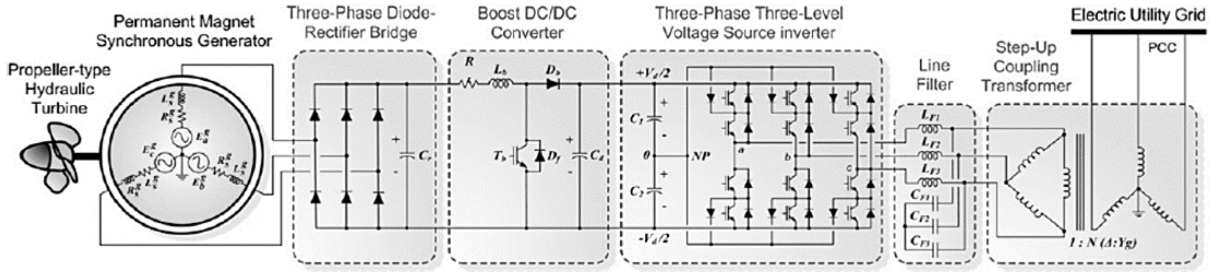


Figure 6-5. Typical Configuration of Variable Speed MHP with Inverter

A study of practical approach of grid-connected picohydro systems with PV inverter has been carried out successfully. It is similar to a typical low power wind system but instead of a wind inverter with a specific parametrized power curve, it uses a conventional PV inverter. This solution has some important advantages such as broad range of products and technological independence. Furthermore, these wide-spread PV inverters are very cost competitive. By using a PV inverter for a grid-connected pico-hydro turbine, the input voltage of the PV inverter is the rectified output voltage of the generator instead of a DC voltage provided by a PV string. The solution is very simple but in order to be reliable and safe, the integration of the inverter with the generator must be properly assured.

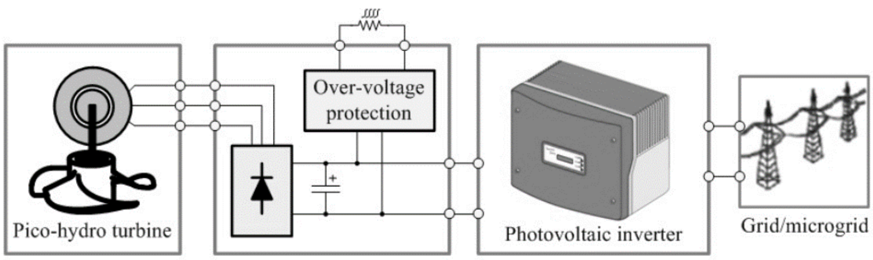


Figure 6-6. Configuration of practical approach of grid-connected picohydro systems with PV inverter

7. Simulation Analysis and Case Studies

7.1. MHP-MHP Interconnection at Baglung

7.1.1. Features

MHP-MHP interconnection at Baglung consists of 6 (six) MHPs operating into a common grid which involve 11 kV MV distribution line. With this interconnection, there are changes in the power load flow between MHPs/Villages. Therefore, it is necessary to simulate the load flow at the 11 kV side (MV distribution line) on each MHP switchgear.

This section describes the results of load flow calculations in the interconnection development plan for the Baglung Mini-grid system. Baglung Mini-grid consists of 6 distributed MHPs which are interconnected into a common grid with a total capacity of 107 kW, connected by 11 kV transmission line with total length of 8 km. The configuration of the Baglung mini-grid plan is shown in the following figure:

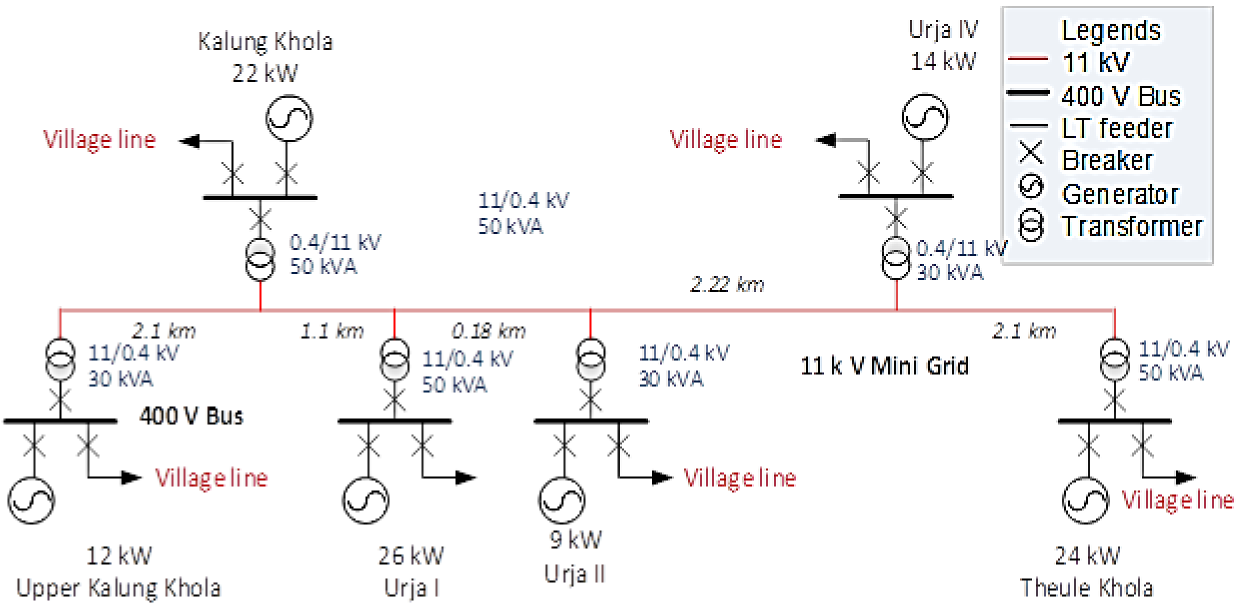


Figure 7-1. Configuration of Baglung Mini-grid Plan

The load flow study is to the determine or calculate the voltage, current, active power and reactive power found at various points of the power grid in normal operating conditions, both those that are currently running and those that are expected to occur in the future.

In addition, with the interconnection of several MHPs, it will certainly increase the short circuit current if there is a fault. Short circuit fault study is an analysis or evaluation of an electrical system to determine the amount of current that can flow in the event of an electrical fault and to compare this value with the rating of the equipment installed. Therefore, in this simulation, it also presents the results of the 3-phase short circuit current in the Mini-gird Baglung interconnection system.

The purposes of simulation study are:

- To determine the voltage profile of the 11 kV and 0.4 kV side at each Power Plant and Load.
- To determine the active and reactive power flow from the generator to each load, and the power sent to the 11 kV network.

- To determine network losses.
- Short circuit calculation is used to determine the breaking capacity and momentary of the existing equipment or to be installed

7.1.2. Simulation Data

Simulation data used in this analysis comprises of several actual data, whether primary or secondary data, combined with typical data (approximation approach).

7.1.2.1. Generator Data

Generator data is in accordance with existing data. However, subtransient, transient and steady state reactance use the default data in the software.

Table 7-1. Technical Data of MHP Baglung Mini-grid

SN	Name of MHP Plant	Generator Capacity			Rate Voltage	Rate Current	Gross Head	Design Discharge	Channel Length	Year of Establishment	Turbine Type	Governor Type
		(kW)	kVA	Cos Φ	(Volt)	(Amp)	(Meter)	(lps)	(m)			
1	Upper Kalung Khola MHP	12	25	0.8	415	35	57	45	345	2062	Cross Flow	ILC
2	Kalung Khole MHP	22	40	0.8	415	55.6	56	70	550	2054	Double jet peloton	ILC
3	Urja Khola I MHP	26	50	0.8	415	70	26	54	100	2057	Cross Flow	ILC
4	Urja Khola II MHP	9	20	0.8	415	28	17	110	195	2062	Cross Flow	ILC
5	Urja Khola IV MHP	14	30	0.8	415	42	16	164	250	2068	Cross Flow	ILC
6	Theule Khola MHP	24	50	0.8	415	69.6	50	150	550	2056	Cross Flow	ILC

7.1.2.2. Load Data

It is essential to understand the daily load demand of the system. It is necessary to know the characteristics of the daily load of MHP Baglung. The load profile is very important for simulating data flow and short circuit calculations. Electricity load for each location varies, during the day, the load is relatively lower than at night and the peak load is at 7 PM. Loads for each location and Baglung mini-grid interconnection can be seen in in Hourly Load Data in Baglung Mini-grid table in the Annex 3.1.

In the stand-alone mode, the micro hydropower is used to feed the load only near its vicinity. But in the interconnection system, the six power plants of size 9 kW to 26 kW are used to supply power to 1184 households.

The hourly load consumption pattern has been plotted combining all the reading of 6 energy meters in the respective power houses. It has been observed that the base load of the system is 25.2 kW while the peak load is 93.5 kW. The daily load curve on the Baglung mini-grid system is shown in the following figure.

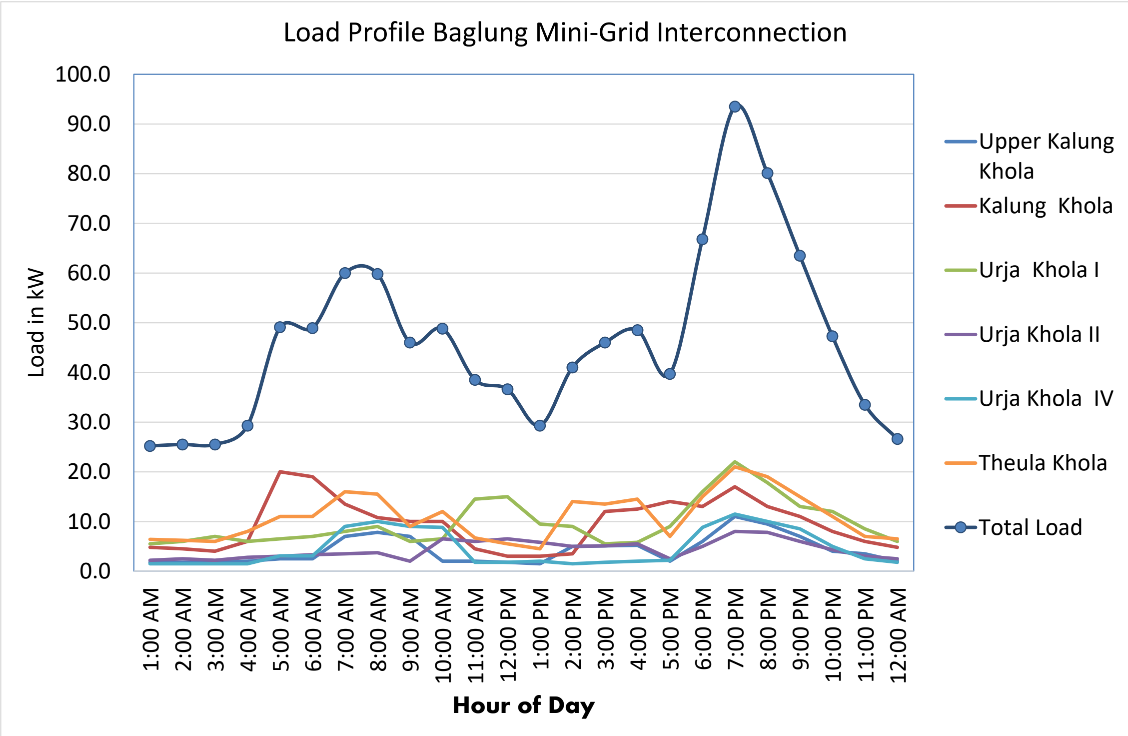


Figure 7-2. Daily load profile Baglung mini-grid interconnection

7.1.2.3. Low Voltage Distribution Line Data

Table 7-2. LV Distribution Line Data

Location	Households (Number)	Ballast load (kW)	Conductor Type	Line length
Upper Kalung Khola	114	15	Weasel (30mm²)	1200 m, 3-phase & 1000 m 1-phase
Kalung Khola	232	30	Squirrel (20 mm²)	2000 m, 3-phase & 1000 m 1-phase
Urja Khola I	267	30	Dog (100mm²), Weasel (30mm²) & Squirrel (20 mm²)	4500 m, 3-phase & 800 m 1-phase
Urja Khola II	165	15	Weasel (30mm²)	1500 m, 3-phase & 500 m 1-phase
Urja Khola IV	124	18	Weasel (30mm²)	3000 m, 3-phase & 1000 m 1-phase
Theule Khola	282	36	Dog (100mm²) - 500m, Rabbit (50mm²) - 2500m	2500 m, 3-phase & 500 m 1-phase
Total	1,184			

Table 7-3. Conductor Resistance and Reactance

Line	Length (m)	Conductor Type	R (Ohm/km) at 20°C	X(Ohm/km) at 20°C
UKK to Village	1,200	Weasel (30mm²)	0.9077	0.1306
KK to Village	2,000	Squirrel (20mm²)	1.394	0.2005
UKI to Village	4,500	Dog (100mm²)	0.2794	0.0402
UKII to Village	2,000	Weasel (30mm²)	0.9077	0.1306
UKIV to Village	3,000	Weasel (30mm²	0.9077	0.1306
TK to Village	2,500	Dog (100mm²)	0.2794	0.0402

7.1.2.4. Transformer Data

Table 7-4. Transformer Data

Transformer Name	Capacity (kVA)	Z (%)	Voltage (kV)
T- UKK	30	4	11/0.4 kV
T-KK	50	4	11/0.4 kV
T-UKI	50	4	11/0.4 kV
T-UKII	30	4	11/0.4 kV
T-UKIV	30	4	11/0.4 kV
T-TKI	50	4	11/0.4 kV

7.1.2.5. Medium Voltage Distribution Line Data

Table 7-5. MV Distribution Line Data

Line	Length (m)	Conductor Type	R (Ohm/km) at 20°C	X(Ohm/km) at 20°C
UKK to KK	2,100	Weasel (30mm²)	0.9077	0.1306
KK to UKI	1,100	Weasel (30mm²)	0.9077	0.1306
UKI to UKII	180	Weasel (30mm²)	0.9077	0.1306
UKII to UKIV	2,220	Weasel (30mm²)	0.9077	0.1306
UKIV tot KI	2,100	Weasel (30mm²)	0.9077	0.1306

7.1.3. Simulation Approaches

In this simulation, it is assumed that all generators are in droop mode. This means that all generators serve the load proportionally according to their respective nominal power capacities. In this study it is also assumed that all ballast loads at these 6 locations are operating according to their respective capacities.

When the load is low, all generators continue to generate power according to their capacity. The power generated is used to serve existing loads and ballast loads. Because the load for the village is low, most of the power generated by the generator will be absorbed by the Ballast Load.

However, at night, the load on all villages will increase, especially at 19.00 at night. Of course, the power generated by the generator is mostly absorbed by the load and partially absorbed by the Ballast load.

The simulation is only carried out during the peak load, which is at 19.00. This is done to ensure that the existing generator can serve the entire load with a sufficiently voltage.

Simulation analysis and case studies is carried out to determine system behaviour in Baglung mini-grid using ETAP and DiGSILENT software. The analysis focused on three subjects which are:

1. Load flow analysis
2. Short circuit analysis
3. Transient stability analysis.

7.1.4. Model and Simulation (ETAP)

7.1.4.1. Load Flow Study Result at peak load period (Maximum Load – ETAP)

Based on the load data as shown in Hourly Load Data in Baglung Mini-grid table in the annex 3.2, the maximum load occurs at 07:00 PM, which is 93.5 kW. Of course, this load must be able to be served by 6 MHP generating units which are interconnected on the 11 kV network. To ensure that the MHP can serve the load with the voltage at its rating, it is necessary to simulate. The simulation results of the mini-grid power flow system at maximum load can be shown in the following Figure.

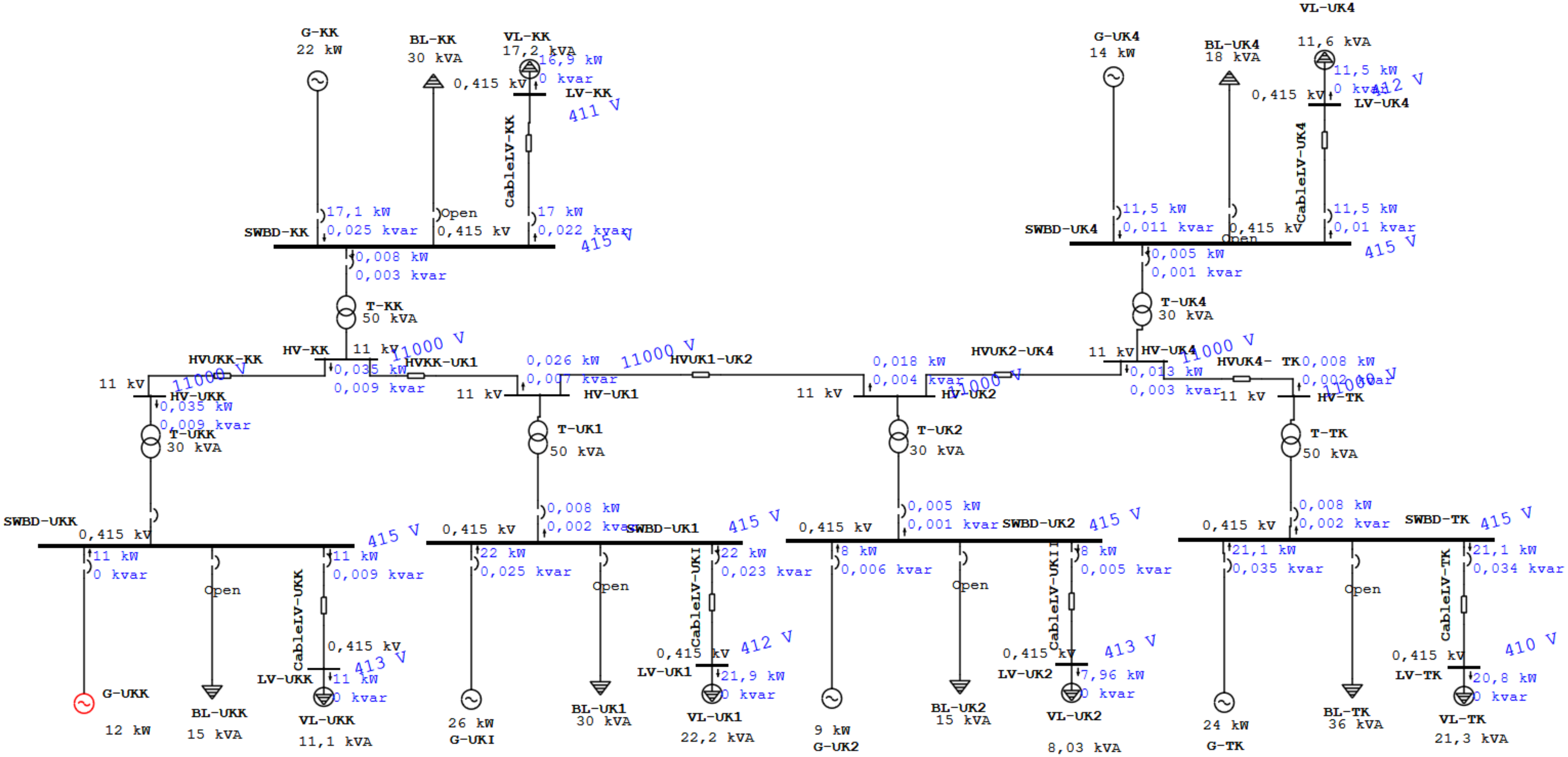


Figure 7-3. Load Flow Result of Baglung Mini-grid in Maximum Load Scenario

Based on the simulation results at full load which are all active loads, the power generated by each generator can be absorbed by rural households. There is no flow of 11 kV of power to the network; this is because the power generated by each generator is fully absorbed by each household load in the village. The voltage on each switchboard is the same as the generator output voltage. This means that in operating conditions like this the mini-grid system can function properly. A summary of the simulation results is shown in the following table.

Table 7-6. Simulation result at full load

MHP	Capacity (kW)	Generated Power					Load Village				% Loading
		kW	kVAr	kVA	PF	Voltage (V)	kW	kVAr	kVA	PF	
Upper Kalung Khola	12	11	0	11.0	1.00	415	11	0.009	11.0	1.00	91.67
Kalung Khola	22	17.1	0.025	17.0	0.99	415	16.9	0.022	17.0	0.99	77.27
Urja Khola I	26	22	0.025	22.0	0.99	415	21.9	0.023	22.0	0.99	84.62
Urja Khola II	9	8	0.006	8.0	1.00	415	7.96	0.005	8.0	1.00	88.89
Urja Khola IV	14	11.5	0.011	11.5	1.00	415	11.5	0.01	11.5	1.00	82.14
Theule Khola	24	21	0.044	21.0	0.99	415	20.8	0.042	21.0	0.99	87.50
Total/ Average	107	90.6	0.111			415	89.66	0.111	90.5		85.35

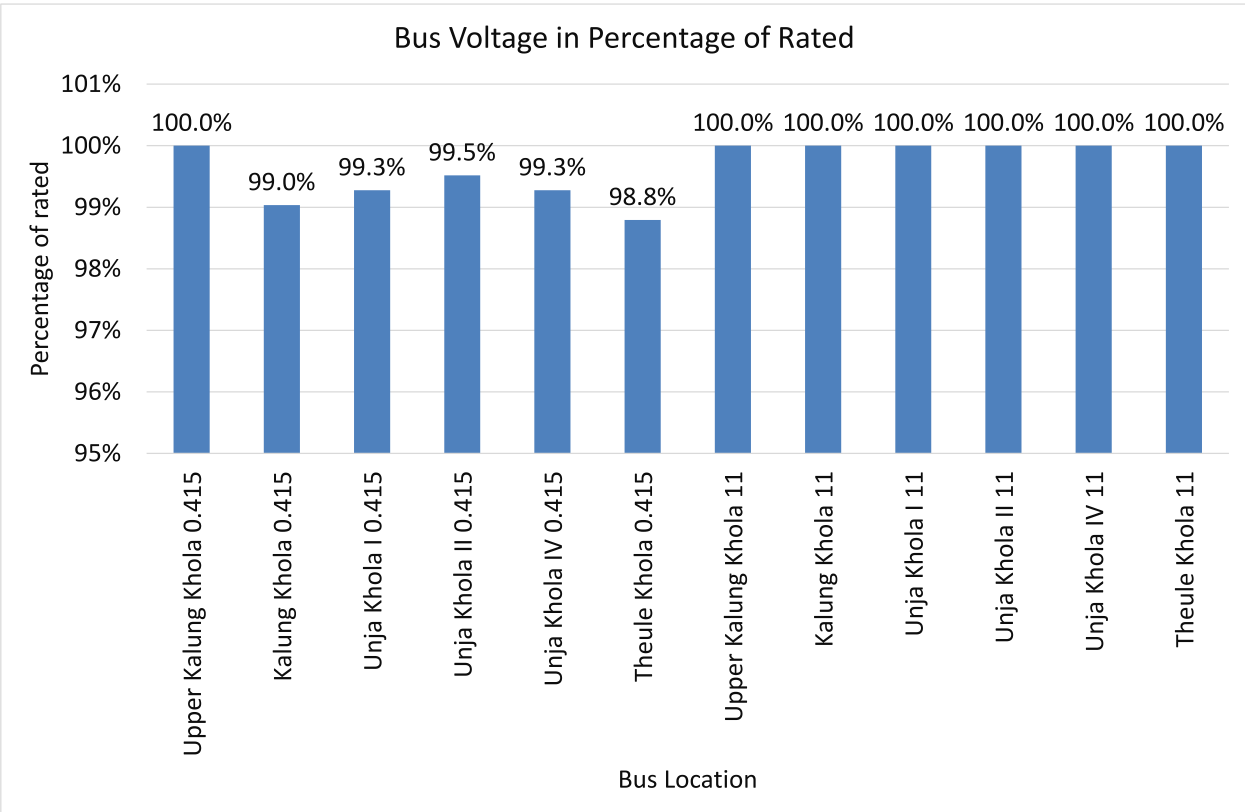


Figure 7-4. Bus voltages of different bus during peak period

Figure 7-4 above depicts that during Peak period all the bus voltages will be within the limits of ± 5% of the rated voltage. Total loss during the peak period will be around 940W.

In fact, the load is not pure kW. Therefore, in this second calculation it is assumed that the electric load in addition to the kW load, there is also an inductive load kVAr. In this calculation, the load is assumed to be a power factor of about 0.85 (lagging). The results of calculations with the power factor at each load of 0.9 (lagging) can be seen in the following figure and table.

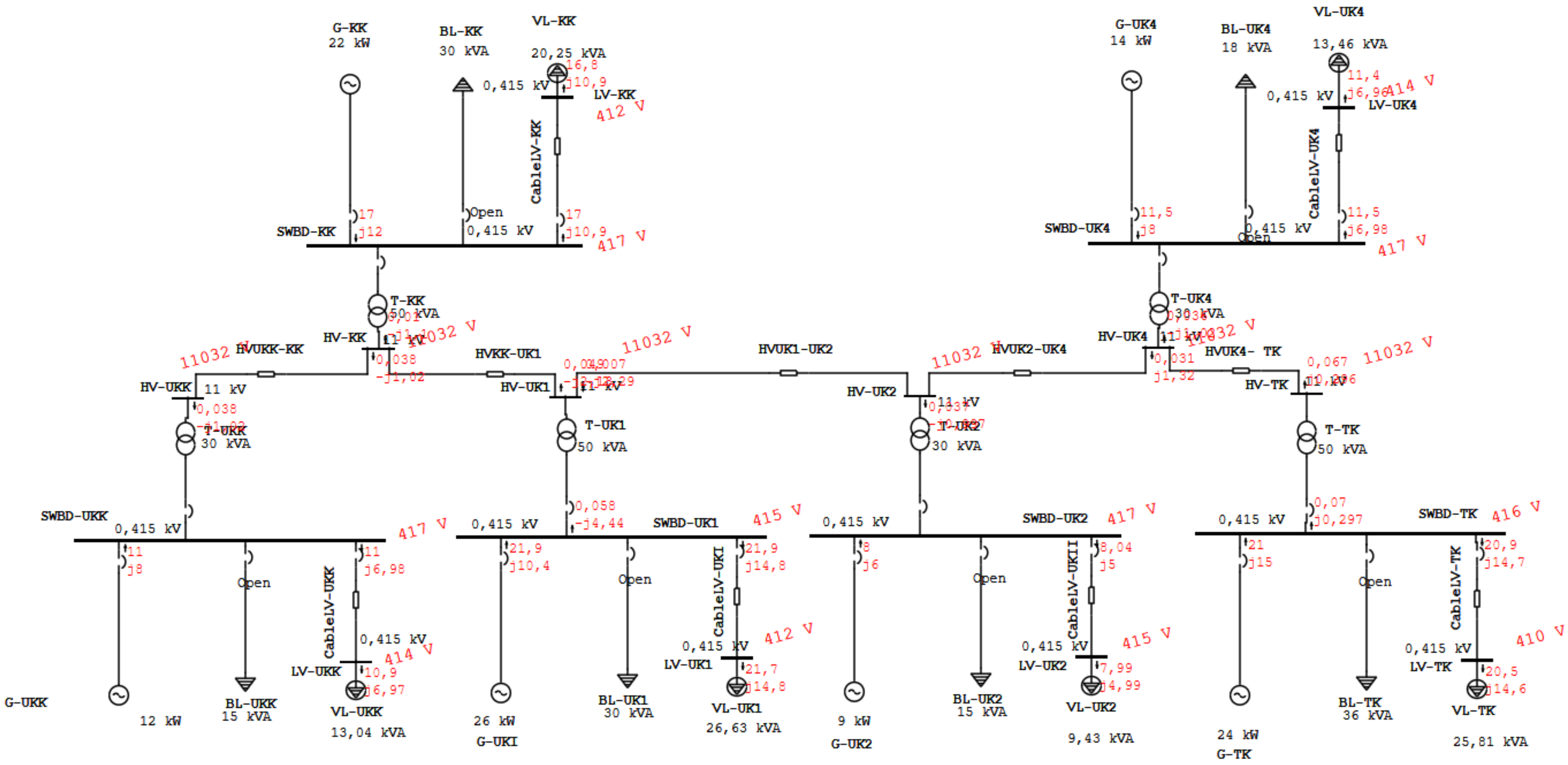


Figure 7-5. Load Flow Result of Baglung Mini-grid in Maximum Load Scenario with 15% reactive load

Table 7-7. Generated power, load and voltage profile at a power factor of 0.85

MHP	Capacity (kW)	Generated Power					Load Village			
		kW	kVar	kVA	Pf	Voltage (V)	kW	kVar	kVA	Pf
Upper Kalung Khola	12	11.00	8.00	13.60	0.81	415.00	10.90	6.97	12.94	0.84
Kalung Khola	22	17.00	12.00	20.81	0.82	415.00	16.80	10.90	20.03	0.84
Unja Khola I	26	21.90	10.40	24.24	0.90	415.00	21.70	14.80	26.27	0.83
Unja Khola II	9	8.00	6.00	10.00	0.80	415.00	7.99	4.99	9.42	0.85
Unja Khola IV	14	11.50	8.00	14.01	0.82	415.00	11.40	6.96	13.36	0.85
Theule Khola	24	21.00	15.00	25.81	0.81	415.00	20.50	14.60	25.17	0.81
Total/Average	**107**	**90.4**	**59.4**	**108.17**	**0.83**	**2490**	**89.29**	**59.22**	**107.14**	**0.84**

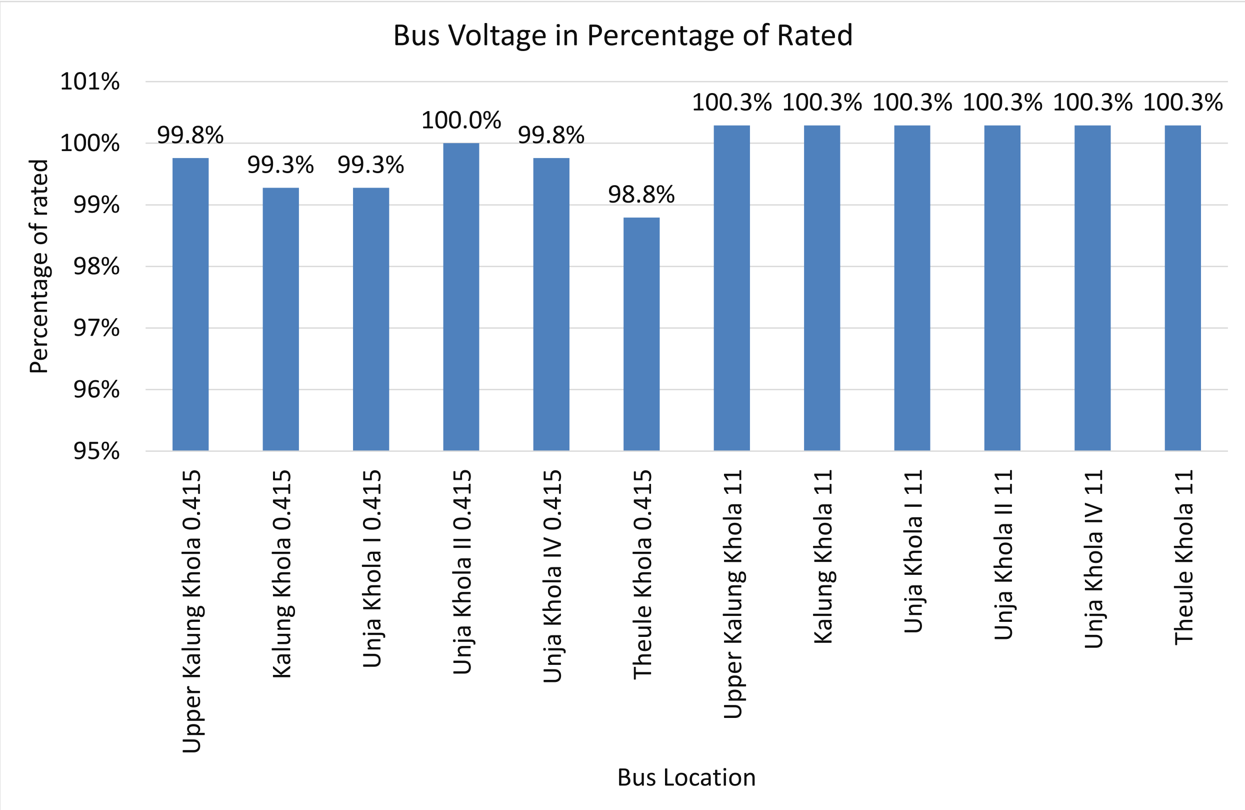


Figure 7-6. Bus voltages of different bus during peak period with 15% reactive load

Figure above depicts that during Peak period all the bus voltages will be within the limits of ± 5% of the rated voltage. Total loss during the peak period will be around 1,110 W.

There is a possibility that at peak load one of the generators is off. A simulation is needed to ensure that all loads can still be supplied from the 5 interconnected generators. The following table shows the simulation results of the load flow when the 9 kW generator in Urja Khola II is off.

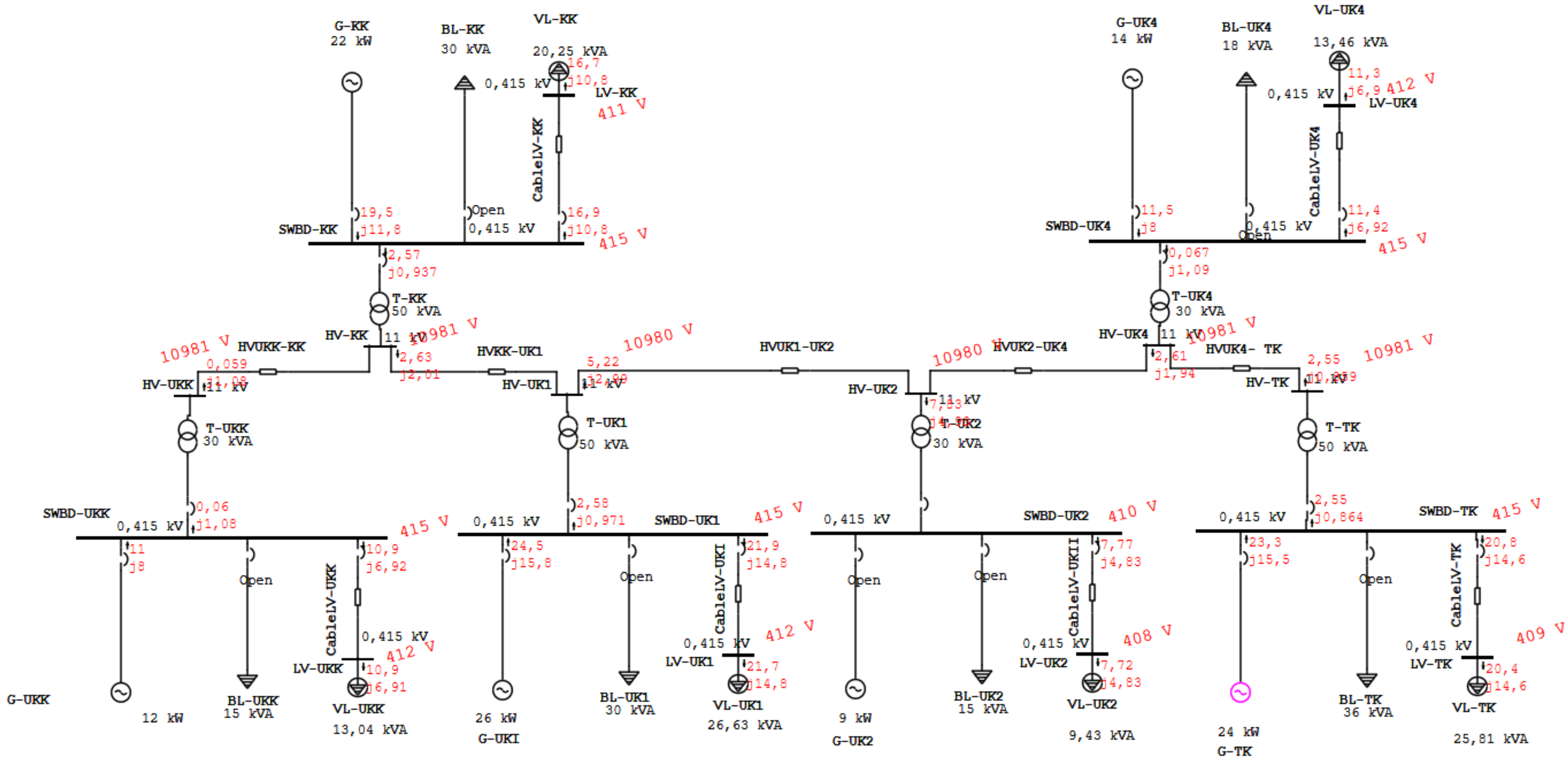


Figure 7-7. Load Flow Result of Baglung Mini-grid in MHP Urja Khola Failure

Table 7-8. The load flow result when Generator Urja Khola II is fault

MHP	Capacity (kW)	Generated Power					Load Village					To grid 11 kV	
		kW	kVar	kVA	Pf	Voltage (V)	kW	kVar	kVA	Pf	Volt	kW	kVar
Upper Kalung Khola	12	11	8	13.60	0.81	415	10.9	6.91	12.91	0.84	412	0.08	1.08
Kalung Khola	22	19.5	11.8	22.79	0.86	415	16.7	10.8	19.89	0.84	411	2.57	0.957
Unja Khola I	26	24.5	15.8	29.15	0.84	415	21.7	14.8	26.27	0.83	412	2.58	0.971
Unja Khola II	9	0	0	0.00	0.00	410	7.72	4.83	9.11	0.85	408	-7.83	-4.73
Unja Khola IV	14	11.5	8	14.01	0.82	415	11.6	6.9	13.50	0.86	412	0.067	1.09
Theule Khola	24	23	15.5	27.74	0.83	415	20.4	14.6	25.09	0.81	409	2.55	0.864
Total/Average	**107**	**89.5**	**59.1**	**107.25**	**0.83**		**89.02**	**58.84**	**106.71**	**0.83**			

The figure and table above show that when the peak load and 9 kW Urja Khola II Generator is failure, all household loads in 6 villages can be supplied from 5 interconnected generators. The power contribution from the Upper Kalung Khola is 0.08 kW, from Kalung Khola is 2.57 kW, Urja Khola I: 2.58 kW, Urja Khola IV is 0.067 kW and the largest comes from the Theula Khola generator which is 2.55 kW. The total losses is 1.2 W. Figure below depicts that during Peak period all the bus voltages will be within the limits of ± 5% of the rated voltage.

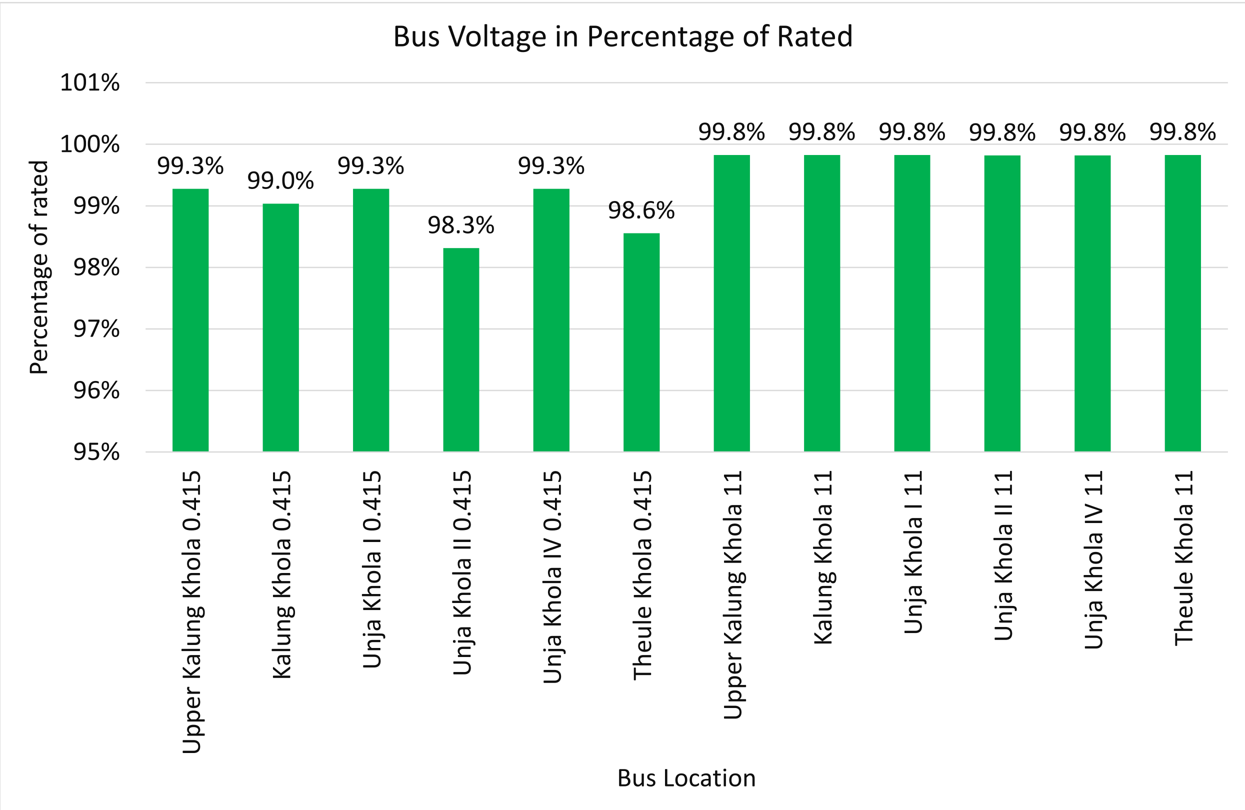


Figure 7-8. Bus voltages of different bus during peak period (kW Urja Khola II Generator Off)

The figure and table above show that when the peak load and 9 kW Urja Khola II Generator is failure, all household loads in 6 villages can be supplied from 5 interconnected generators. The power contribution from the Khola Necklace is 2.24 kW, from Urja Khola I: 2.23 kW, Urja Khola IV is 1.32 kW and the largest comes from the Theula Khola generator which is 2.27 kW. The total losses on the line are quite low, only 0.12 kW.

7.1.4.2. Load Flow Study Result at off peak load (at 10 pm – 5 pm)

Electricity load from 10 PM to 5 PM in the afternoon is relatively lower. In this condition, it can be ensured that all the loads that occur can be handled properly by the 6 existing generators. So, even if one of the largest generators, Urja Khola I, has a problem, the 5 existing generators can still provide the total load. The data used in the calculation simulation is 7 AM data, because the biggest power consumption is during that time for 19 hours between 10 pm and 5 PM. At that time, it is possible that 1 or 2 generators can be off, especially when the river flow is low. For example, the Upper Kalung Khola Generator and the Kalung Khola then the 4 generators can still serve the total loads in the 6 villages. What is not possible is MHP Kalung Khola I and Theule Khola experiencing interference at the same time. The complete simulation results can be seen in the simulation results summary table in the annex 3.3.

Based on the results of the load flow study simulation as shown in the table above, it can be seen that during the off peak load period, if one of the power plants is off, all the loads in all villages can still be served properly. This shows that this mini-grid interconnection system will improve service reliability.

The simulation results also show that it is possible if there are 2 generator units off simultaneously, especially those with small capacities. Like the Kalung Khola Generator and Urja Khola II off simultaneously.

7.1.4.3. Short Circuit Calculation

There are 3 (three) types of short circuit faults that may occur in the electrical network, namely: 3-phase short circuit, 2-phase (phase-phase) short circuit and 1-phase (phase-ground) short circuit. Among the three disturbances, the highest short circuit current occurs in the 3-phase short circuit fault. Therefore, on this occasion only the 3-phase short circuit fault was carried out. The results of short circuit calculations using ETAP can be seen in the following figure and table

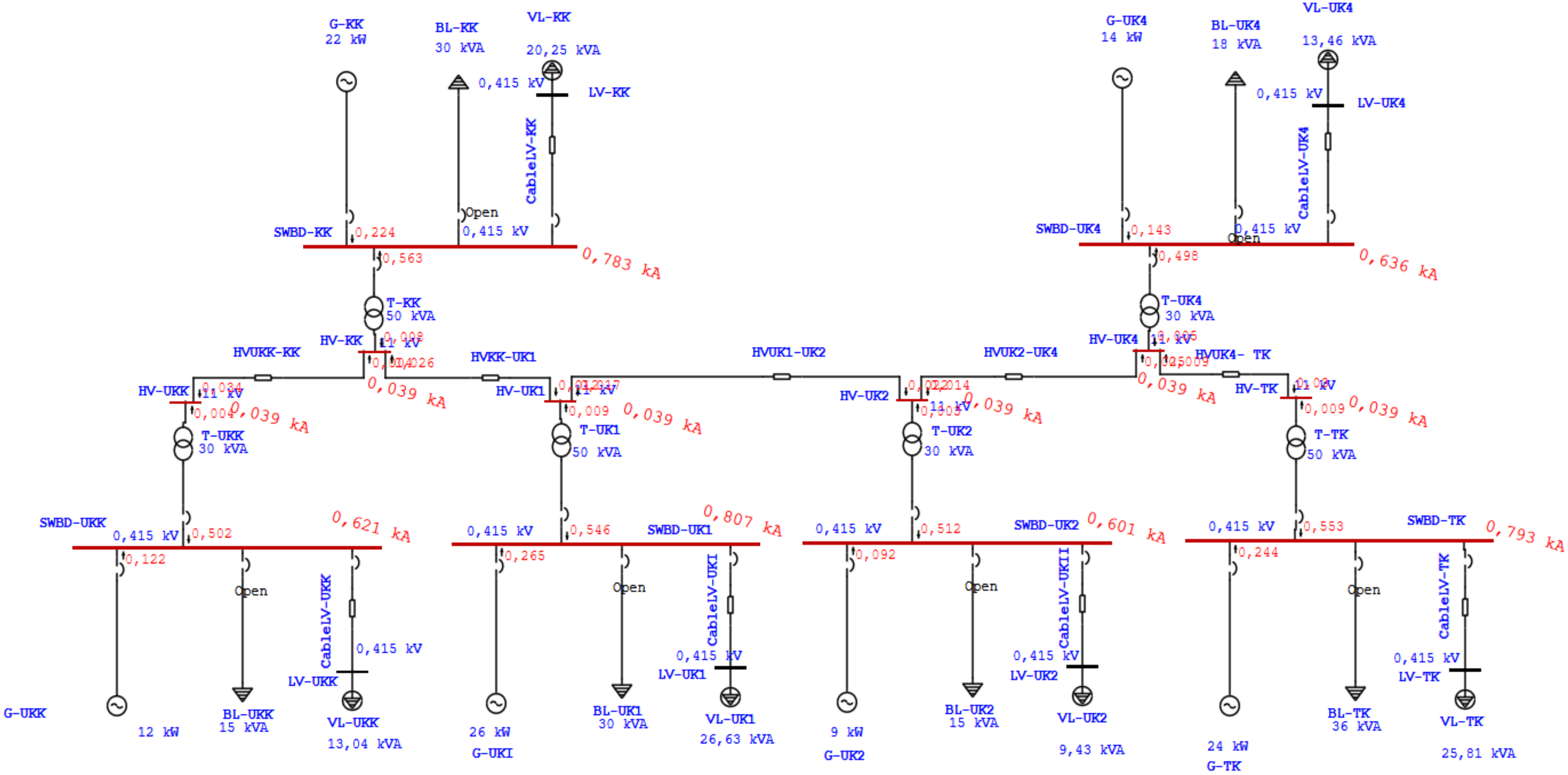


Figure 7-9. Short Circuit Calculation Result of Baglung Mini-grid Interconnection

Table 7-9. Short Circuit current levels of different MHP

MHP	Faulted Bus	Short Circuit Current
Upper Kalung Khola	Fault at 11 kV side	0.039 kA
	Fault at SWBD 0.415 kV side	0.621 kA
Kalung Khola	Fault at 11 kV side	0.039 kA
	Fault at SWBD 0.415 kV side	0.783 kA
Urja Khola I	Fault at 11 kV side	0.039 kA
	Fault at SWBD 0.415 kV side	0.807 kA
Urja Khola II	Fault at 11 kV side	0.039 kA
	Fault at SWBD 0.415 kV side	0.601 kA
Urja Khola IV	Fault at 11 kV side	0.039 kA
	Fault at SWBD 0.415 kV side	0.636 kA
Theule Khola	Fault at 11 kV side	0.039 kA
	Fault at SWBD 0.415 kV side	0.793 kA

Based on the results of the short circuit calculation as shown in the table, it can be seen that the short circuit current in the 11 kV side is 0.039 kA.

7.1.4.4. Transient Analysis

Transient Simulation for Mini-grid Interconnection in Baglung has been performed on the software ETAP 16.00. The major purpose of the study is to determine three different stability criteria for the project namely Voltage Stability, Rotor Angle Stability, and the Frequency stability.

We have performed the analysis for the time frame of 2021 in an isolated mode and grid connected mode considering all the generation and the transmission lines that the Consultant assumes are likely to be online by the time frame. Four different scenarios have been simulated during the stability study. They are as follows:

Case 1: Three Phase fault on the line from Kalung Khola 1

Case 2: Tripping of Kalung Khola 1 without reclose

We have assumed several standard and generic models for the generator, excitation system, governor, and the stabilizer due to unavailability of the data for the existing system. The fault clearing time of 11 kV system is assumed to be 7.5 cycles or 0.15 sec as per Nepalese grid code. Consultant assumes following criteria to evaluate the stability the system:

- Transient undervoltage after the fault clearance should remain above 0.7 p. u and the voltage should recover above 0.9 p. u within 2 seconds from the fault occurrence

- Transient overvoltage should remain below 1.3 p. u for first 200 m.s. from the fault occurrence and the voltage should recover below 1.1 p. u after that.
- The frequency deviation must be within the ± 2.5% of the nominal frequency

As the ELC are semiconductor-based devices, ELC could not be modelled in ETAP. The limitation of this study is that the ELC based plants are supposed to have constant power output despite of the faults in the power system. For each of the scenarios, the parameters like bus voltage, frequency deviation, rotor angle has been observed for different critical bus and generator

This study is based on the standard values of models and assumptions made by us and thus may not represent the actual behaviour of the system and is prone some margin of error.

Case 1: Three Phase fault on the line from Kalung Khola 1

Three-phase fault has been applied at generation of Kalung Khola I MHP and cleared at 150 m.s. During the normal flow condition, Kalung Khola I generates 21. 9 kW which drops down to 0 kW after the application of the three-phase fault. This also causes a loss of reactive power, and recovering immediately after the distraction is gone. The flow resumes to original condition after the removal of fault followed by some transient oscillations as shown in Figure below

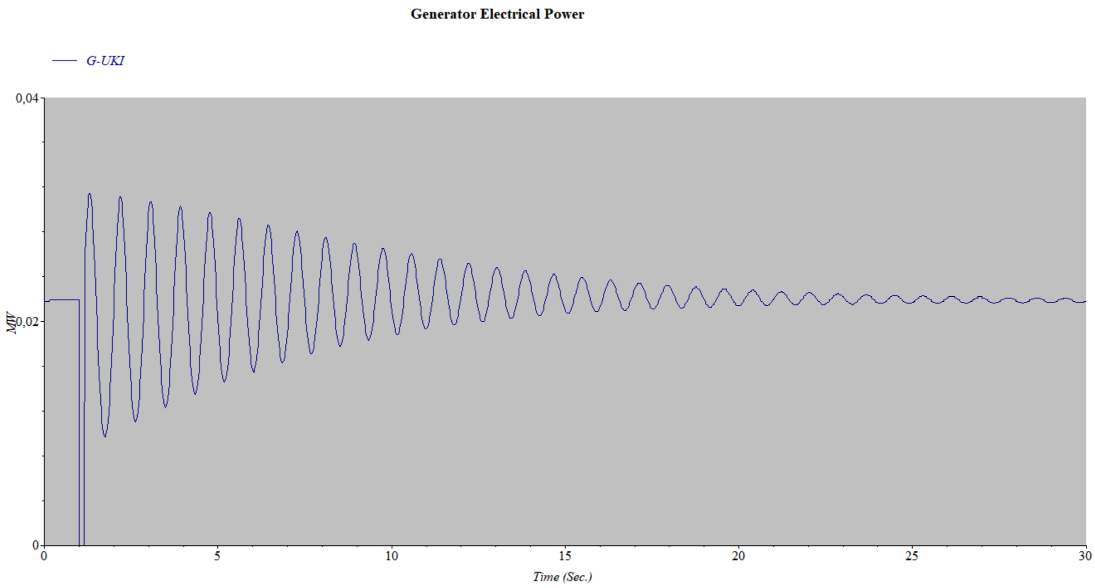


Figure 7-10. Power Active flow through Three Phase fault on the line from Kalung Khola 1

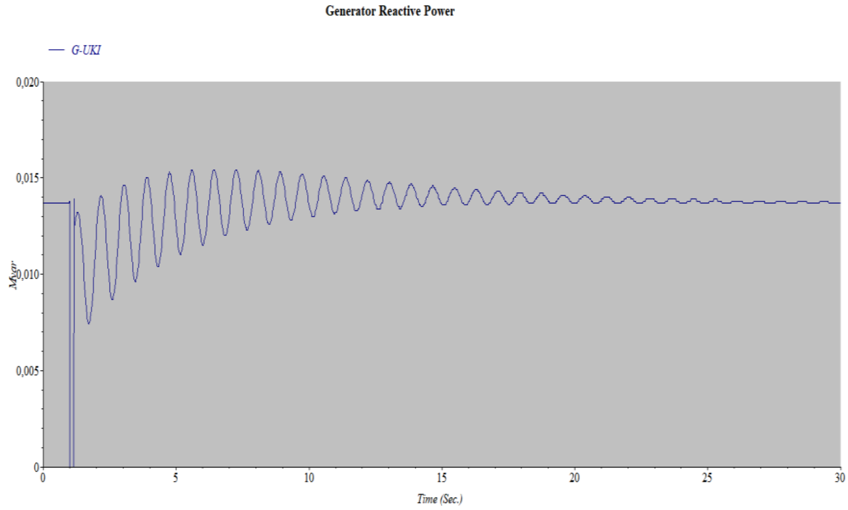


Figure 7-11. Power Reactive flow through Three Phase fault on the line from Kalung Khola 1

Figure below depicts the frequency deviation of the 11 kV Baglung bus during the event. It is evident that the system frequency will be higher a few second but will later settle to nominal value if the fault is cleared within the specified time.

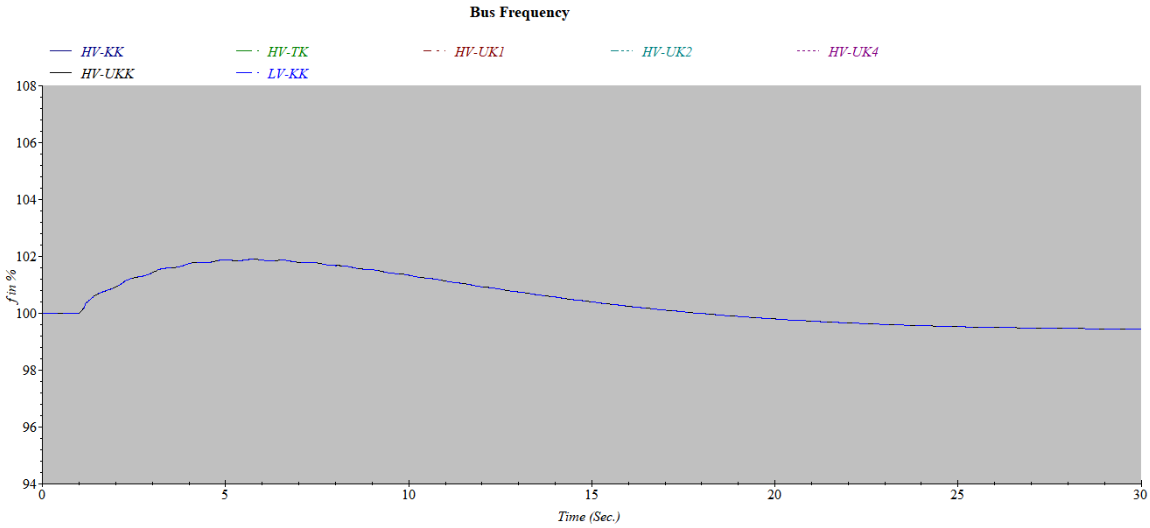


Figure 7-12. Frequency deviation of Baglung in Hz for case#1

Figure above shows that during the three-phase line fault, the bus voltages will be within the tolerable limit of 1.1 p.u.

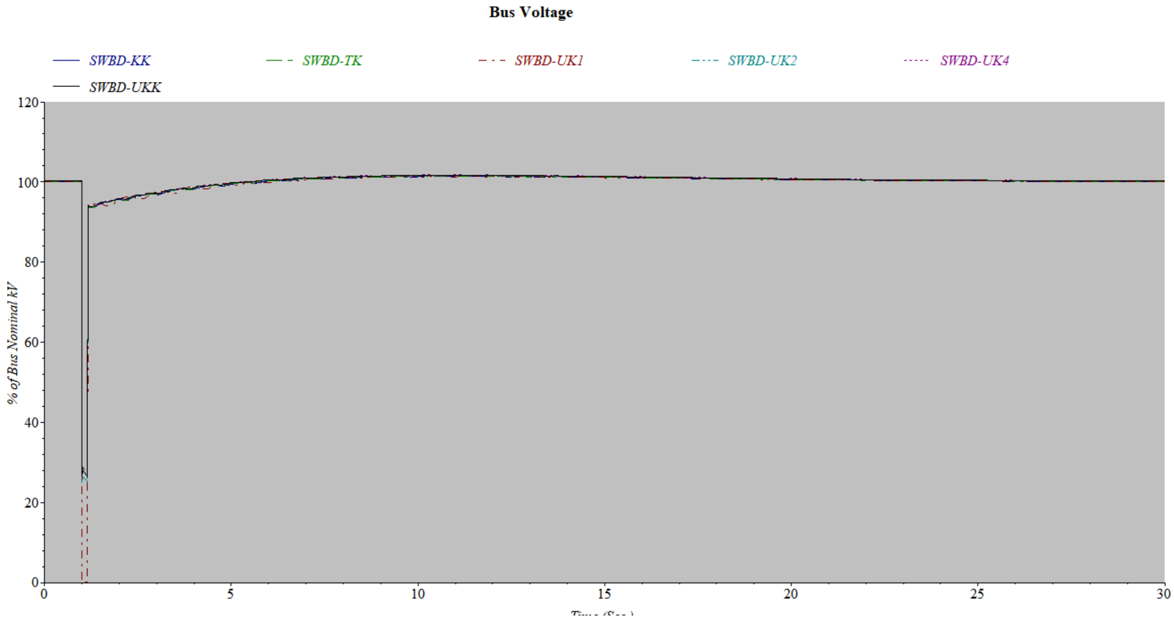


Figure 7-13. Bus Voltage of different 415 V bus in p.u for Case#1

Figure above shows that during the three-phase line fault, the bus voltages will be within the tolerable limit of 1.1 p.u.

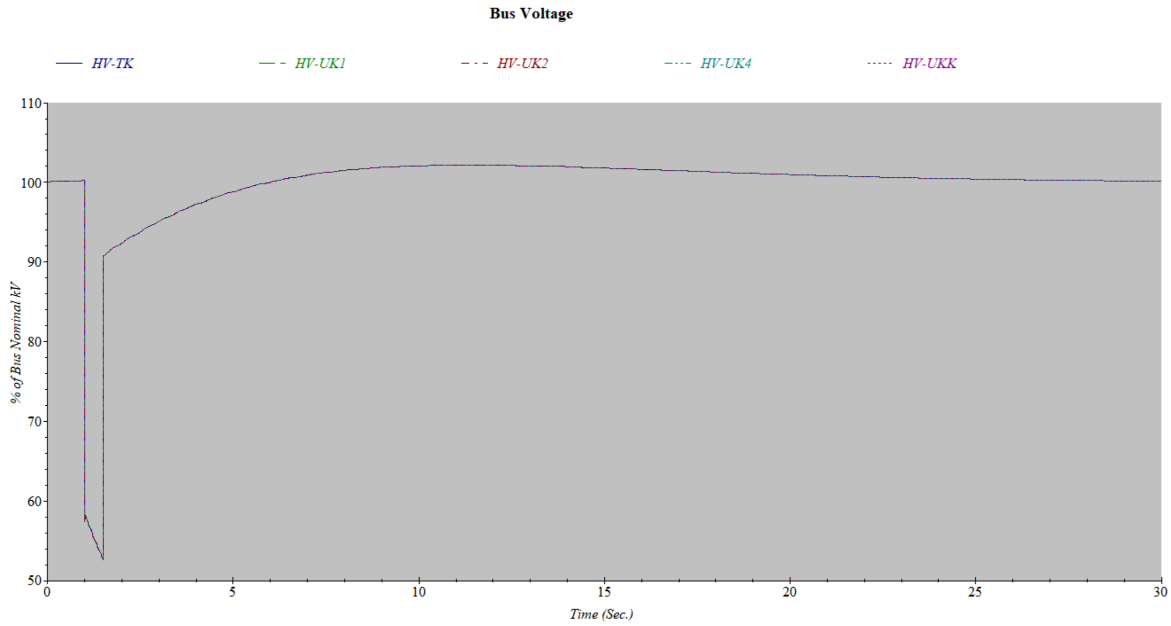


Figure 7-14. Bus Voltage of different 11 kV bus in p.u for Case#1

Figure above shows that the rotor angle deviation relative to Baglung MHP of the different MHPs stabilizes after certain time after the fault has been cleared. This implies the generator will be stable during the three-phase line fault.

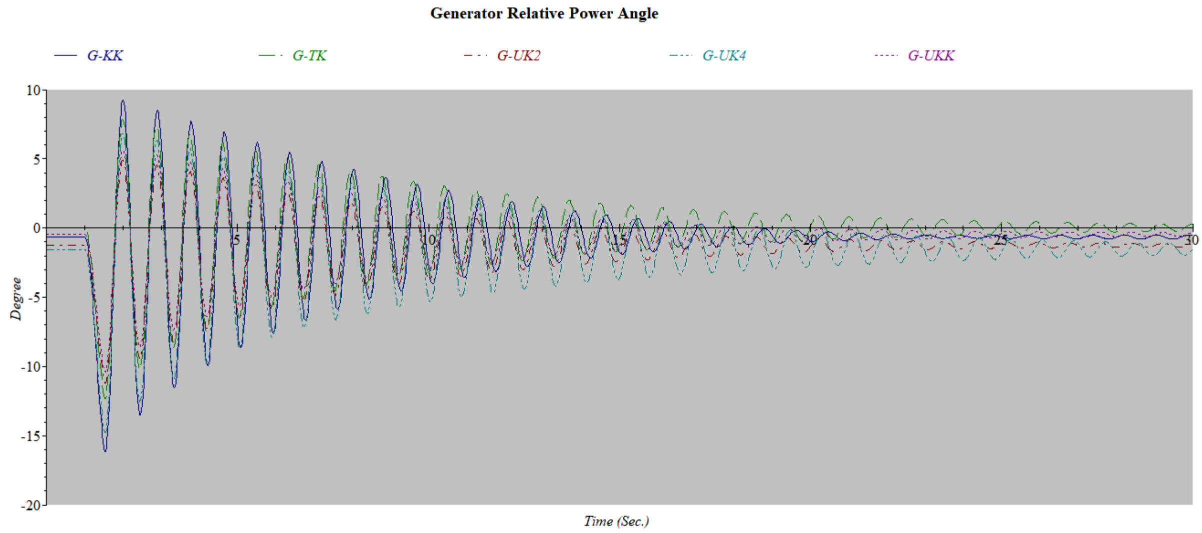


Figure 7-15. Generator Relative Power Angle of different MHPs for Case 1

Case 2: Tripping of Kalung Khola 1 without reclose, Case#2

For this scenario, MHP Kalung Khola I has been isolated from the system. Figure 7-16 illustrates that the generator cannot return to stable providing power when Kalung Khola I MHP's permanent fault. It is clear that the system frequency is unstable, and the frequency will be lost. This is because Kalung Khola I is the largest generating unit and occupies the largest share of the total generation.

To maintain system stability, loads must be shed. Automatic load shedding relays can be installed for isolated Mini-grid of Baglung.

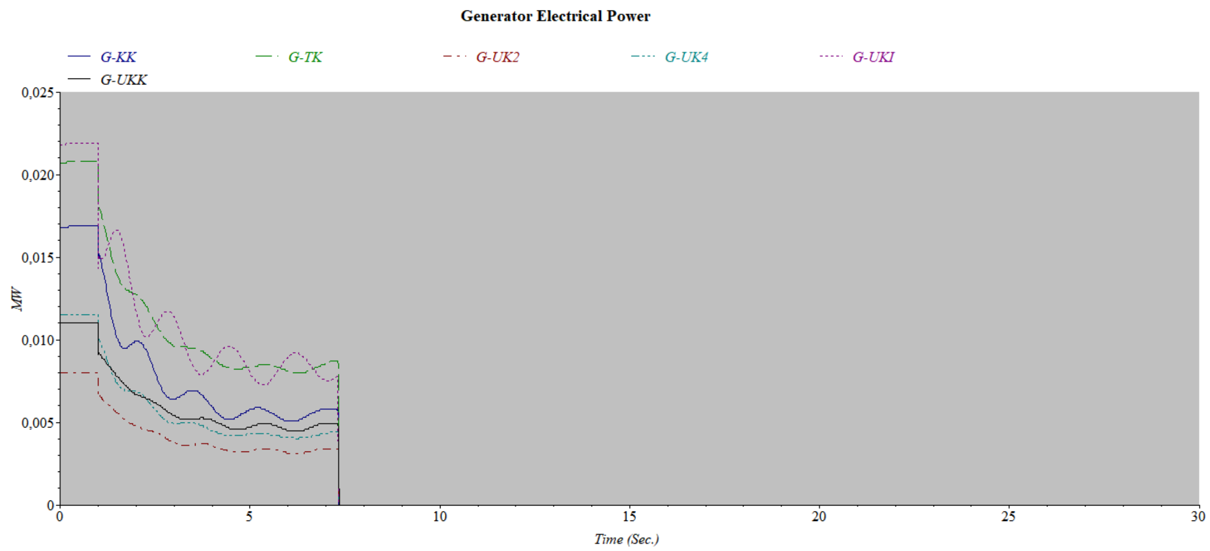


Figure 7-16. The generator cannot return to stable providing power when Kalung Khola I MHP Permanent Trip case#2

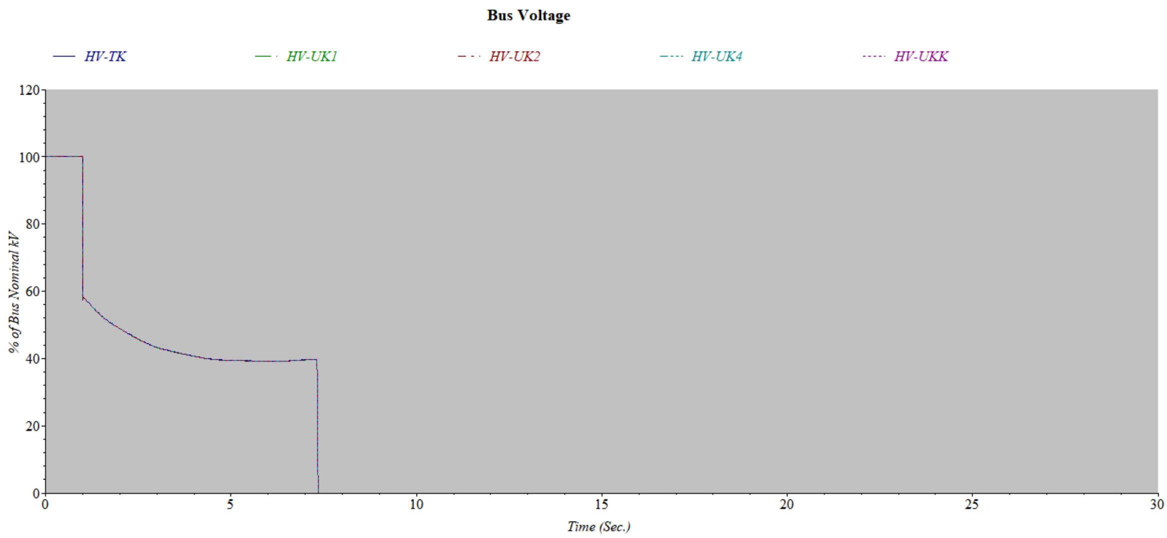


Figure 7-17. Bus Voltage of different HV (11 kV) bus in p.u for Case#2

7.1.5. Model and Simulation (DIgSILENT Powerfactory)

This chapter will discuss model of Baglung Mini-grid developed with DIgSILENT Powerfactory Software. Existing data that is taken into account in the modeling process include:

a. Generator Data
b. Transformer Data
c. Conductor Data
d. Load Data

Model of the Baglung Mini-grid system is as depicted below.

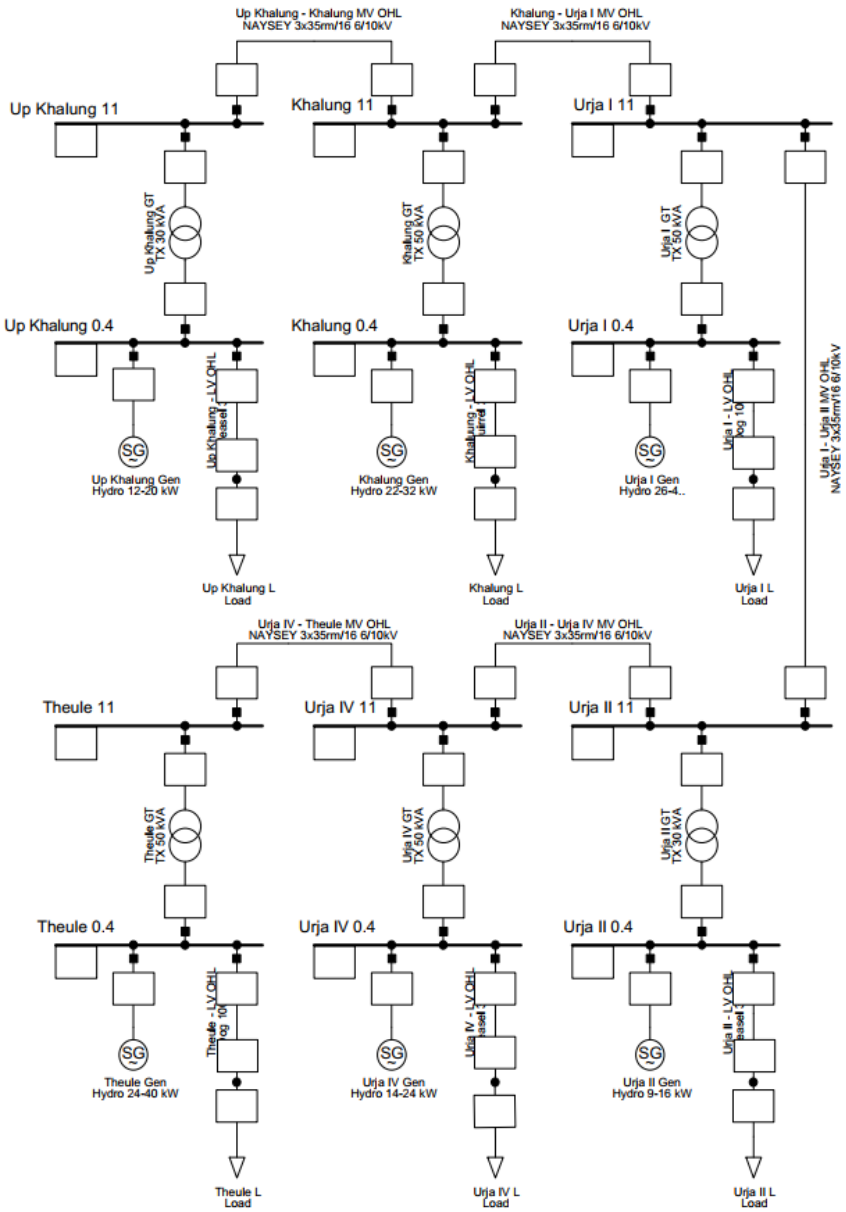


Figure 7-18. Model of Baglung Mini-grid in DIgSILENT Powerfactory

The desired system behaviour in the interconnection is that each generator will be operating in Droop mode with identical characteristic in droop setting (5%) thus allowed all the generators to share active power loading proportionally. As for reactive power, all the generators will be operating in Automatic Voltage Control mode with each generator's 0.4 kV output bus as reference.

Such characteristic will make each generator to operate according to their own droop curve as shown in the picture below.

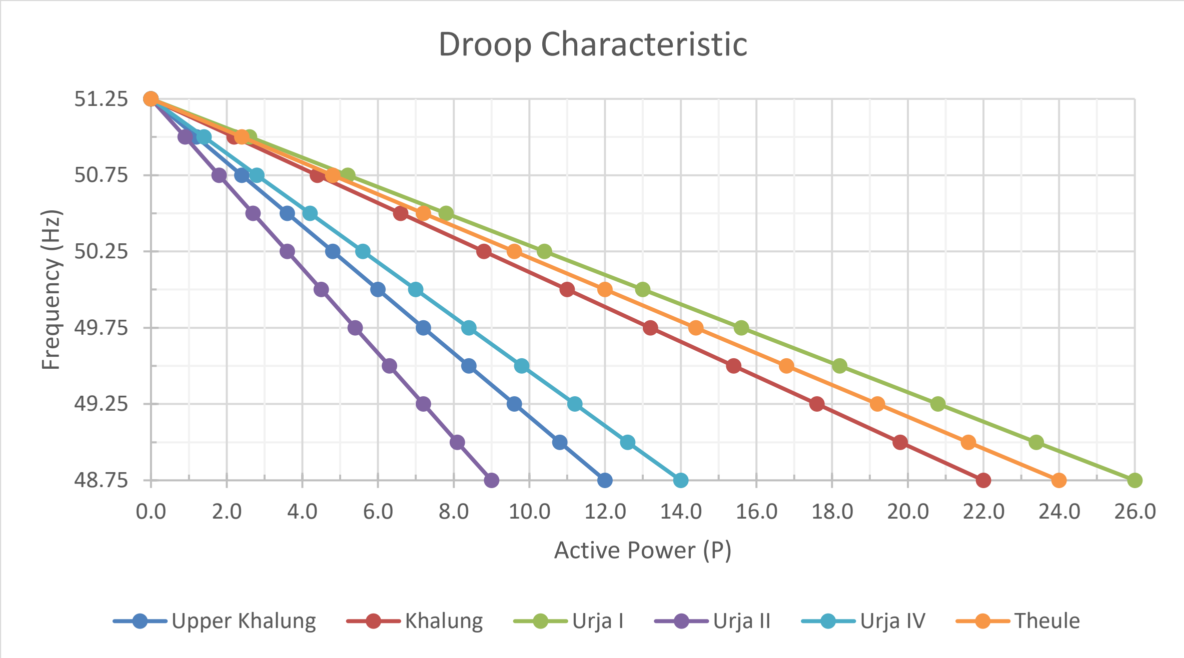


Figure 7-19. Droop Characteristic of MHPs in Baglung Mini-grid

The load data used in further load flow study is as previously mentioned, particularly the average load for and maximum load.

Table 7-10. Loading Conditions in Baglung Mini-grid

	Load in kW						
Condition	**Upper Kalung**	**Kalung**	**Urja I**	**Urja II**	**Urja IV**	**Theule**	**Total Load**
Average Load in kW	4.24	9.50	9.63	4.36	4.59	10.89	46.21
Minimum Load in kW	1.50	3.00	5.50	2.00	1.50	4.50	25.20
Maximum Load in kW	11.00	20.00	22.00	8.00	11.50	21.00	93.50
Max Load Gen Loading (%)	0.92	0.91	0.85	0.89	0.82	0.88	

Based on the equipment and loading data, the simulation will be carried out in several scenarios as follow:

1. Load Flow Study
   a. Maximum Load Period
   b. Minimum Load Period
2. Short Circuit Study
   a. Fault at each 11 kV Bus
3. Transient Stability Study
   a. Loss of generation in Theule Khola (far end section of the system and large generator) during maximum load.
   b. Loss of generation in Theule Khola (far end section of the system and large generator) during maximum load followed by automatic local load shedding (Theule Khola Local Load).

7.1.5.1. Load Flow Study Result

a. Maximum Load Period

Load flow study is conducted with both maximum load and average load of each generator. Maximum load scenario load flow is as shown in Figure 7-20.

It can be seen that each generator is operating near it's active power limit with various power factor, mostly leading power factor. Leading power factor is caused by excess/surplus reactive power which is generated by the 11 kV distribution lines that is not absorbed/utilized by local/village load. Dispatched power of each generator is as follows:

Table 7-11. Operation of Each MHP in Maximum Load Scenario

No	Generator	Capacity (kW)	Dispatch (kW)	Dispatch (kVAR)	Dispatch (kVA)	Loading (% kW)	Power Factor
1	Up Kalung	12	10.6	-1.9	10.8	88.3%	0.98
2	Kalung	22	19.5	-3.7	22.5	88.6%	0.87
3	Urja I	26	23	-2.7	23.2	88.5%	0.99
4	Urja II	9	8	-4	8.8	88.9%	0.91
5	Urja IV	14	12.4	-8.6	15.1	88.6%	0.82
6	Theule	24	21.2	-2.2	21.4	88.3%	0.99
Total/Average		107	94.7	-23.1	101.8	88.5%	0.93

While the generators loading is high, loading of the 11 kV distribution line is quite low, ranging from 0.3 – 0.6%. This underloading of distribution line leads to excessive reactive power from line capacitance which induce undesired voltage rise in the system. The simulation shows that the excessive reactive power is absorbed by the generators by operating in leading power factor (under-excited) with average power factor of 0.93 (leading). This operation region is still within the generators' tolerance. However, Urja IV is marked red since it is operating with 0.82 leading power factor which is outside generator's tolerance. During the long-term operation of a generator, either in over- or in under-excited modes, undesirable premature ageing of the stator and rotor insulation may occur due to overheating.

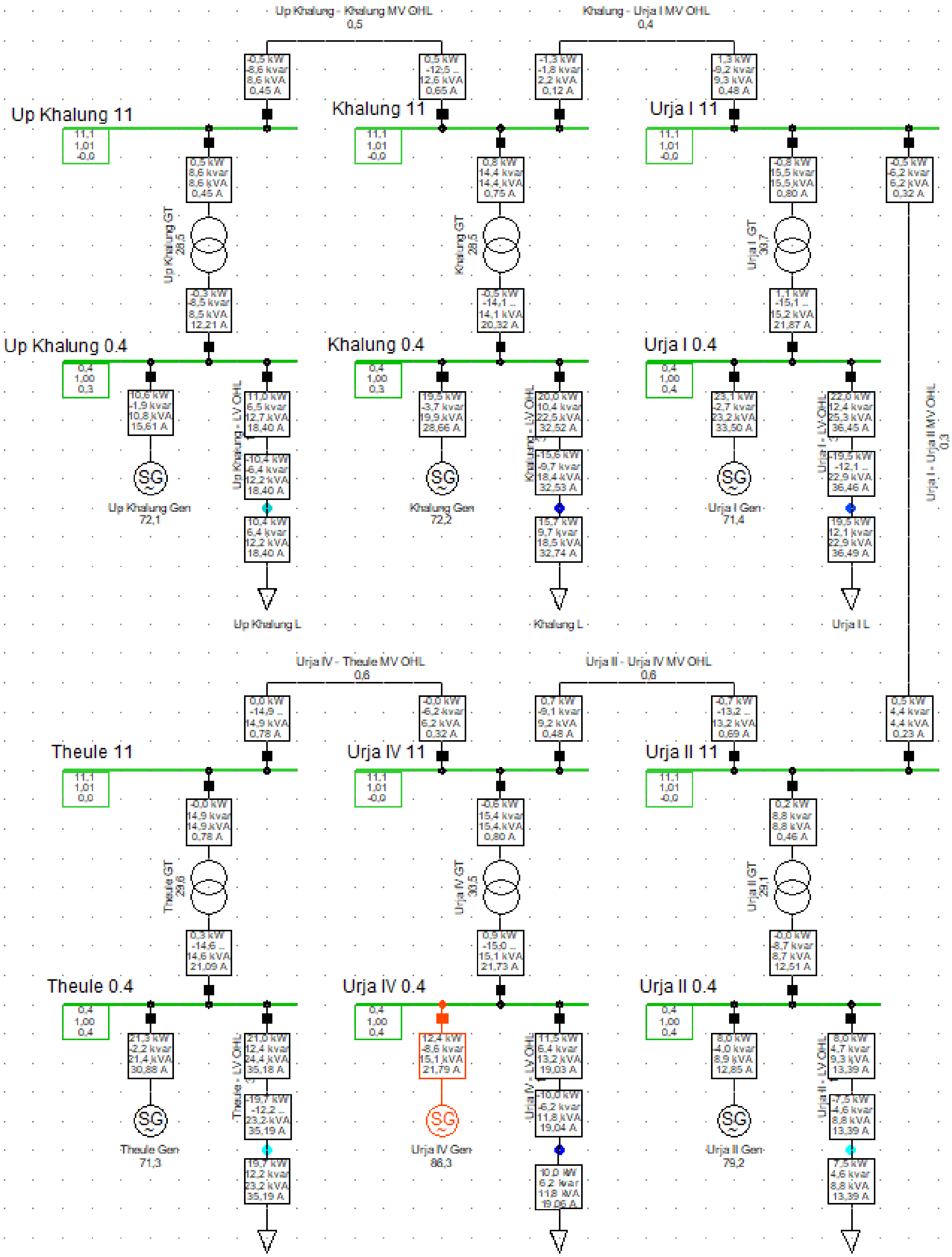


Figure 7-20. Load Flow Result in Maximum Load Scenario

b. Average Load Period

Average load operation as can be seen in Table 7-10, it can be seen that average loading is approximately 50% of peak/maximum load. Therefore, the load flow study is carried out with 50% load scaling as in Figure 7-21. Load Flow Result in Average Load Scenario is shown in Figure 7-22.

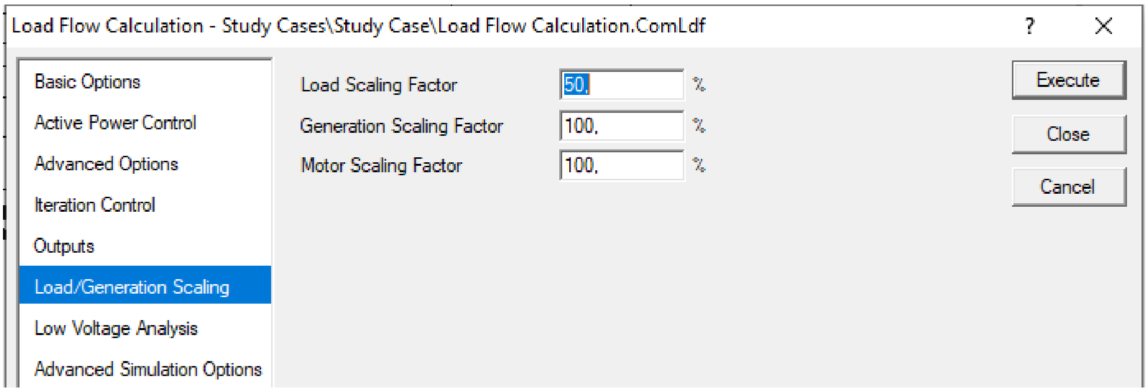


Figure 7-21. Global Load Scaling in Minimum Load Scenario Load Flow Study

It can be seen that each generator is operating with less than 50% loading with various power factor, mostly leading power factor. Leading power factor is caused by excess/surplus reactive power which is generated by the 11 kV distribution lines that is not absorbed/utilized by local/village load. Dispatched power of each generator is as follows:

Table 7-12. Operation of Each MHP in Average Load Scenario

No	Generator	Capacity (kW)	Dispatch (kW)	Dispatch (kVAR)	Dispatch (kVA)	Loading (% kW)	Power Factor
1	Up Kalung	12	4.8	-5.3	7.1	40.0%	0.68
2	Kalung	22	8.8	-10.2	13.5	40.0%	0.65
3	Urja I	26	10.4	-8.9	13.7	40.0%	0.76
4	Urja II	9	3.6	-6.3	7.3	40.0%	0.49
5	Urja IV	14	5.6	-11.8	13.1	40.0%	0.43
6	Theule	24	9.6	-8.2	12.6	40.0%	0.76
Total/Average		107	42.8	-50.7	67.3	40.0%	0.63

While the generator's active power loading is low, the generator is forced to absorb large amount of reactive power to maintain system voltage. As the load decreases, the loading of the 11kV distribution line is even lower, which leads to excessive reactive power from line capacitance which induce undesired voltage rise in the system. The simulation shows that the excessive reactive power is absorbed by the generators by operating in leading power factor (under-excited) with average power factor of 0.63 (leading). This operation region is exceeding generators' tolerance. During the long-term operation of a generator, either in over- or in under-excited modes, undesirable premature ageing of the stator and rotor insulation may occur due to overheating.

This high reactive power loading on the generators can be solved by adding shunt reactor in 11 kV substation to absorb reactive power. The low active power loading of the generators can be solved by switching off several generators, preferably in mid-section of the system.

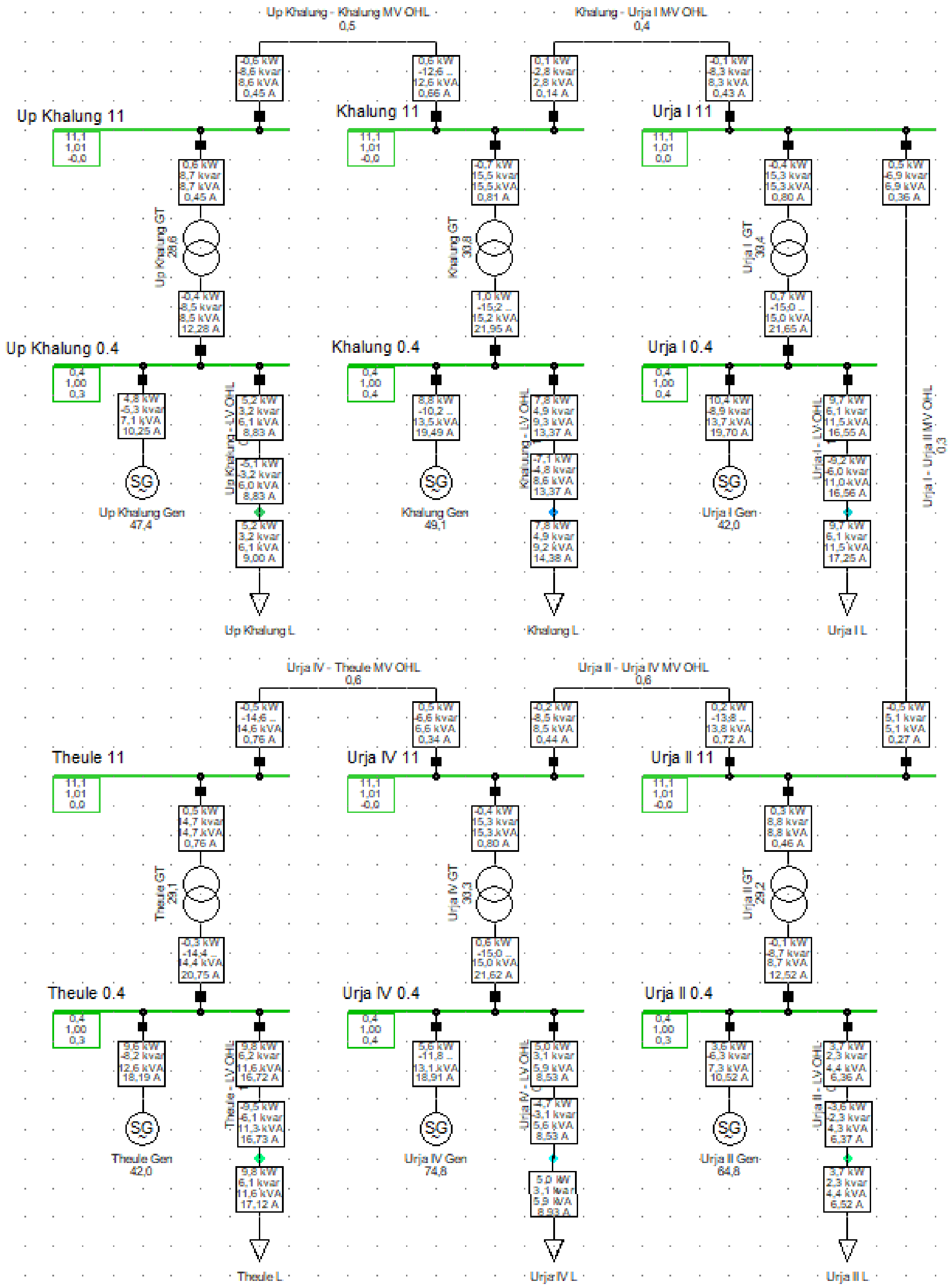


Figure 7-22. Load Flow Result in Average Load Scenario

7.1.5.2. Short Circuit Study

Short circuit study was carried out to identify the maximum short circuit current at 11kV side to further determine the appropriate rating of the switchgear to be used.

To identify the largest fault current, the type of fault used is a symmetrical 3-phase fault (IEC 60909) is used on the 11 kV side at each 11 kV Substation.

The magnitude of the short circuit current at each 11 kV Substation is shown in Figure 7-23 and Table 7-13.

Table 7-13. Maximum Short Circuit Current on Each 11 kV Substation

MHP	Faulted Bus	Short Circuit Current
Upper Kalung Khola	Fault at 11 kV side	0.029 kA
	Fault at SWBD 0.415 kV side	0.532 kA
Kalung Khola	Fault at 11 kV side	0.029 kA
	Fault at SWBD 0.415 kV side	0.650 kA
Urja Khola I	Fault at 11 kV side	0.029 kA
	Fault at SWBD 0.415 kV side	0.667 kA
Urja Khola II	Fault at 11 kV side	0.029 kA
	Fault at SWBD 0.415 kV side	0.517 kA
Urja Khola IV	Fault at 11 kV side	0.029 kA
	Fault at SWBD 0.415 kV side	0.615 kA
Theule Khola	Fault at 11 kV side	0.029 kA
	Fault at SWBD 0.415 kV side	0.657 kA

Looking at Table 7-13 above, the maximum short circuit current in both 11 kV and 0.4kV system is relatively low which are below 1 kA. Therefore standard design and rating of the 11 kV switchgear with 12.5 or 16 kA short circuit current rating is adequate.

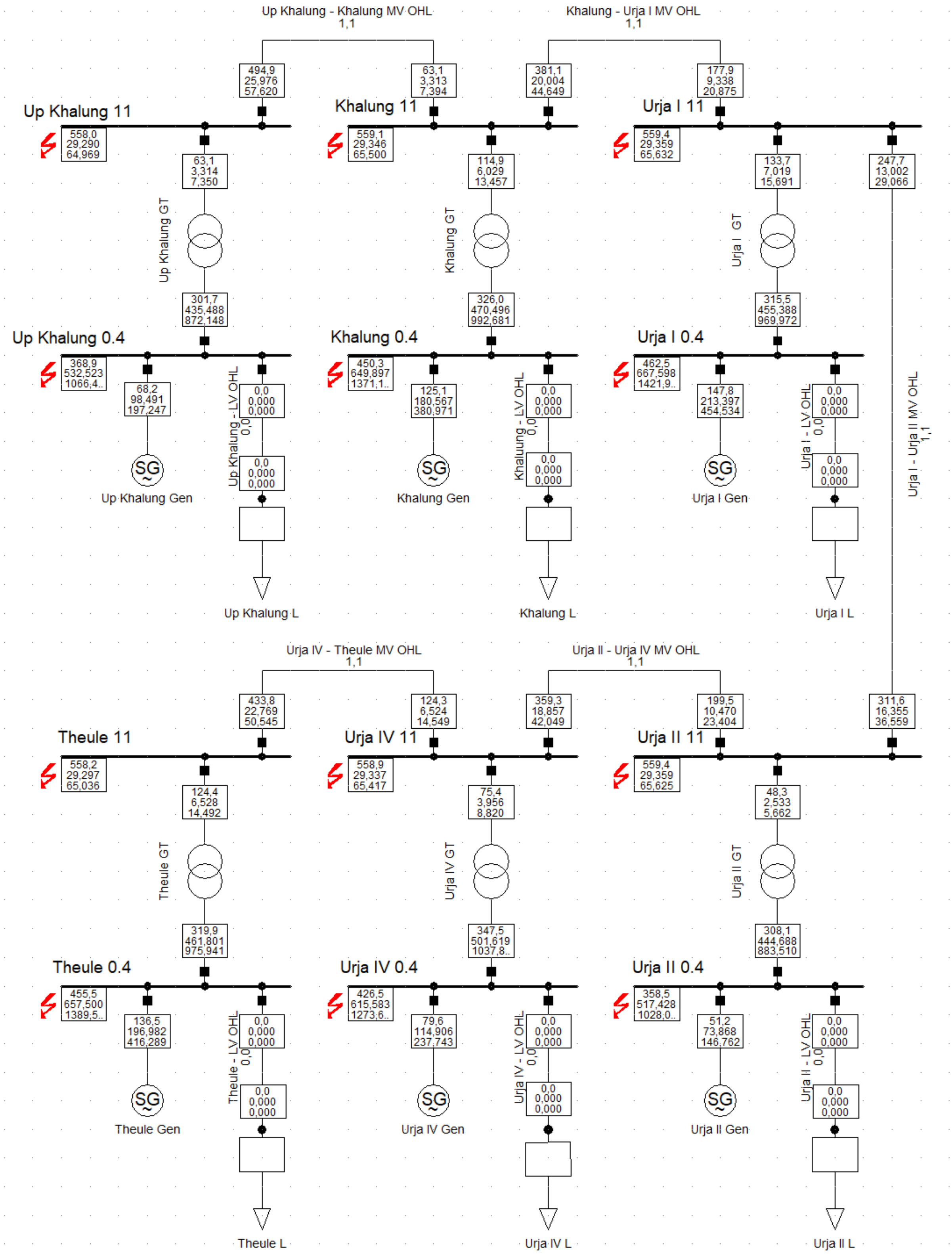


Figure 7-23. Three Phase Short Circuit Study for Maximum Short Circuit Current Determination

7.1.5.3. Transient Stability Study

System stability study is carried out to see the impact of the loss of generation of one MHP due to possible disruption or damage. The simulation was carried out with the worst possibility, which is loss of generation of large MHP at the far end side of the system (Theule Khola) with 2 scenarios, namely:

1. Loss of generation in Theule Khola (far end section of the system and large generator) during maximum load.
2. Loss of generation in Theule Khola (far end section of the system and large generator) during maximum load followed by automatic local load shedding (Theule Khola Local Load).

The details of the simulation on scenario #1 are as follows:

a. The simulation duration is 25s.
b. At t = 0s, normal power flow at maximum load scenario.
c. At t = 2s, loss of generation of Theule Khola MHP.

While details of the simulation on scenario #2 are as follows:

a. The simulation duration is 25s.
b. At t = 0s, normal power flow at maximum load scenario.
c. At t = 2s, loss of generation of Theule Khola MHP.
d. At t = 2.1s, automatic (interlocked) load shedding of Theule Khola local village load.

The generator models in the Baglung mini-grid are then equipped with AVR as in Figure 7-24 and governor as in Figure 7-25.

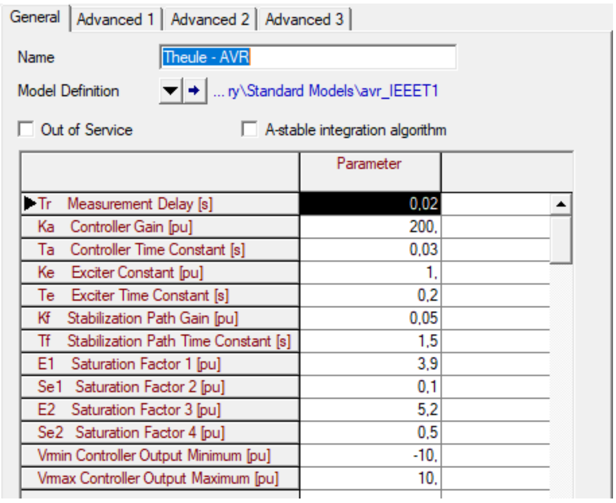


Figure 7-24. AVR Model of Each Generator in Baglung Mini-grid

The applied AVR is standard model AVR in DIgSILENT library (IEEET1) with standard parameter. While the governor applied for the model is standard hydro turbine governor with few modifications on the parameter to better mimic the behavior/response of an ELC.

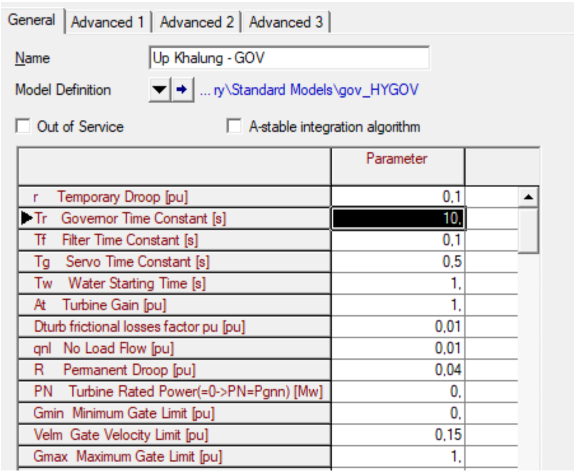


Figure 7-25. Governor Model of Each Generator in Baglung Mini-grid

The modified parameters are mostly time constant parameters. The modification was done considering ELC operation typically has much faster response compared to governor operation since there is only electrical switching, no mechanical moving parts nor change in water flow through the turbine. The modified parameter of the governor model is shown in Figure 7-26.

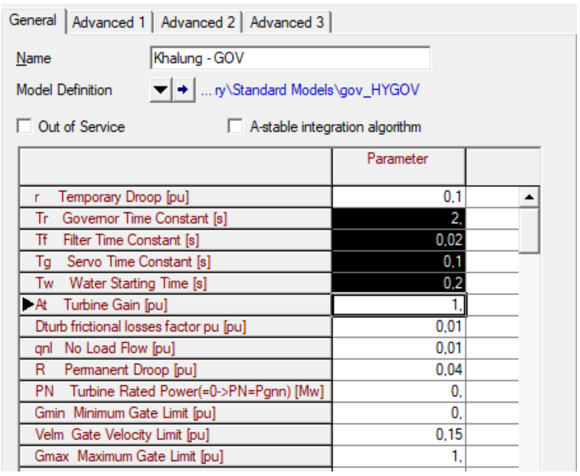


Figure 7-26. Modified Governor Model of Each Generator in Baglung Mini-grid

On each scenario, the analysis will be focused on certain parameter which are:

a. Frequency and voltage profile at Theule Khola 0.4kV bus.
b. Voltage and power profile at Urja I Khola 0.4kV bus (largest MHP).

c. Loss of Generation in Theule Khola During Maximum Load

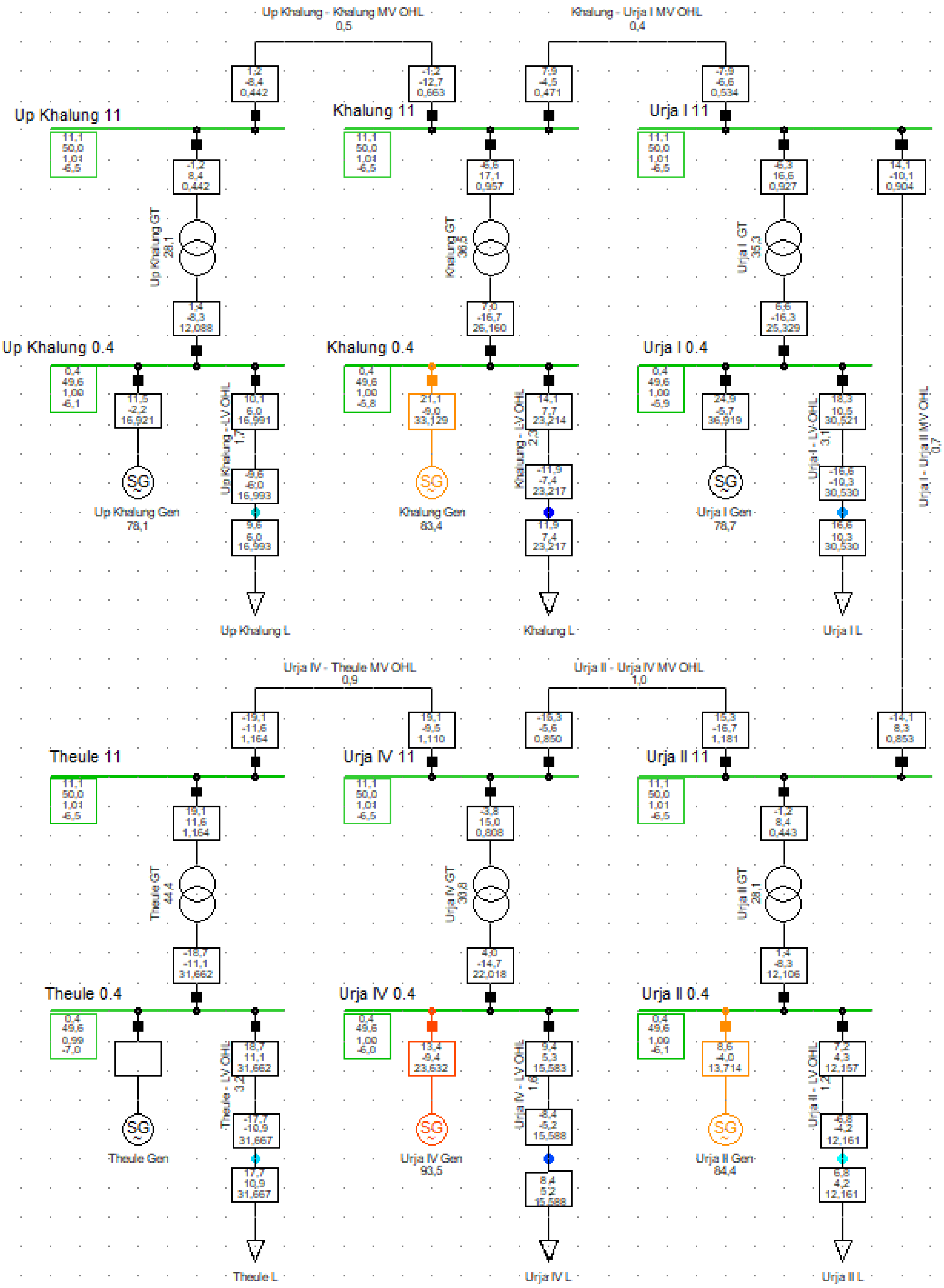


Figure 7-27. Loss of Generation at Theule Khola (Scenario #1)

Loss of generation in Theule Khola is resulting in Theule Khola local load being supplied from 11 kV distribution line. Therefore, loading of the other 5 generators increase significantly to supply Theule Khola local load, which can be seen in Table 7-14 and Figure 7-27.

Table 7-14. Loading of MHP After Loss of Generation in Theule Khola (Scenario #1)

No	Generator	Capacity (kW)	Dispatch-1 (kW)	Loading-1 (% kW)	Dispatch-2 (kW)	Loading-2 (% kW)
1	Up Kalung	12	10.6	88.3%	11.5	95.8%
2	Kalung	22	19.5	88.6%	21.1	95.9%
3	Urja I	26	23	88.5%	24.9	95.8%
4	Urja II	9	8	88.9%	8.6	95.6%
5	Urja IV	14	12.4	88.6%	13.4	95.7%
6	Theule	24	21.2	88.3%	0	0.0%
Total/Average		107	94.7	88.5%	79.5	95.8%

While load was constantly supplied from another source, frequency profile on Theule Khola plunges to lowest level of approximately 48.5Hz and voltage dips to almost 98% (392V) which can be seen in Figure 7-28. The voltage fluctuation is still within tolerance which is ± 10%, while the frequency fluctuation was out of tolerance limit.

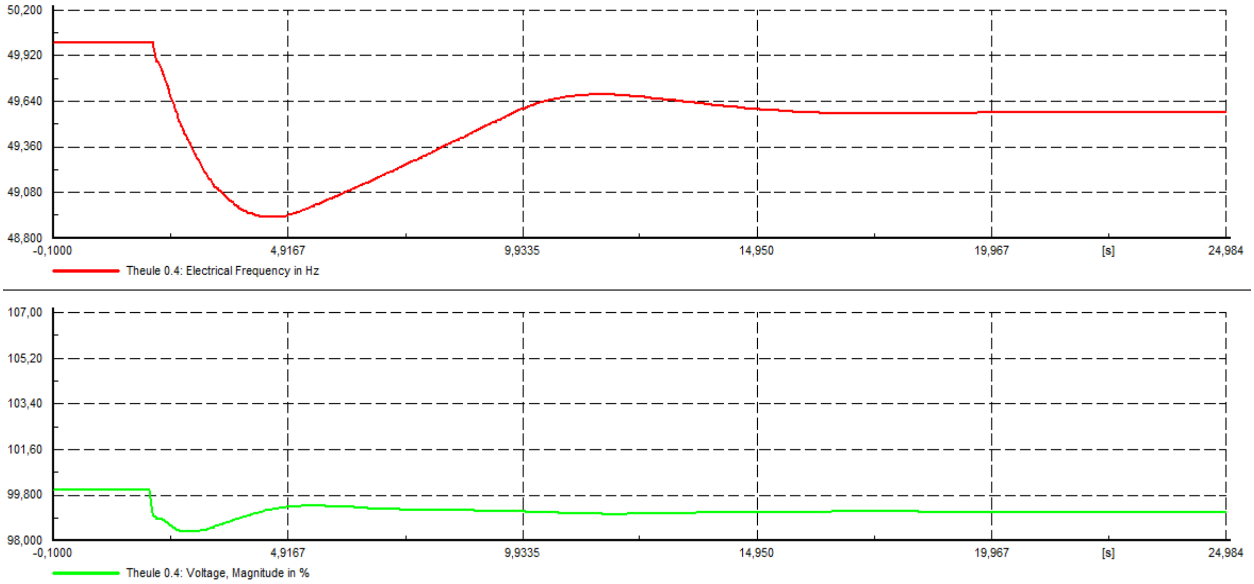


Figure 7-28. Frequency and voltage profile at Theule Khola 0.4kV bus (Scenario #1)

The voltage and power response of other generator can be seen in Figure 7-29 where the is sudden substantial loading of active power in Urja I MHP as the largest MHP in the system. While the voltage profile is similar to Theule Khola with insignificant dip (1%).

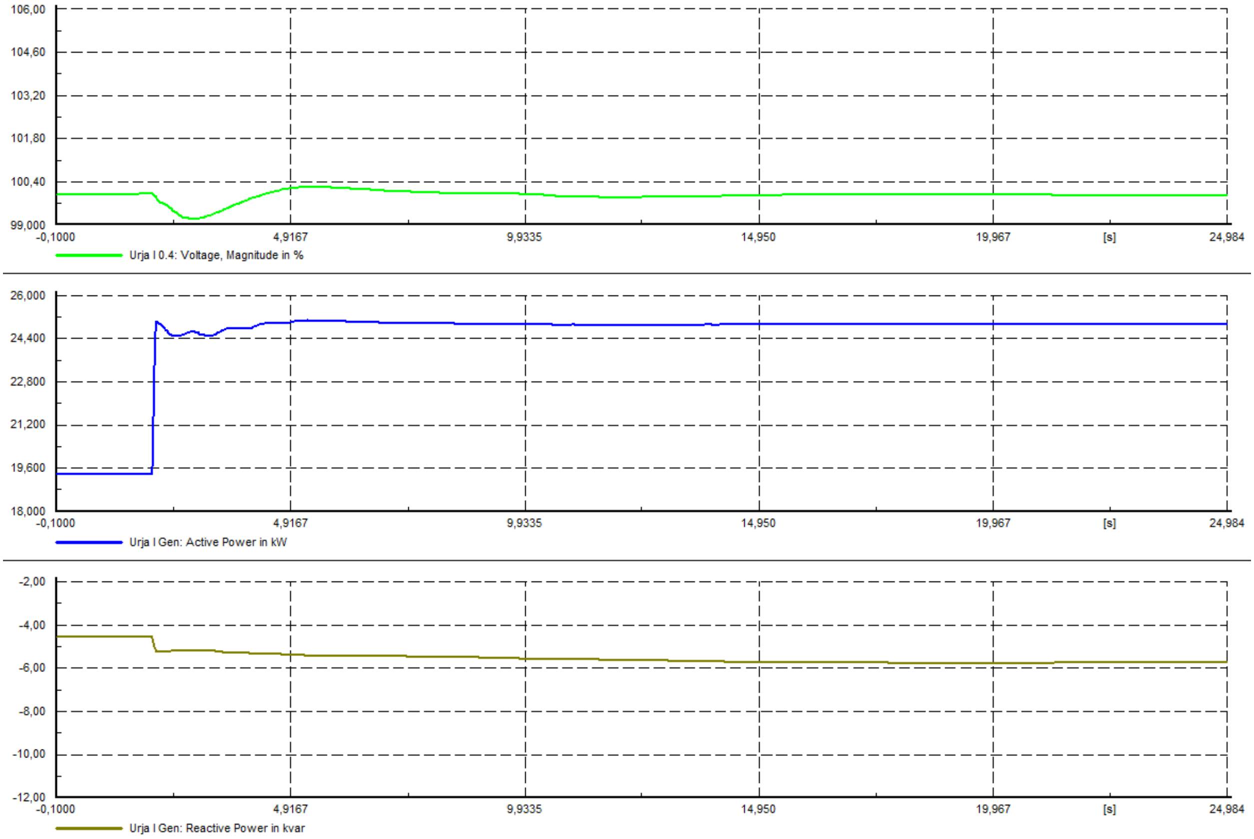


Figure 7-29. Voltage and power profile at Urja I Khola 0.4kV (Scenario #1)

d. Loss of Generation in Theule Khola During Maximum Load Followed by Local Load Shedding

To avoid excessive frequency fluctuation such as in scenario #1, automatic load shedding of local village load can be set (interlocked) according to the local MHP status. Therefore, loss of generation in Theule Khola will automatically cut the supply to local village load in Theule Khola which then could be reclosed manually should the reserve power is adequate. Such scheme will reduce frequency fluctuation. With the local load disconnected, loading of the other 5 generators only increase slightly which can be seen in Table 7-15 and Figure 7-30.

Table 7-15. Loading of MHP After Loss of Generation in Theule Khola (Scenario#2)

No	Generator	Capacity (kW)	Dispatch-1 (kW)	Loading-1 (% kW)	Dispatch-2 (kW)	Loading-2 (% kW)
1	Up Kalung	12	10.6	88.3%	11.5	95.8%
2	Kalung	22	19.5	88.6%	21.1	95.9%
3	Urja I	26	23	88.5%	24.9	95.8%
4	Urja II	9	8	88.9%	8.6	95.6%
5	Urja IV	14	12.4	88.6%	13.4	95.7%
6	Theule	24	21.2	88.3%	0	0.0%
Total/Average		107	94.7	88.5%	79.5	95.8%

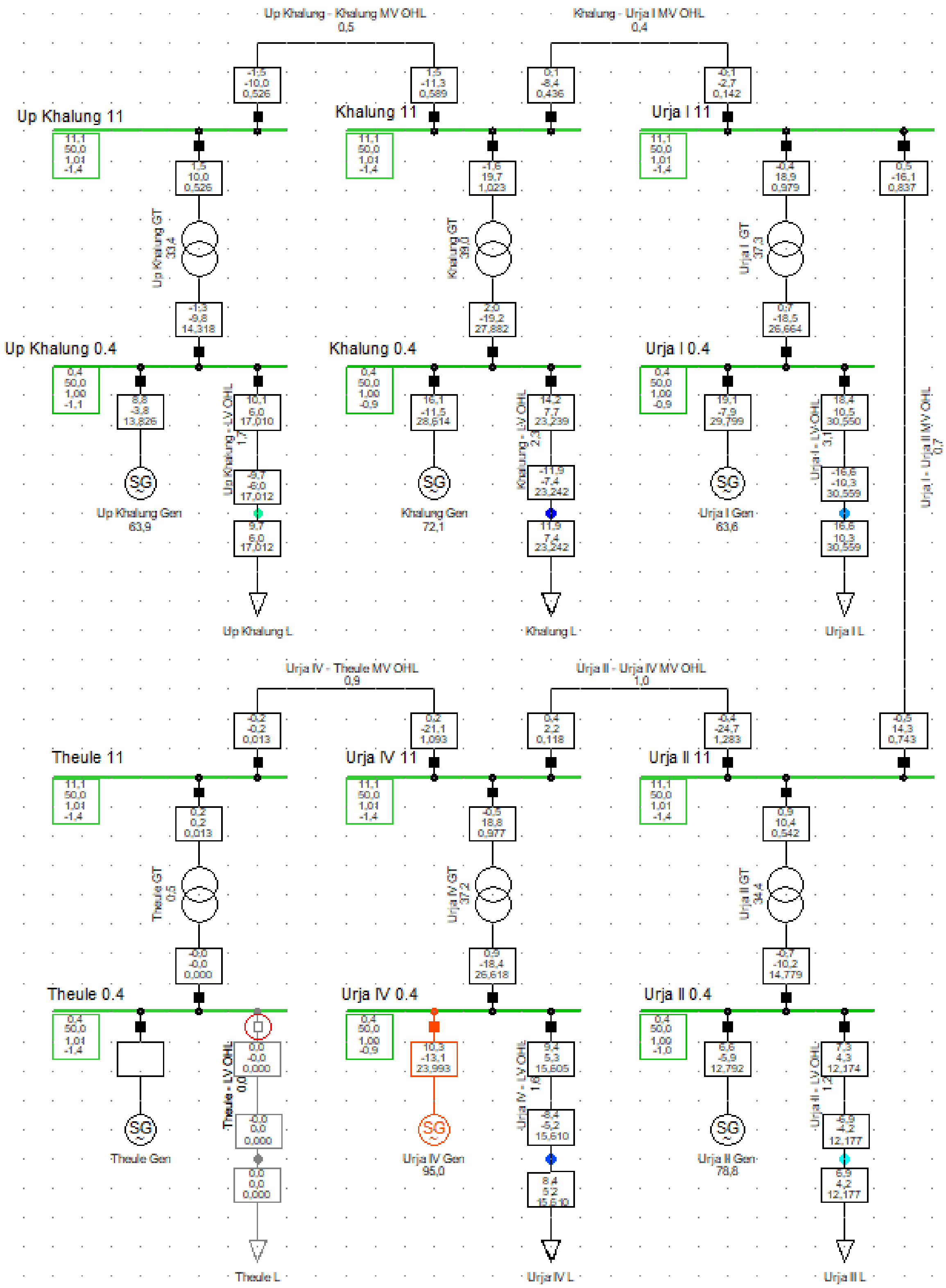


Figure 7-30. Loss of Generation at Theule Khola Followed by Load Shedding at Local Village Load (Scenario #2)

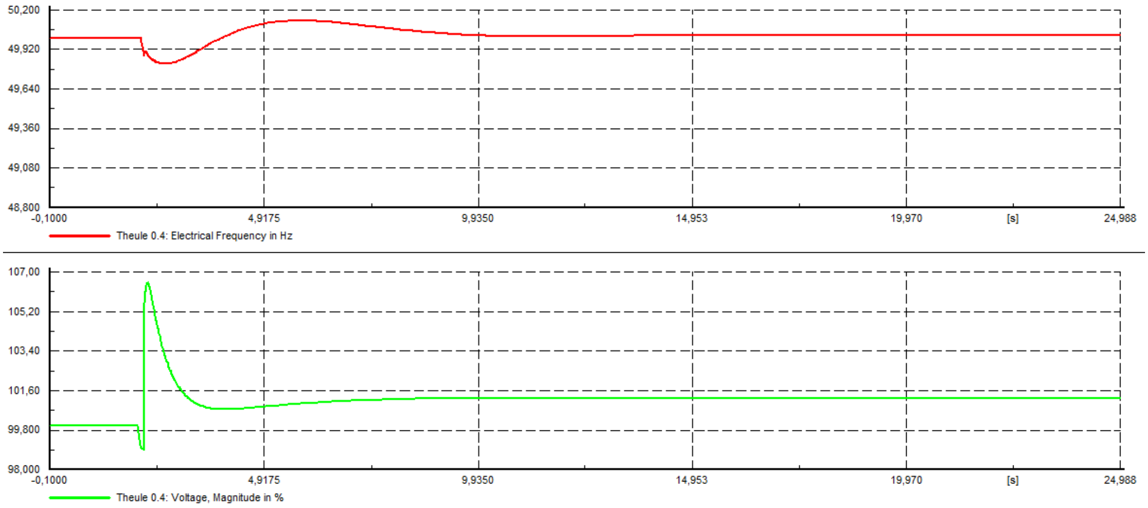


Figure 7-31. Frequency and voltage profile at Theule Khola 0.4kV bus (Scenario #2)

With the automatic load shedding scheme, frequency profile on Theule Khola only fluctuates to lowest level of approximately 49.75Hz. However, there is a momentary voltage rise up to 106% which soon normalize within second. With this scheme, both frequency and voltage fluctuation are still within tolerance.

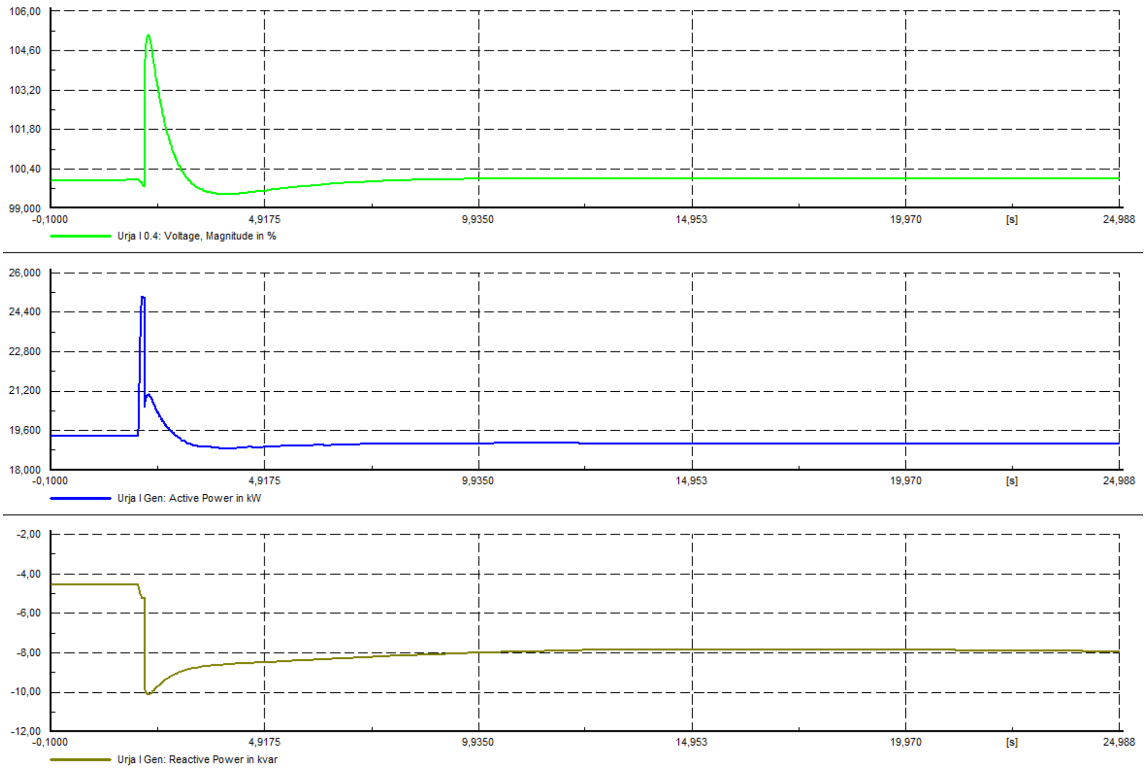


Figure 7-32. Voltage and power profile at Urja I Khola 0.4kV (Scenario #2)

The voltage and power response of other generator can be seen in Figure 7-32 where the is sudden momentary loading of active power in Urja I MHP as the largest MHP in the system which then normalize within second. The voltage profile is similar to Theule Khola with momentary voltage rise of about 5%.

7.1.5.4. DIgSILENT Model and Simulation Analysis

- Load flow (maximum load) simulation shows that the excessive reactive power is absorbed by the generators by operating in leading power factor (under-excited) with average power factor of 0.93 (leading). This operation region is still within the generators' tolerance. The average generator loading is 88%.

- Load flow (Average load) simulation shows that the excessive reactive power is absorbed by the generators by operating in leading power factor (under-excited) with average power factor of 0.63 (leading). This operation region is exceeding generators' tolerance. The Average generator loading is 40%.

- The extremely low power factor of 0.63 in Load flow (Average load) simulation due to high reactive power loading on the generators can be solved by adding shunt reactor in 11 kV substation to absorb reactive power. As for the low active power loading of the generators can be solved by switching off several generators, preferably in mid-section of the system.

- Based on the short circuit simulation to determine maximum possible short circuit current (3 phase, IEC 60909), maximum short circuit current in both 11 kV and 0.4 kV system is relatively low which are below 1 kA. Therefore standard design and rating of the 11 kV switchgear with 12.5 or 16 kA short circuit current rating is adequate.

- Transient stability study on loss of generation of Theule Khola MHP (scenario #1) results in Theule Khola local load was constantly supplied from another source, frequency profile on Theule Khola plunges to lowest level of approximately 48.5Hz and voltage dips to almost 98% (392V). The voltage fluctuation is still within tolerance which is ± 10%, while the frequency fluctuation was out of tolerance limit

- Transient stability study on loss of generation of Theule Khola MHP followed by automatic load shedding of Theule Khola local load (scenario #2) results in frequency profile on Theule Khola only fluctuates to lowest level of approximately 49.75Hz. However, there is a momentary voltage rise up to 106% which soon normalize within second. With this scheme, both frequency and voltage fluctuation are still within tolerance.

7.2. MHP – Grid Interconnection in Syaure Bhumi

7.2.1. Simulation Data

Data used for the simulation and analysis is obtained both from primary data and assumption made based on best practice or software derived data which summarized in the table below.

Table 7-16. Simulation Parameter Summary

No	Parameter	Value	Remark
1	33kV Grid Short Circuit Level	1560 MVA_{SC}	
2	33/11 kV Substation Transformer		
	Type	ONAN/ONAF	
	Vector group	Dyn11	
	Capacity	As per SLD	
	Impedance	Typical ETAP Data	
	Load Loss	Typical ETAP Data	
	OLTC	17 Step, ± 10%	
3	11 kV Distribution Line		
	Type	Weasel ($30mm^2$)	
	Impedance	Typical ETAP Data	
	Length	As per SLD	
4	11/0.4 kV Distribution Transformer		
	Type	ONAN	
	Vector group	Dyn11	
	Capacity	As per SLD	
	Impedance	Typical ETAP Data	
	Load Loss	Typical ETAP Data	
	NLTC	± 5%	
5	Load		
	Installed Capacity & Power Factor	As per SLD	
	Maximum Loading	100% Load Capacity	
	Average Loading	60% Load Capacity	
	Minimum Loading	45% Load Capacity	
6	Syaure Bhumi MHP		
	Turbine Power	33 kW	
	Generator Capacity	50 kVA	
	PF Range	0.8	
	MHP Generation	30 kW	
	Mode of Operation	Voltage Control (AVR)	
	Line type & length	Rabbit ($30mm^2$), 60m	

While the topology of the modelled grid (Chahare Feeder) is according to single line diagram provided which is shown in figure 7-33 below.

7.2.2. Simulation Approach

With simplification of the model, transient stability analysis is not possible, therefore the analysis will focus on two subjects with ETAP software which are:

1. Load flow analysis
2. Short circuit analysis (3 phase symmetrical fault)

7.2.3. Model and Simulation

With parameter and assumption mentioned earlier and single line diagram of Chahare Feeder, the model developed using ETAP software is shown as shown below.

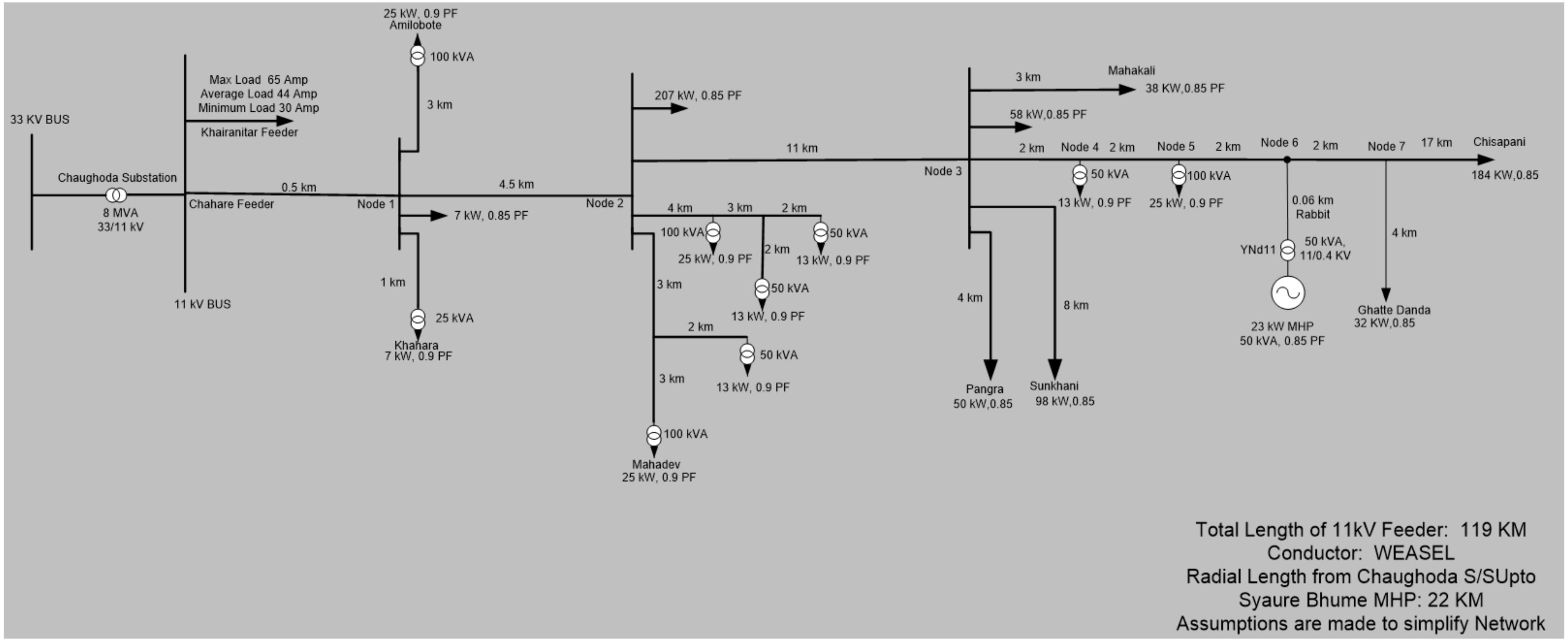


Figure 7-33. Single Line Diagram of Chahare Feeder

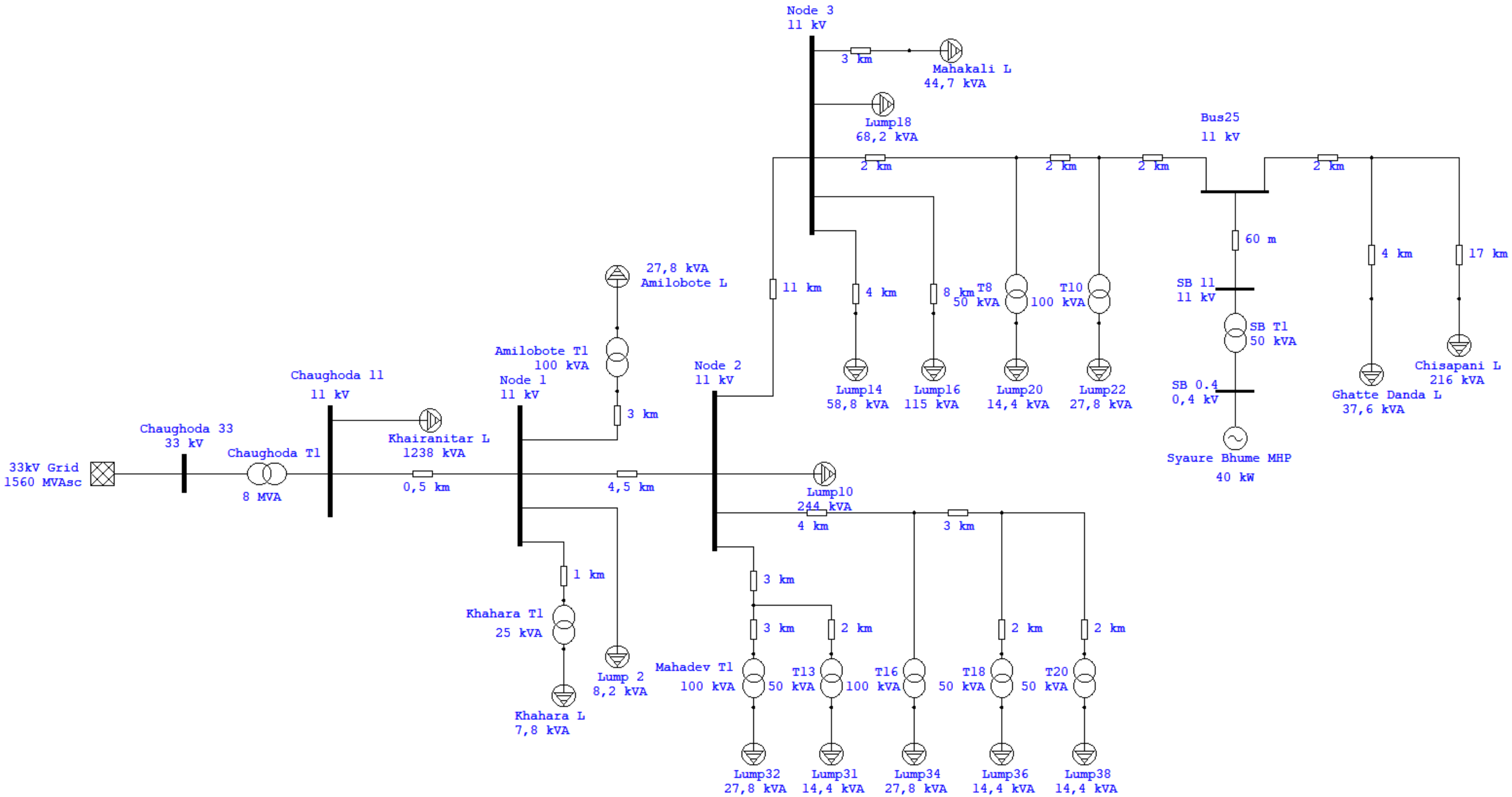


Figure 7-34. Model of Chahare Feeder for Load Flow and Short Circuit Analysis

7.2.3.1. Load Flow Analysis

Load flow analysis is carried out mainly to determine the direction and magnitude of the power flow to be compared with continuous rating of installed equipment such as:

i. Transmission and Distribution line.
ii. Substation and Distribution transformer.
iii. Generator

Load flow analysis is divided into three scenarios based on loading magnitude namely:

a. Maximum Load
Maximum load scenario is load flow analysis with assumption of 100% loading of all (global) installed load on the grid.

b. Average Load
Average load scenario is load flow analysis with assumption of 60% loading of all (global) installed load on the grid.

c. Minimum Load
Minimum load scenario is load flow analysis with assumption of 45% loading of all (global) installed load on the grid.

a. Maximum Loading

Maximum load scenario (100%) results in 1989 kW of total load as shown in table below.

Table 7-17. Load Flow Summary for Maximum Loading Scenario Before Interconnection

Data Revision	Base	Power Grids	1
Configuration	Normal	Loads	18
Loading Cat	Design	Load-MW	1,989
Generation Cat	Design	Load-MVAr	1,196
Diversity Factor	Global 100%	Generation-MW	1,989
		Generation-MVAr	1,196
Buses	32	Loss-MW	0,092
Branches	31	Loss-MVAr	0,042
Generators	0		

Load flow simulation of Chahare Feeder before interconnection of Syaure Bhumi MHP is shown in figure below. It can be seen that the voltage level on Bus 25 (11kV interconnection point of Syaure Bhumi) is 93.8%. It is achieved by increasing the 11kV voltage level in Chaughoda substation slightly within tolerance limit to 105.3%.

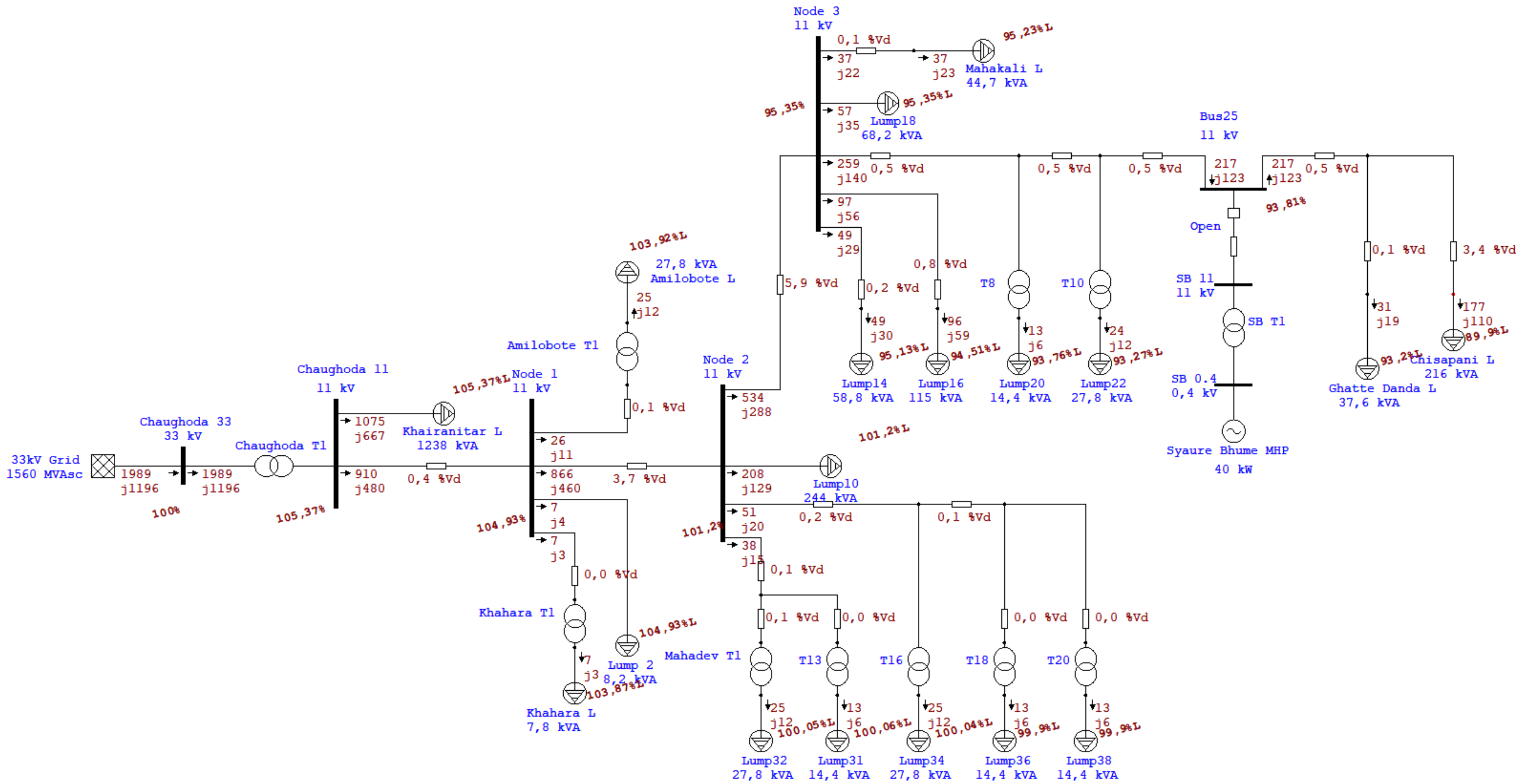


Figure 7-35. Maximum Loading Load Flow Simulation Result Before Syaure Bhumi MHP Interconnection

Further simulation exercise by interconnecting the Syaure Bhumi MHP results in load flow as shown in the table and figure below (maximum loading scenario). With 23 kW and 17.25 kVAR (0.8 PF) power dispatch from Syaure Bhumi MHP, voltage level on Bus 25 increases slightly from 93.8% to 94.4% while the voltage level on the farthest end of the grid which is at Chisapani 216kVA load is increased from 89.9% to 90.5 %. Slight increase is considering the relatively small size of the MHP compared with total size of the grid.

Table 7-18. Load Flow Summary for Maximum Loading Scenario After Interconnection

Data Revision	Base	Power Grids	1
Configuration	Normal	Loads	18
Loading Cat	Design	Load-MW	1,983
Generation Cat	Design	Load-Mvar	1,193
Diversity Factor	Global 100%	Generation-MW	1,983
		Generation-Mvar	1,193
Buses	32	Loss-MW	0,086
Branches	31	Loss-Mvar	0,038
Generators	0		

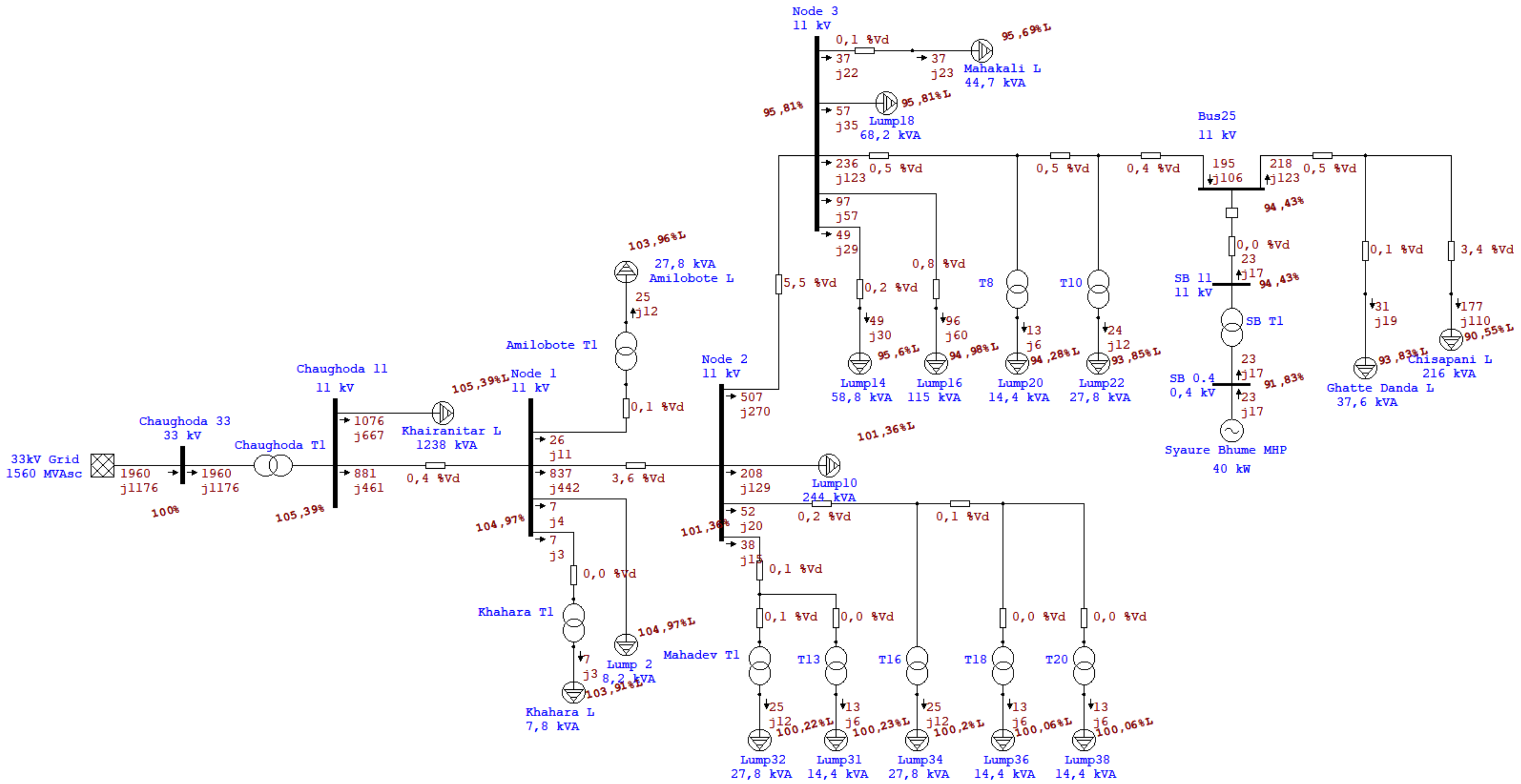


Figure 7-36. Maximum Loading Load Flow Simulation Result After Syaure Bhumi MHP Interconnection

Furthermore, losses of the total system (calculated from Chaughoda 33 kV Substation) is decreased substantially from 92.4 kW to 85.5 kW due to lower power dispatch from the substation. Therefore interconnection of Syaure Bhumi MHP is considered to cut distribution losses as much as 6.9 kW continuously with details shown in losses summary table in annex 2.3.

On the table below is the transformer tap data to maintain the voltage level within standard/tolerance. It is assumed that the transformers have OLTC function capability with the step size and count is as per specification supplied.

Table 7-19. Chaughoda & Syaure Bhumi Transformer Tap Position

Transformer Load Tap Changer Setting					
% Min. Tap	% Max. Tap	% Step	Regulated Bus ID	% V	kV
-10.00	10.00	1.250	Chaughoda 11	105.00	11.550
-5.00	5.00	1.000	SB 11	100.00	11.000

b. Average Loading

Average load scenario (60%) before interconnection results in 1172 kW of total load as shown in table below.

Table 7-20. Load Flow Summary for Average Loading Scenario Before Interconnection

Data Revision	Base	Power Grids	1
Configuration	Normal	Loads	18
Loading Cat	Design	Load-MW	1,172
Generation Cat	Design	Load-MVAr	0,684
Diversity Factor	Global 100%	Generation-MW	1,172
		Generation-MVAr	0,684
Buses	32	Loss-MW	0,031
Branches	31	Loss-MVAr	-0,011
Generators	0		

Load flow simulation of Chahare Feeder before interconnection of Syaure Bhumi MHP is shown in figure below. It can be seen that the voltage level on Bus 25 (11 kV interconnection point of Syaure Bhumi) is 97.82%. It is achieved by increasing the 11 kV voltage level in Chaughoda substation slightly within tolerance limit to 104.5%.

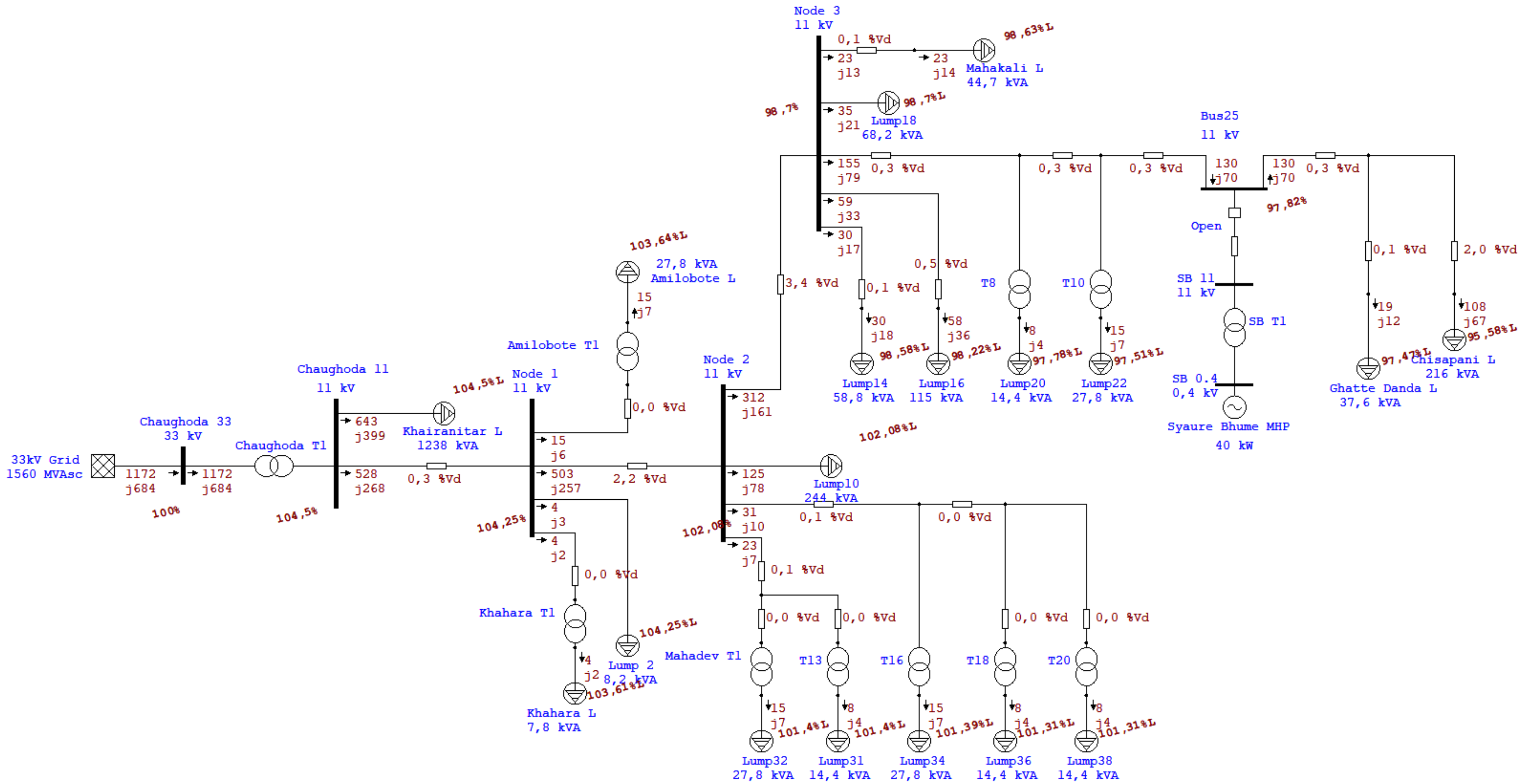


Figure 7-37. Average Loading Load Flow Simulation Result Before Syaure Bhumi MHP Interconnection

Average load scenario (60%) after interconnection results in 1169 kW of total load as shown in table below.

Table 7-21. Load Flow Summary for Average Loading Scenario After Interconnection

Data Revision	Base	Power Grids	1
Configuration	Normal	Loads	18
Loading Cat	Design	Load-MW	1,169
Generation Cat	Design	Load-MVAr	0,682
Diversity Factor	Global 60%	Generation-MW	1,169
		Generation-MVAr	0,682
Buses	34	Loss-MW	0,027
Branches	33	Loss-MVAr	-0,012
Generators	1		

Average loading load flow simulation of Chahare Feeder is shown in figure below. Lower loading directly affects voltage level on the grid which is better than voltage level during maximum loading as the voltage drop on each transmission/distribution line is decreased. The voltage level on Bus 25 is calculated at 98.4% while voltage level at the farthest end of the grid which is at Chisapani 216 kVA load is at 96.17 %.

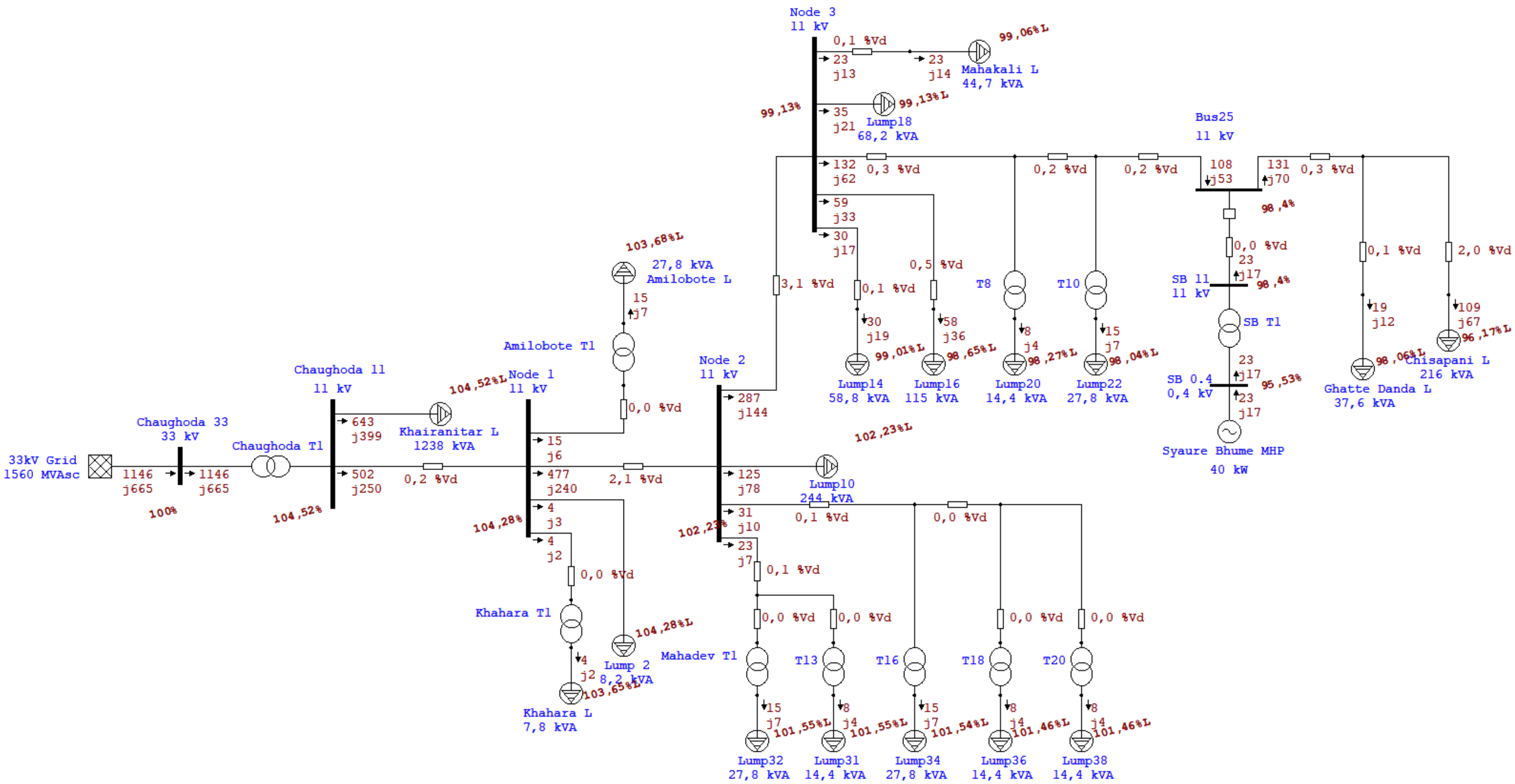


Figure 7-38. Average Loading Load Flow Simulation Result After Syaure Bhumi MHP Interconnection

Furthermore, losses of the total system (calculated from Chaughoda 33 kV Substation) is decreased substantially from 30.8 kW to 27.4 kW due to lower power dispatch from the substation. Therefore interconnection of Syaure Bhumi MHP is considered to cut distribution losses as much as 3.4 kW continuously with details shown in losses summary table in annex 3.4.

c. Minimum Loading

Minimum load scenario (45%) before interconnection results in 875 kW of total load as shown in table below.

Table 7-22. Load Flow Summary for Minimum Loading Scenario Before Interconnection

Data Revision	Base	Power Grids	1
Configuration	Normal	Loads	18
Loading Cat	Design	Load-MW	0,875
Generation Cat	Design	Load-MVAr	0,498
Diversity Factor	Global 100%	Generation-MW	0,875
		Generation-MVAr	0,498
Buses	32	Loss-MW	0,017
Branches	31	Loss-MVAr	-0,024
Generators	0		

Load flow simulation of Chahare Feeder before interconnection of Syaure Bhumi MHP is shown in figure below. It can be seen that the voltage level on Bus 25 (11 kV interconnection point of Syaure Bhumi) is 97.82%. It is achieved by increasing the 11 kV voltage level in Chaughoda substation slightly within tolerance limit to 104.5%.

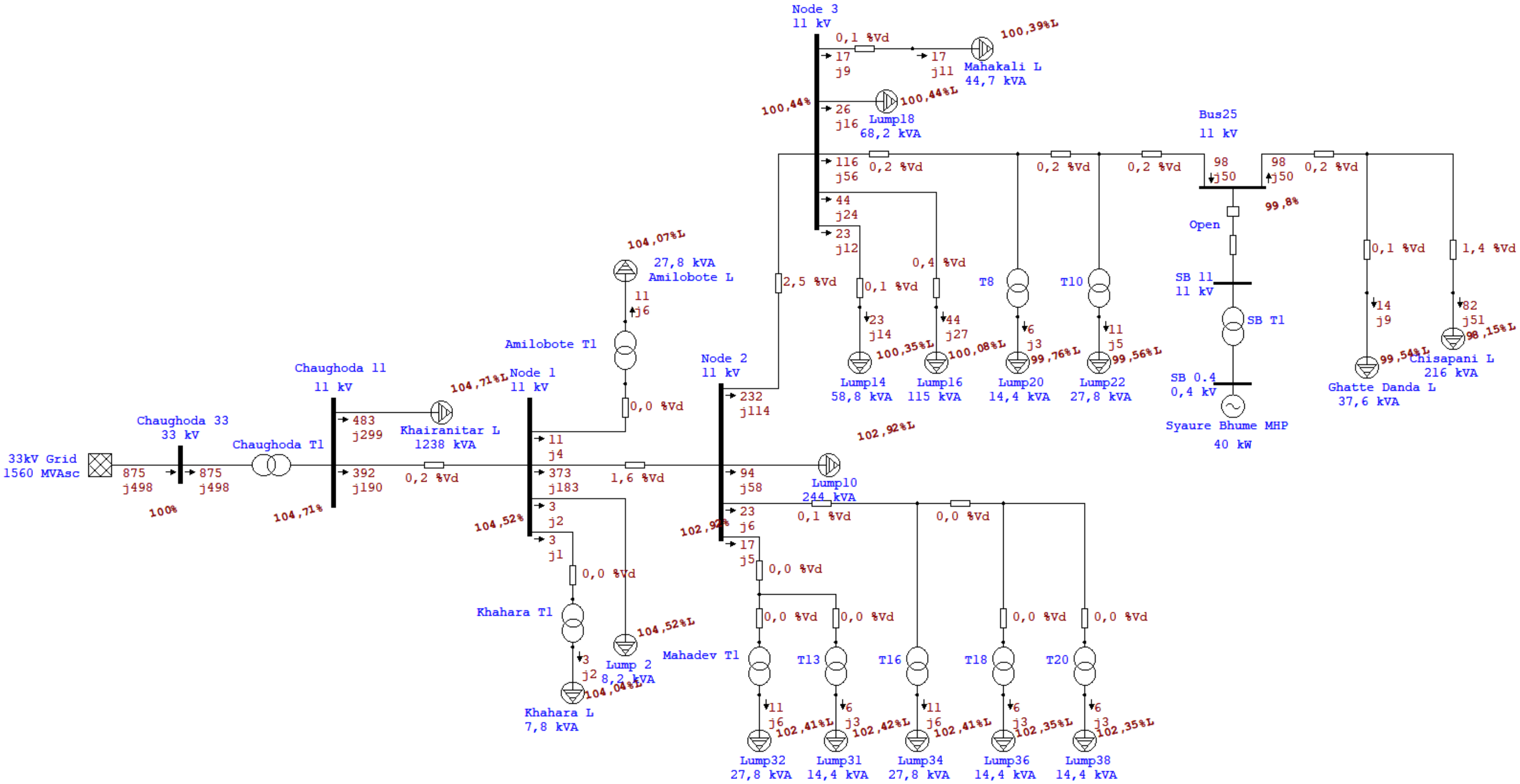


Figure 7-39. Minimum Loading Load Flow Simulation Result Before Syaure Bhumi MHP Interconnection

Minimum load scenario (45%) results in 874 kW of total load as shown in table below.

Table 7-23. Load Flow Summary for Minimum Loading Scenario After Interconnection

Data Revision	Base	Power Grids	1
Configuration	Normal	Loads	18
Loading Cat	Design	Load-MW	0,874
Generation Cat	Design	Load-MVAr	0,498
Diversity Factor	Global 45%	Generation-MW	0,874
		Generation-MVAr	0,498
Buses	34	Loss-MW	0,014
Branches	33	Loss-MVAr	-0,025
Generators	1		

Minimum loading load flow simulation of Chahare Feeder is shown in figure below. Lower loading directly affects voltage level on the grid which is better than voltage level during maximum and average loading as the voltage drop on each transmission/distribution line is decreased. The voltage level on Bus 25 is calculated at 100.36% while voltage level at the farthest end of the grid which is at Chisapani 216 kVA load is at 98.72 %

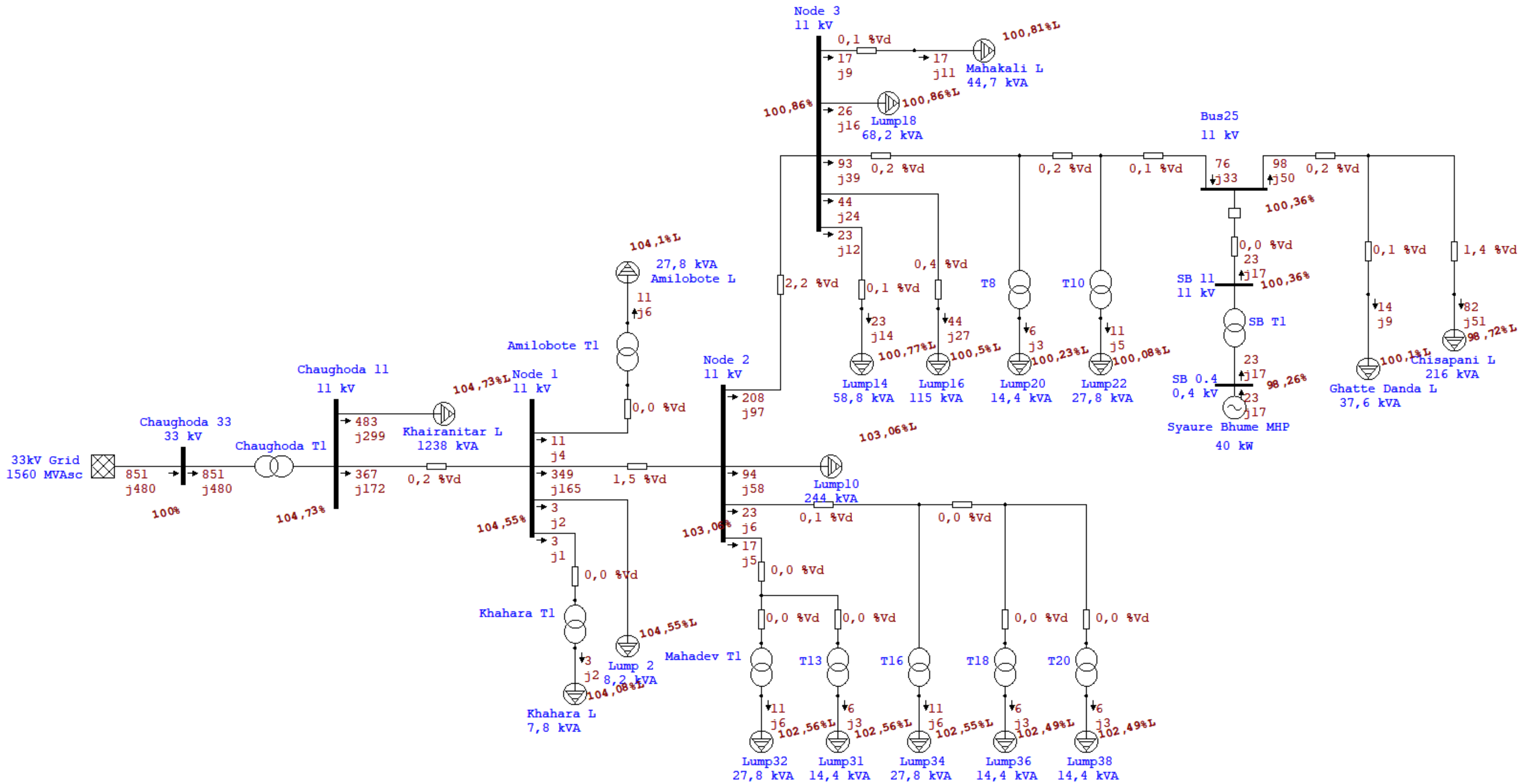


Figure 7-40. Minimum Loading Load Flow Simulation Result After Syaure Bhumi MHP Interconnection

Additionally, losses of the total system (calculated from Chaughoda 33kV Substation) is decreased substantially from 16.6 kW to 14.3 kW due to lower power dispatch from the substation. Therefore interconnection of Syaure Bhumi MHP is considered to cut distribution losses as much as 2.3 kW continuously with details shown in losses summary table in annex 3.5.

7.2.3.2. Short Circuit Analysis

Short circuit study was carried out to identify the maximum short circuit current at 11 kV and 0.4 kV side to further determine the appropriate rating of the switchgear to be used.

To identify the largest fault current, the type of fault used is a symmetrical 3-phase fault (IEC 60909) is used on the 11 kV and 0.4 kV side.

The magnitude of the short circuit current at each 11 kV Substation is shown in Figure 7-41 and Table 7-24.

Table 7-24. Maximum Short Circuit Current on Syaure Bhumi Interconnection

Faulted Bus	Short Circuit Current
Node 3 (11kV)	0.518 kA
Bus 25 (11kV)	0.383 kA
SB 11 (Syaure Bhumi 11kV Interconnection Point)	0.382 kA
SB 0.4 (Syaure Bhumi Generator Bus)	2.2 kA

Looking at Table 7-24 above, the maximum short circuit current in both 11 kV and 0.4 kV system is relatively low with maximum short circuit current at 2.2 kA (on 0.4 kV Generator Bus). Therefore standard design and rating of the 11 kV switchgear with 12.5 or 16 kA short circuit current rating is adequate.

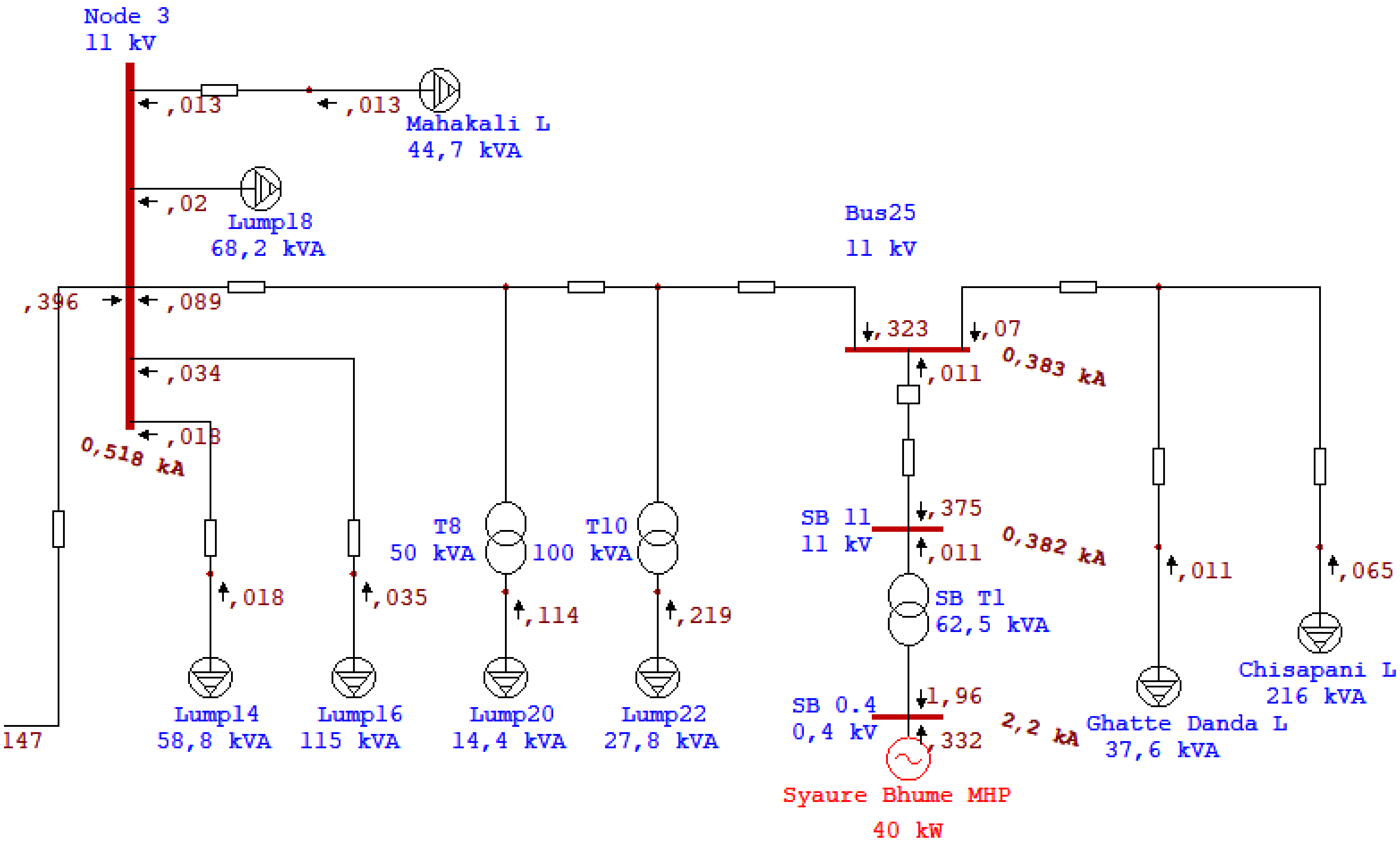


Figure 7-41. Three Phase Short Circuit Study for Maximum Short Circuit Current Determination

8. Financial Cost Benefit Analysis

In order to check the commercial viability for investment in interconnection of MHPs or Grid-connection of MHPs, it is necessary to go through financial cost benefit analysis. The analysis helps to aggregate net benefits and draw conclusions on whether the project is desirable and worth implementing. Usually, it is evaluated on an incremental basis, by considering the difference between the project scenario and an alternative scenario without the project. It is estimated in constant prices for a selected year, typically using the official exchange rate at the time of appraisal. The cost benefit analysis should particularly aim to:

- e

The following financial parameters are checked when determining financial viability:

- Financial Net Present Value
- Financial Benefit-cost ratio
- Financial Internal rate of return

While carrying out the financial cost benefit analysis, following considerations are included:

1. Formulation of baseline assumptions and parameters – this includes determining life of the project and appropriate discount rate. The economic life of key assets should be considered while determining life.

2. Determining depreciation cost of MHPs: In the cost estimate, there is need to put present value of MHPs after deducting depreciation cost.

3. eFor grid interconnection, there is need to make investment for feasibility analysis, MHP upgradation and infrastructures installation for interconnection.

4. Identify sources of financing: The sources of financing for capital cost investment could be grants, subsidies, loan or equity.

5. Calculation of recurring costs: Recurring costs include periodic costs incurred during operating the system, such as, cost of labour and staff, periodic maintenance and office running expenses, cost of tools, consumables, etc.

6. Calculation of recurring revenues: Recurring revenues include tariffs or fees collected from consumers and revenue from electricity sale to NEA. This is a measure of the extent to which the project can bear the capital expenditure. The revenue is measured over a period of time that matches the life of the system.

7. Calculation of annual net cash flow: Net cash flow refers to the difference between a project's cash inflows (revenue) and outflows (costs) on annual basis. This is calculated for each year of the assumed project life horizon.

8. Perform discounting of cost and benefit flows: Costs and benefits occurring at different times have different value in real terms so must be discounted. The future values of project cost and benefit should be adjusted to present values using a discount rate.

9. Calculation of Benefit Cost Ratio (BCR): The BCR is derived by dividing the discounted benefits by the discounted costs. A value of BCR greater than 1 indicates a financially viable project.

10. Calculation of the financial net present value (FNPV): The financial net present value is the sum that results when the expected investment and operating costs of the

project (suitably discounted) are deducted from the discounted value of the expected revenues. The FNPV should have positive value. The negative FNPV suggests that the project should be rejected because the undertaking entity would be worse off.

11. Calculation of the financial internal rate of return (FIRR): It is defined as the discount rate that produces a zero FNPV, If the estimated FIRR value is greater than the capital cost of investment in the market (10 percent in the above example), the project is considered viable from a FIRR criteria. The FIRR equal to or greater than the financial opportunity cost of capital implies the project is financially viable.

8.1. Cash Flow Analysis

The project should have adequate income to meet operation and maintenance cost, and payback annuity (equal instalment payment). The financial sustainability of the project should be assessed by checking that the cumulated (undiscounted) net cash flows are positive over the entire reference period considered. The net cash flow is net revenue after deducting operating expenses and annual debt service payment (annuity).

8.2. Financial Analysis Tool

A MS-Excel (spreadsheet) based interactive and flexible software has been developed to facilitate performing financial analysis of grid interconnection projects. The tool is helpful to accomplish following tasks:

- Check financial viability and sustainability of the project
- Check financial viability of the project at different level of subsidy, loan and equity mix

The results generated from above mentioned analysis are helpful for decision makers to make decision for investment in the proposed project. The MS Excel spreadsheet has different sheets as mentioned in following sections:

8.2.1. Data Entry Sheet

The data entry sheet allows entering the basic information required to carry-out financial appraisal. To generate results the software needs basic data of a project as outlined below:

- capital cost
- means of financing
- loan terms and draw down schedule
- basic information and assumptions
- asset life and rehabilitation requirement
- tariff rate and expected revenue
- recurrent cost (personnel, energy, spare parts, maintenance etc)
- annual growth rate of recurrent cost

8.2.2. Cash flow (data analysis) sheet

As per the requirement, various data analysis sheets including cash flow sheet have been created.

8.2.3. Summary Result Sheet

The summary result sheet present summary of financial cost benefit analysis of the project. Additionally, the summary sheets present result of cash flow analysis which is helpful to check financial sustainability of the project.

9. Conclusion and Recommendation

9.1. Conclusion

9.1.1. MHP-MHP Interconnection

In terms of technical considerations, the current combination of use of ELC, synchronous generator and synchroniser is the best solution for MHP-MHP interconnection as per different literatures and practices. With this scheme, each MHP is still able to provide electricity services to the respective village load in case a black out occurs with the mini-grid. Installation of central ELC and central ballast systems seems not possible due to technical limitations as generator, ELC and ballast are one package. ELC and ballast are designed to function based on generator specifications.

In order for generators to work properly, they have to be synchronised before they can be interconnected. This is to bring them to the same voltage, frequency and aligning their phase. It is important to understand here that, for example, each generator cannot try to control the frequency, rather then they would have to do so in a collaborative manner. The same would apply for the voltage and reactive power. If, after synchronisation, all operators are trying to control the frequency independently of the other, they may end up working “against” each other. In such case, it would be advisable to have one operator in charge as a master to maintain voltage and frequency. This master operator would not only make the required adjustments on the master MHP, but also give instructions to the other MHP operators to fix the operating point of their plants. This is what would be called a hierarchical control of MHP – MHP interconnection. This requires communication among the MHP plants and established standard operating procedure. The master plant can be selected from the best sites where it provides stable electricity output over the year and/or the most reliable plant operation.

The use of synchronous generator as master and asynchronous generators as slave combination may be suitable in case of each plant does not have village load to be served. If the slave plants have their own village load, these plants will shut down if the mini-grid goes off due to any reasons.

The interlock control (ILC) is required for MHP-MHP interconnection in order to avoid overload to the mini-grid when one MHP is experiencing an unexpected shutdown. This will serve more reliable operation of the mini-grid.

In terms of enabling environment, clear policies, standard and guidelines are deemed necessary for MHP interconnection purposes. Similarly, engagement of all stakeholders in the market system, including the capacity development of directly engages actors are required for smooth functioning and scaling-up of the efforts. However, more R&D is required in this sector as the complexities of managing and operating the systems are higher and highly technical human resources as well as good communication infrastructure is required at MHP level.

9.1.2. MHP-Grid Connection

For MHPs less than 100 kW, a combination of synchronous generator with ELC, ballast load and synchronizer remain the most preferable solution. For MHP greater than 100 kW a combination of the utilization of a synchronous generator in combination with automatic actuator (to control the water flow) and synchronizer is preferable. When there is no local or village load to be served by the MHP, the use of asynchronous generator is possible.

Looking into the enabling environment, the policy regime and practices are being supportive for grid-connection of MHPs. However, clear and simplified policies, standard and guidelines are necessary for MHP-grid connection purposes. Likewise, capacity development promotion of linkages and engagement of all stakeholders in the market system are required for mainstreaming and scaling-up of the efforts in near future. Similar to MHP-MHP interconnection, design of a viable business model including management strategy is required for sustainability of the projects, looking into the factor od feasibility of already constructed MHPs. Linkages of national manufacturers with international companies such as Renerconsys PT pave way for technology transfer and engagement of more manufactures, once the interconnection activities pick up pace. Renerconsys PT is eager to partner with local manufacturers of Nepal.

9.2. Recommendations

- Formation of mini-grid only may not only be sufficient for optimal use and revenue generation of MHP, so the priority should be given for the Grid interconnection of mini-grid. Integration of productive uses of electricity may be necessary if the national grid is not available near-by.

- Well define standards guidelines/code should be developed for MHP-MHP and MHP-Grid interconnection.

- Simplification of PPA document as well as process for the grid connection of MHPs and mini-grid should be required unlike that of larger hydropower plants.

- The MHP PPA process can be completed through the Provincial office of NEA with approval from NEA central PPA department (if necessary).

- Continuation of extensive collaboration between NEA and AEPC is required to resolve some issues like costlier interconnection scheme (Metering /VCB requirement). Similarly NEA's concerns like safety, protection, reliability of breaking equipment, operation and maintenance issues upon the interconnection of MHP should be resolved jointly. A joint integrated master plan for the MHP-Grid interconnection and Minigrid–Grid interconnection may be the milestone for grid interconnection of MHP in future.

- Clustering of nearby MHPs and formation of Mini-grid may be the better option for grid connection of MHPs. As per the lesson learnt from Baglung mini-grid, interconnection of micro grid to nearby distribution substation with novel method of mini-grid network operation and maintenance needs to be explored. With this concept cost of interconnection can be minimized, on the other hand it helps to address the issues raised by NEA as NEA needs to handle through a single point.

- Knowledge and technology transfer are expected by local manufacturer from their international peers. Linkages with the international manufacturers and vendors can be key for increasing the manufacturing and supply of necessary equipment in Nepal

- Some local governments have reached out to the manufacturers for grid connection possibilities, hence more awareness for local government can also be prioritised. Viable business models with public private partnership approach can be explored in discussion with the stakeholders involved.

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Annexes

- Checklist and questionnaire for data collection
- Indonesia: Institutional Framework and Regulations related to RE and grid connection
- Simulation Data and Results

Annex 1: Mini-grid and Grid in-feeding Checklist

Site Information:

Name of Hamlet/Village:

District

Province

Geographical position coordinates

Population

Number of households

Major economic activities

MHP Hydrology and Hydraulic Information

- Catchment Area
- Headrace channel design
- Headrace length
- Gross-head
- Net-head
- Design flow
- Penstock length
- Penstock material
- Penstock diameter

Electro-mechanical Information

Turbine

- Branch
- Turbine type
- Maximum RPM
- Turbine-generator coupling method

Generator

- Branch
- Generator type
- RPM of generator
- Configuration (...Units x ...kW)
- Rated Power factor
- Rated Voltage
- Grounding system (Solid or resistive (... Ω)
- Generator protection relay functions/schemes

AVR

- Branch

- AVR Type
- Sensing input voltage
- Sensing input frequency
- AVR response time
- Power factor control capability (Power Factor as operating setpoint)
- Voltage control capability (Output voltage as operating setpoint)

Electronic Load Controller/Governor

- Branch
- ELC/Governor Type
- Control method
    - Droop capability
    - Isochronous capability
    - Load share capability
- Power capacity
- Voltage range
- Phase
- Frequency
- Ballast or dummy load type

Load Characteristics

- MHP own use/house load (...kW)
- Daily Load profile (min 1-month period)
- Maximum peak-load (min 1-month period)
- Minimum base-load (min 1-month period)
- Distance (Distribution line) of MHP powerhouse to load center

Mini-grid Interconnection Scheme

- Distance between MHP Mini-grid
- Detailed profile of MHP to be interconnected

Grid Interconnection Scheme

- National grid code/standard (voltage & frequency & system protection requirements)
- The closest distance to the grid
- Distribution line type (cable/overhead) and cross section (...mm2)
- Grid configuration (Y or Δ) and grounding system (Solid or resistive (... Ω)
- Grid single line diagram/map (Details of other generators, substations, transformers, transmission & distribution lines)
- Grid capacity (Monthly peak, average & minimum load)
- Grid voltage for interconnection
- System Average Interruption Duration Index (SAIDI)
- System Average Interruption Frequency Index (SAIFI)

Component Costs:

Description	Value	Unit	Explanation (if required)
10 mm2 grid cable cost			
25 mm2 cable cost			
Pole cost			
20 kW Synchroniser			
50 kW Synchroniser			
2.5 kW MHP cost installed			
6 kW MHP cost installed			
100 kW MHP cost installed			
50 kVA step-up transformer			
Skilled labour cost			
Semi-skilled labour cost			
Unskilled labour cost			
Synchroniser life time			
Turbine life time			

Scenario data

Scenario	Enter Value	Unit
Grid power factor		%
Annuity period		Years
MHP capacity		kW
Maximum monthly operating times		Hrs/month
Planned shut-down per month		Hrs/month
Unplanned shut-down per month		Hrs/month
Number of skilled staff per month		Staff/month
Number of unskilled staff		
Capacity variation		%
Operating hours variation		%
Grid distance		Km
Grid power line size		mm2
Number of households		Number
Synchroniser size		kW

Note: Data on existing use of electricity generated for productive uses and community services will also be collected.

Annex 2: Indonesia: Institutional Framework and Regulations related to RE and Grid connection

A. Institutional Framework of Indonesia

The policy measures on energy matters are basically covered under the Ministry of Energy and Mineral Resources (MEMR). However, energy is one of the basic elements that have multi sectorial aspects. Therefore, the development of energy policies requires holistic approach. Unfortunately, the developments of energy regulatory framework are in many cases dominated by sectorial policies rather than integrated.

MEMR is a government body of Republic of Indonesia responsible for energy related matters. MEMR jurisdiction covers: direction setting, planning, implementation and regulation of energy policies.

Through the Presidential Regulation No. 24, year 2010, a new Directorate General within MEMR namely "Directorate General for New Renewable Energy and Energy Conservation (DG-NREEC)" was established on 14 April 2010. DG-NREEC was established to undertake the implementation of Clean Energy Initiative. In this context four policy instruments will be required as follows:

Legal Instrument: legislation and implementing regulations need to implement the clean energy in each energy sub-sector

- Fiscal Instrument: incentives and disincentives, particularly for public and private stakeholders to attract stakeholder's involvement in the clean energy implementation
- Financial Instrument: the implementation of clean energy technologies and programs can be costly, and sometimes unattractive to private investors. Therefore, Government should develop attractive financial mechanism, such as fund with low interest rate and accessible to private investors.
- Institutional Instrument: to increase coordination and cooperation with the related institutions, not only to energy stakeholders, but also among other climate-change related stakeholders.

Before the establishment of DG-NREEC, activities related to renewable energy development was coordinated by the Directorate General for Electricity and Energy Utilization (DG-EEU). DG-EEU promoted renewable energy developments (including MHPP) through various means, such as: workshops, conferences and seminars.

National Energy Council (DEN)

The National Energy Council (DEN) is established due to the mandate by the Indonesian Energy Act no. 30, 2007 issued in 10 August 2007.

The council is established to carry the following tasks:

- plan and formulate the national energy policy
- establish the general plan of national energy
- establish the safety measures in case of energy crisis and emergency
- supervise the energy policy measures which is cross sectorial.

The council is chaired by the President and co-chaired by Vice President of Indonesia. The day-to-day operation is carried out by the Minister of Energy and Mineral Resources (MEMR). There are 15 (fifteen) members which consists of 7 (seven) members from Ministers and/or government officials and 8 (eight) from other stakeholders related to energy.

PLN

PT PLN (Persero) or in-short PLN is a state-owned electricity enterprise which acts as the Electric Energy Authority of Indonesia by virtue of Act No. 30 of 2009 and Government Regulation (PP) No. 17 of 1990.

In 1994, by virtue of Government Regulation No. 23 of 1994, PLN was transformed from a Public Utility Company into a Limited Liability Company, but retaining its function as the Electric Energy Authority.

With the issuant of the Electricity Act no. 30, 2009 on 23 September 2009, the above PLN arrangement will slightly change. It is indicated that any state enterprise will be prioritized (first right of refusal) for electricity provision in the region where they exist. In addition, private sector, co-operative and community can participate for electricity provision and will be provided a licence for electricity provision by government.

B. Regulations related to RE and Grid Interconnection of Indonesia

Indonesian Energy Act no.30/2007

By the issuance of the Indonesian Energy Act no. 30/2007 in 10 August 2007, the government of Indonesia is urged to develop the national energy policy in accordance mandates within one year after the issuance of this energy act.

The national energy policy must address, among others, the following issues:

- availability of energy for the national needs;
- priority for energy development;
- utilization of national energy resources, and
- national energy buffer reserve.

In order to support the government, energy act gives a mandate to the government for the establishment of national energy council within 6(six) moths after the issuance of Energy Act.

Electricity Act no.30/2009

This electricity act is issued in 23 September 2009 and replacing the Electricity Act no.15/1985. The following is the major highlight of the act:

- Electricity supply controlled by the state which is regulated by the Government and Local Governments based on the principle of local autonomy (Article 3, Paragraph 1);
- Utilization of primary energy sources has to be implemented by prioritizing new and renewable energy sources (Article 6, paragraph 2);
- Electricity supply for public needs is conducted by state-owned enterprises, regionally owned enterprises, private enterprises, cooperatives, and community-based organizations which provides services in the field of electricity supply (Article 11, paragraph 1);
- For the areas where no access to electricity, the Government and/or the local government authority shall give opportunity to the local state-owned, private companies, or cooperatives to act as an integrated electricity provider (Article 11, paragraph 3);

With regards to the electricity pricing, it is stipulated in Article 33 of this Electricity Act:

- The selling price of electricity and rents electric power grid is set based on sound business principles;
- Government or regional government in accordance to its authority to give approval for the selling price of electricity and rents electric power grid;

- Business license holders are prohibited from applying the provision of electricity selling price and rent an electric power network without approval from the Government or local government.

Presidential Regulation on Water Resources Management no.33/2011

Besides regulations which are directly addressed to energy and electricity sectors, the Government of Indonesia issues the Presidential Regulation that stipulates the water resource management in 20 June 2011.

The major mandate of this regulation among others:

- Establish the Management of the National Policy of Water Resources, herein after referred to Jaknas SDA.
- Jaknas SDA is a strategic direction in the management of water resources nationwide for a period of 20 (twenty) years commencing from year 2011 to 2030

With respect to energy, this regulation guides Jaknas SDA to carry some tasks as follows:

- Develop the function of rivers, lakes, reservoirs, and wetlands for water transportation, and hydroelectric power in the region of its electricity needs unmet;
- Provide incentives for business organizations in the development of micro hydro electricity generation infrastructure;

Ministerial Regulation on Feed in Tariff

In 13 November 2009 the Ministry of Energy and Mineral Resources (MEMR) issued a Ministerial Regulation no.31/2009 concerning the feed-in tariff to the PLN grid.

Two classifications are made:

- If the electricity is fed into a medium voltage network (JTM) of 20kV F x 656 IDR/kWh
- If the electricity is fed into a low voltage network (JTR) of 380V F x 1004 IDR/kWh

F is site factor which dependence to the location where the power plant is built as follows:

- F=1 For Java, Bali sites
- F=1.2 For Sumatera and Sulawesi
- F=1.3 For Kalimantan, West Nusa Tenggara, and East Nusa Tenggara (NTT)
- F=1.5 For Maluku and Papua

In order to speed up the PPA, as stipulated in the Article 5 of this Ministerial Regulation; PLN is obliged to establish a standardized PPA contract.

Procedure

The major obstacle on the development of on-grid scheme remains on the procedural aspects to obtain the PPA.

Ministerial Regulation no.31/2009 does not describe any procedure to obtain PPA from PLN. However, as stipulated in the Article 5 of this Ministerial Regulation discussed previously, PLN is obliged to establish a standardized PPA contract.

In comparison to the Ministerial Decree No.1122K/30/MEM/2002 (which is no longer applicable), it provided details about the procedure and process for the PPA, including the time frame of the process.

In accordance to the above-mentioned Ministerial Decree, MHP project developer must submit the proposal and request for grid interconnect to PLN with copy to the Directorate General of Electricity. The proposal shall contain at least:

- Feasibility study - There are two major aspects need to be addressed in this feasibility study. Firstly, the electricity generation cost should show at least fit to that purchase tariff published in the ministerial regulation. Secondly, PLN must be confident that the project developer has financial capacity (whether from its own sources or out-sources) to build the MHP plant;
- Construction plan - For established off-grid MHP it may include work for installation of additional equipment (like: synchronizer and transformer) and transmission line connecting the plant to the interconnecting point;
- Environmental management and monitoring plan;
- Water permit - Water permit is normally issued by the district office (Dinas) for water resources. In case of the location is crossing the district border, the water permit shall be issued by provincial office for water resources.
- Building permit - Building permit is basically to confirm that the site is eligible and environmentally allowed (e.g.: it is not located at the reserve area) to be used for building construction. The civil and electro-mechanical constructions fulfil the existing codes.

The project sequence can be summarized in milestones as follows:

- After the proposal is being approved, normally PLN will issue Minutes or Memorandum of Understanding (MOU) indicating that proposal is approved and project should proceed within the approved time-frame. With this document, the project developer can start with the construction works.
- After the construction is finished, the project developer sends a request to MEMR to obtain a so called IUKU (Operating Permit of Generating Electricity for Public).
- Prior to the issuance of IUKU, MEMR will request for commissioning certificate from the independent and certified institution. Based on this commissioning certificate, the MHP Plant is eligible technically for grid-connect operation.

The schematic of the procedure is presented in the following chart.

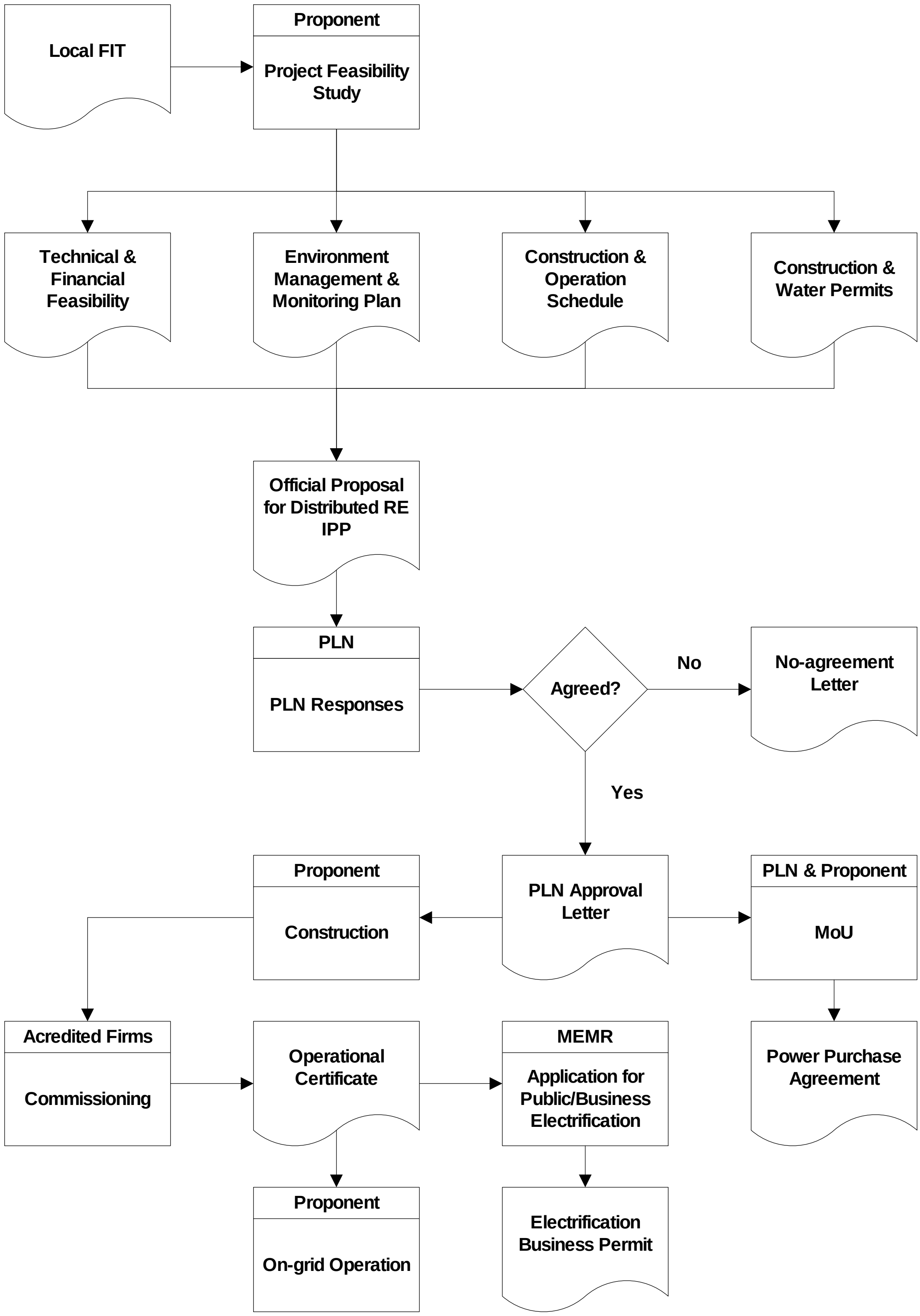

Figure 0-1. MHP Project Sequence Flow

The MHP conversion from standalone operation to grid connect scheme, generally requires additional equipment and services as follows:

a. Synchronizer, which is to synchronize the frequency and voltage systems of the MHP and PLN. In addition, the synchronizer should able to provide protection against reverse current and islanding operation.

b. Transmission line, that connects the MHP Plant to the interconnecting point. For short distance up to approximately 1 km and small MHP Plant capacity of 30 kW, a low voltage transmission line (400 V) might be still technically viable. For larger distances, the use of medium voltage (20 kV) may be considered. The last is needed to reduce significant power losses in the transmission line.

   In case of the using JTM, the additional step-up transformer 400 V/ 20 kV is required. If the interconnecting point be made at 400 V, then additional step-down transformer 20 kV/ 400 V is also needed. In order to reduce second losses in transformer and also the cost, it is preferably to connect the plant directly in the JTM (if exist).

There is no definitive rule the power losses that are acceptable for grid connect a stand-alone into grid connect MHP. For the purpose of the study, the power losses on transmission lines of maximum 5% will be considered as discussed in the latter sections. Based on this 5% allowable power losses, the selection cable size for JTM can be presented in the following figure. This chart is based on the twisted cable and aluminium core available on the market. For cooper wire will require cable cross-section area of approximately be a half of it.

Annex 3.1. Hourly Load Data in Baglung Mini-grid

Time	Load (kW)						
	Upper Kalung Khola	Kalung Khola	Urja Khola I	Urja Khola II	Urja Khola IV	Theula Khola	Total Load
1:00 AM	1.8	4.8	5.5	2.2	1.5	6.4	25.2
2:00 AM	1.8	4.5	6.0	2.5	1.5	6.2	25.5
3:00 AM	1.8	4.0	7.0	2.2	1.5	6.0	25.5
4:00 AM	2.0	6.0	6.0	2.8	1.5	8.0	29.3
5:00 AM	2.5	20.0	6.5	3.0	3.1	11.0	49.1
6:00 AM	2.5	19.0	7.0	3.3	3.1	11.0	48.9
7:00 AM	7.0	13.5	8.0	3.5	9.0	16.0	60.0
8:00 AM	7.8	10.8	9.0	3.7	10.0	15.5	59.8
9:00 AM	7.0	10.0	6.0	2.0	9.0	9.0	46.0
10:00 AM	2.0	10.0	6.5	6.5	8.8	12.0	48.8
11:00 AM	2.0	4.5	14.5	6.0	1.8	6.7	38.5
12:00 PM	1.8	3.0	15.0	6.5	1.8	5.5	36.6
1:00 PM	1.5	3.0	9.5	5.8	2.0	4.5	29.3
2:00 PM	5.0	3.5	9.0	5.0	1.5	14.0	41.0
3:00 PM	5.1	12.0	5.5	5.1	1.8	13.5	46.0
4:00 PM	5.2	12.5	5.8	5.5	2.0	14.5	48.5
5:00 PM	2.0	14.0	9.0	2.5	2.2	7.0	39.7
6:00 PM	6.0	13.0	16.0	5.0	8.8	15.0	66.8
7:00 PM	11.0	17.0	22.0	8.0	11.5	21.0	93.5
8:00 PM	9.5	13.0	17.8	7.8	10.0	19.0	80.1
9:00 PM	7.0	11.0	13.0	6.0	8.5	15.0	63.5
10:00 PM	4.0	8.0	12.0	4.3	5.0	11.0	47.3
11:00 PM	3.5	6.0	8.5	3.0	2.5	7.0	33.5
12:00 AM	2.0	4.8	6.0	2.5	1.8	6.5	26.6
Average Load (kW)	4.2	9.5	9.6	4.4	4.6	10.9	46.2

Annex 3.2. Simulation Results Summary on Several Operation Patterns from 10 PM to 5 PM (Off Peak Load)

Operation Pattern	Generated Power						Total Load		Total Losses	Remarks
	Upper Kalung Khola (kW)	Kalung Khola (kW)	Unja Khola I (kW)	Unja Khola II (kW)	Unja Khola IV (kW)	Theule Khola (kW)	kW	kVAR		
1	7.00	13.50	8.00	3.00	9.00	16.00	56.50	27.40	0.00	Ok
2	OFF	15.20	9.65	4.49	9.97	17.60	56.50	27.40	0.10	Ok
3	9.12	OFF	11.50	5.60	11.10	19.40	56.50	27.40	0.20	Ok
4	8.20	15.60	OFF	4.76	10.20	18.10	56.50	27.40	0.10	Ok
5	7.49	14.30	8.80	OFF	9.49	16.80	56.50	27.40	0.00	Ok
6	8.24	15.26	10.10	4.76	OFF	18.10	56.50	27.40	0.10	Ok
7	9.45	17.60	12.10	5.90	11.50	OFF	56.50	27.40	0.01	Ok
8	OFF	OFF	14.30	7.29	12.80	22.20	56.50	27.40	0.10	Ok
9	OFF	18.20	OFF	6.29	11.80	20.60	56.50	27.40	0.39	Ok
10	OFF	16.40	10.90	OFF	10.70	18.80	56.50	27.40	0.00	Ok
11	OFF	17.90	12.40	6.12	OFF	20.40	56.50	27.40	0.00	Ok
12	OFF	20.5	15.0	7.7	13.3	OFF	56.50	27.40	0.00	Ok
13	11.6	OFF	OFF	8.05	13.5	23.5	56.50	27.40	0.2	Upper KK & Theule K full loaded
14	10.2	OFF	13.3	OFF	12.1	21.2	56.50	27.40	0	Ok
15	11.1	OFF	14.9	7.63	OFF	22.8	56.50	27.40	0	Ok
16	11	OFF	24.7	8	13	OFF	56.50	27.40	0.6	Urja Khola I full loaded
17	9.6	17	OFF	OFF	9.5	20.4	56.50	27.40	0.1	Ok
18	9.8	18.4	OFF	8	OFF	20.7	56.50	27.40	0.2	Ok
19	12.1	22.1	OFF	8	14.2	OFF	56.50	27.40		Not Ok (Over load)

Annex 3.3. Losses Summary on Maximum Load Scenario Before and After Interconnection of Syaure Bhumi MHP

CKT / Branch		Losses Before Interconnection (100%)							Losses After Interconnection (100%						
		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop	From-To Bus Flow		Losses		% Bus Voltage		Vd % Drop
No	ID	MW	MVAR	kW	kVAR	From	To		MW	MVAR	kW	kVAR	From	To	
1	Khahara T1	0.007	0.004	0.1	0.1	103.9	104.9	1.05	-0.007	-0.003	0.1	0.1	103.9	105	1.05
2	Line3	0.026	0.011	0	-1.5	104.9	104.9	0.07	-0.026	-0.013	0	-1.5	104.9	105	0.07
3	Amilobote T1	-0.025	-0.012	0.2	0.2	104.9	103.9	0.94	0.026	0.013	0.2	0.2	104.9	104	0.94
4	Line10	0.259	0.14	1.7	-0.3	94.8	95.3	0.55	-0.234	-0.124	1.3	-0.4	95.3	95.8	0.49
5	Line12	-0.243	-0.134	1.5	-0.4	94.8	94.3	0.52	0.222	0.117	1.2	-0.5	95.3	94.9	0.47
6	T8	-0.013	-0.006	0.1	0.2	94.8	93.8	1.04	0.013	0.006	0.1	0.1	95.3	94.3	1.03
7	Line16	-0.217	-0.123	1.2	-0.4	94.3	93.8	0.47	0.196	0.106	1	-0.5	94.9	94.4	0.42
8	T10	-0.024	-0.012	0.2	0.3	94.3	93.3	1	0.025	0.012	0.2	0.3	94.9	93.9	1
9	Line18	0.038	0.015	0	-1.4	101.1	101.2	0.11	-0.038	-0.016	0	-1.4	101.2	101.4	0.11
10	Line21	-0.025	-0.012	0	-1.4	101.1	101	0.07	0.025	0.011	0	-1.4	101.2	101.2	0.07
11	Line23	-0.013	-0.006	0	-0.9	101.1	101.1	0.03	0.013	0.006	0	-0.9	101.2	101.2	0.03
12	Mahadev T1	-0.025	-0.012	0.2	0.3	101	100.1	0.96	0.025	0.012	0.2	0.3	101.2	100.2	0.96
13	Line36								-0.023	-0.017	0	0	94.4	94.4	0
14	Line38	-0.216	-0.123	1.2	-0.4	93.8	93.3	0.47	0.218	0.123	1.2	-0.4	94.4	94	0.47
15	T13	0.013	0.006	0.1	0.1	100.1	101.1	1	-0.013	-0.006	0.1	0.1	100.2	101.2	1
16	Line27	0.051	0.02	0.1	-1.8	101	101.2	0.2	-0.051	-0.022	0.1	-1.8	101.2	101.4	0.2
17	Line28	-0.026	-0.011	0	-1.4	101	100.9	0.08	0.026	0.01	0	-1.4	101.2	101.1	0.08
18	T16	-0.025	-0.012	0.2	0.3	101	100	0.96	0.025	0.012	0.2	0.3	101.2	100.2	0.96
19	T18	0.013	0.006	0.1	0.1	99.9	100.9	1	-0.013	-0.006	0.1	0.1	100.1	101.1	1
20	Line31	0.013	0.006	0	-0.9	100.9	100.9	0.03	-0.013	-0.006	0	-0.9	101.1	101.1	0.03
21	Line33	-0.013	-0.006	0	-0.9	100.9	100.9	0.03	0.013	0.006	0	-0.9	101.1	101.1	0.03
22	T20	0.013	0.006	0.1	0.1	99.9	100.9	1	-0.013	-0.006	0.1	0.1	100.1	101.1	1
23	Line41	0.031	0.018	0.1	-1.6	93.2	93.3	0.14	-0.031	-0.019	0.1	-1.6	93.8	94	0.14
24	Line42	0.185	0.106	7.8	-4.1	89.9	93.3	3.43	-0.177	-0.11	7.7	-4.2	90.5	94	3.42
25	Line44	0.007	0.003	0	-0.5	104.9	104.9	0.01	-0.007	-0.004	0	-0.5	105	105	0.01
26	Line46	0.049	0.029	0.1	-1.6	95.1	95.3	0.21	-0.049	-0.03	0.1	-1.6	95.6	95.8	0.21
27	Line47	0.097	0.056	1	-3	94.5	95.3	0.83	-0.096	-0.06	1	-3	95	95.8	0.83

CKT / Branch		Losses Before Interconnection (100%)							Losses After Interconnection (100%						
		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop	From-To Bus Flow		Losses		% Bus Voltage		Vd % Drop
No	ID	MW	MVAR	kW	kVAR	From	To		MW	MVAR	kW	kVAR	From	To	
28	Line49	0.037	0.022	0.1	-1.2	95.2	95.3	0.12	-0.037	-0.023	0.1	-1.2	95.7	95.8	0.12
29	Line1	-0.905	-0.479	4.1	1	105.4	104.9	0.43	0.881	0.461	3.9	0.9	105.4	105	0.42
30	Chaughoda T1	1.989	1.196	3.8	49.3	105.4	100	5.37	-1.957	-1.128	3.7	47.8	105.4	100	5.39
31	Line6	-0.831	-0.452	34.1	8.1	104.9	101.2	3.74	0.837	0.442	31.8	7.4	105	101.4	3.61
32	Line8	-0.499	-0.283	34.4	5.5	101.2	95.3	5.85	0.507	0.27	30.8	4.4	101.4	95.8	5.55
33	SB T1								0.023	0.017	0.3	0.5	91.8	94.4	2.61
Sum				**92.4**	**41.8**						**85.5**	**38.4**			

Annex 3.4. Losses Summary on Average Load Scenario Before and After Interconnection of Syaure Bhumi MHP

KT / Branch		Losses Before Interconnection (60%)							Losses After Interconnection (60%)						
		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop	From-To Bus Flow		Losses		% Bus Voltage		Vd % Drop
No	ID	MW	MVAR	kW	kVAR	From	To		MW	MVAR	kW	kVAR	From	To	
1	Khahara T1	0.004	0.002	0	0	103.6	104.2	0.63	0.004	0.002	0	0	103.6	104.3	0.63
2	Line3	0.015	0.006	0	-1.5	104.2	104.3	0.04	0.015	0.006	0	-1.5	104.2	104.3	0.04
3	Amilobote T1	-0.015	-0.007	0.1	0.1	104.2	103.6	0.56	-0.015	-0.007	0.1	0.1	104.2	103.7	0.56
4	Line10	0.155	0.079	0.5	-0.7	98.4	98.7	0.31	0.132	0.062	0.4	-0.8	98.9	99.1	0.26
5	Line12	-0.146	-0.077	0.5	-0.7	98.4	98.1	0.3	-0.123	-0.06	0.3	-0.8	98.9	98.6	0.25
6	T8	-0.008	-0.004	0	0.1	98.4	97.8	0.61	-0.008	-0.004	0	0.1	98.9	98.3	0.6
7	Line16	-0.13	-0.07	0.4	-0.8	98.1	97.8	0.27	-0.108	-0.053	0.3	-0.8	98.6	98.4	0.22
8	T10	-0.015	-0.007	0.1	0.1	98.1	97.5	0.58	-0.015	-0.007	0.1	0.1	98.6	98	0.58
9	Line18	0.023	0.007	0	-1.4	102	102.1	0.07	0.023	0.007	0	-1.4	102.2	102.2	0.06
10	Line21	-0.015	-0.007	0	-1.4	102	102	0.04	-0.015	-0.007	0	-1.4	102.2	102.1	0.04
11	Line23	-0.008	-0.004	0	-0.9	102	102	0.02	-0.008	-0.004	0	-0.9	102.2	102.1	0.02
12	Mahadev T1	-0.015	-0.007	0.1	0.1	102	101.4	0.57	-0.015	-0.007	0.1	0.1	102.1	101.5	0.57
13	Line36								0.023	0.017	0	0	98.4	98.4	0
14	Line38	-0.13	-0.071	0.4	-0.7	97.8	97.6	0.27	-0.13	-0.071	0.4	-0.8	98.4	98.1	0.27
15	T13	0.008	0.004	0	0	101.4	102	0.59	0.008	0.004	0	0	101.6	102.1	0.59
16	Line27	0.031	0.01	0	-1.9	102	102.1	0.12	0.031	0.01	0	-1.9	102.1	102.2	0.12
17	Line28	-0.016	-0.006	0	-1.4	102	101.9	0.04	-0.016	-0.006	0	-1.4	102.1	102.1	0.04
18	T16	-0.015	-0.007	0.1	0.1	102	101.4	0.57	-0.015	-0.007	0.1	0.1	102.1	101.5	0.57
19	T18	0.008	0.004	0	0	101.3	101.9	0.59	0.008	0.004	0	0	101.5	102.1	0.59
20	Line31	0.008	0.003	0	-0.9	101.9	101.9	0.02	0.008	0.003	0	-0.9	102.1	102.1	0.02
21	Line33	-0.008	-0.004	0	-0.9	101.9	101.9	0.02	-0.008	-0.004	0	-0.9	102.1	102.1	0.02
22	T20	0.008	0.004	0	0	101.3	101.9	0.59	0.008	0.004	0	0	101.5	102.1	0.59
23	Line41	0.019	0.01	0	-1.7	97.5	97.6	0.08	0.019	0.01	0	-1.7	98.1	98.1	0.08
24	Line42	0.111	0.061	2.6	-6.4	95.6	97.6	1.97	0.111	0.061	2.5	-6.5	96.2	98.1	1.96
25	Line44	0.004	0.002	0	-0.5	104.2	104.3	0	0.004	0.002	0	-0.5	104.3	104.3	0
26	Line46	0.03	0.017	0	-1.8	98.6	98.7	0.12	0.03	0.017	0	-1.8	99	99.1	0.12
27	Line47	0.059	0.033	0.3	-3.4	98.2	98.7	0.49	0.059	0.033	0.3	-3.5	98.6	99.1	0.48

KT / Branch		Losses Before Interconnection (60%)							Losses After Interconnection (60%)						
		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop	From-To Bus Flow		Losses		% Bus Voltage		Vd % Drop
No	ID	MW	MVAR	kW	kVAR	From	To		MW	MVAR	kW	kVAR	From	To	
28	Line49	0.023	0.013	0	-1.3	98.6	98.7	0.07	0.023	0.013	0	-1.3	99.1	99.1	0.07
29	Line1	-0.526	-0.268	1.4	0.2	104.5	104.3	0.25	-0.501	-0.25	1.2	0.1	104.5	104.3	0.24
30	Chaughoda T1	1.172	0.684	1.3	17.3	104.5	100	4.5	1.146	0.665	1.3	16.5	104.5	100	4.52
31	Line6	-0.491	-0.256	11.5	1.3	104.3	102.1	2.17	-0.467	-0.239	10.3	0.9	104.3	102.2	2.06
32	Line8	-0.3	-0.163	11.4	-1.6	102.1	98.7	3.37	-0.278	-0.146	9.5	-2.2	102.2	99.1	3.09
33	SB T1								-0.023	-0.017	0.3	0.5	95.5	98.4	2.87
Sum				**30.8**	**-10.8**						**27.4**	**-12.5**			

Annex 3.5. Losses Summary on Minimum Load Scenario Before and After Interconnection of Syaure Bhumi MHP

KT / Branch		Losses Before Interconnection (60%)							Losses After Interconnection (60%)						
		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop	From-To Bus Flow		Losses		% Bus Voltage		Vd % Drop
No	ID	MW	MVAR	kW	kVAR	From	To		MW	MVAR	kW	kVAR	From	To	
1	Khahara T1	0.003	0.002	0	0	104	104.5	0.47	0.004	0.002	0	0	103.6	104.3	0.63
2	Line3	0.011	0.004	0	-1.5	104.5	104.5	0.03	0.015	0.006	0	-1.5	104.2	104.3	0.04
3	Amilobote T1	-0.011	-0.006	0	0	104.5	104.1	0.42	-0.015	-0.007	0.1	0.1	104.2	103.7	0.56
4	Line10	0.116	0.056	0.3	-0.8	100.2	100.4	0.23	0.132	0.062	0.4	-0.8	98.9	99.1	0.26
5	Line12	-0.11	-0.055	0.3	-0.8	100.2	100	0.22	-0.123	-0.06	0.3	-0.8	98.9	98.6	0.25
6	T8	-0.006	-0.003	0	0	100.2	99.8	0.45	-0.008	-0.004	0	0.1	98.9	98.3	0.6
7	Line16	-0.098	-0.05	0.2	-0.8	100	99.8	0.2	-0.108	-0.053	0.3	-0.8	98.6	98.4	0.22
8	T10	-0.011	-0.005	0	0.1	100	99.6	0.43	-0.015	-0.007	0.1	0.1	98.6	98	0.58
9	Line18	0.017	0.005	0	-1.4	102.9	102.9	0.05	0.023	0.007	0	-1.4	102.2	102.2	0.06
10	Line21	-0.011	-0.006	0	-1.4	102.9	102.8	0.03	-0.015	-0.007	0	-1.4	102.2	102.1	0.04
11	Line23	-0.006	-0.003	0	-1	102.9	102.9	0.01	-0.008	-0.004	0	-0.9	102.2	102.1	0.02
12	Mahadev T1	-0.011	-0.006	0	0.1	102.8	102.4	0.43	-0.015	-0.007	0.1	0.1	102.1	101.5	0.57
13	Line36								0.023	0.017	0	0	98.4	98.4	0
14	Line38	-0.098	-0.051	0.2	-0.8	99.8	99.6	0.2	-0.13	-0.071	0.4	-0.8	98.4	98.1	0.27
15	T13	0.006	0.003	0	0	102.4	102.9	0.44	0.003	0.002	0	0	104.1	104.5	0.47
16	Line27	0.023	0.006	0	-1.9	102.8	102.9	0.09	0.011	0.004	0	-1.5	104.5	104.6	0.03
17	Line28	-0.012	-0.004	0	-1.4	102.8	102.8	0.03	-0.011	-0.006	0	0	104.5	104.1	0.42
18	T16	-0.011	-0.006	0	0.1	102.8	102.4	0.43	0.093	0.039	0.2	-0.9	100.7	100.9	0.18
19	T18	0.006	0.003	0	0	102.3	102.8	0.44	-0.087	-0.038	0.2	-0.9	100.7	100.5	0.17
20	Line31	0.006	0.002	0	-1	102.8	102.8	0.01	-0.006	-0.003	0	0	100.7	100.2	0.45
21	Line33	-0.006	-0.003	0	-1	102.8	102.8	0.01	-0.076	-0.033	0.1	-0.9	100.5	100.4	0.15
22	T20	0.006	0.003	0	0	102.3	102.8	0.44	-0.011	-0.005	0	0.1	100.5	100.1	0.43
23	Line41	0.014	0.007	0	-1.8	99.5	99.6	0.06	0.017	0.005	0	-1.4	103	103.1	0.05
24	Line42	0.084	0.044	1.4	-7.1	98.1	99.6	1.45	-0.011	-0.006	0	-1.4	103	103	0.03
25	Line44	0.003	0.001	0	-0.5	104.5	104.5	0	-0.006	-0.003	0	-1	103	103	0.01
26	Line46	0.023	0.012	0	-1.8	100.3	100.4	0.09	-0.011	-0.006	0	0.1	103	102.6	0.42
27	Line47	0.044	0.024	0.2	-3.6	100.1	100.4	0.36	0.023	0.017	0	0	100.4	100.4	0

KT / Branch		Losses Before Interconnection (60%)							Losses After Interconnection (60%)						
		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop	From-To Bus Flow		Losses		% Bus Voltage		Vd % Drop
No	ID	MW	MVAR	kW	kVAR	From	To		MW	MVAR	kW	kVAR	From	To	
28	Line49	0.017	0.009	0	-1.4	100.4	100.4	0.05	-0.098	-0.051	0.2	-0.8	100.4	100.2	0.2
29	Line1	-0.391	-0.19	0.8	0	104.7	104.5	0.19	0.006	0.003	0	0	102.6	103	0.44
30	Chaughoda T1	0.875	0.498	0.7	9.5	104.7	100	4.71	0.023	0.006	0	-1.9	103	103.1	0.09
31	Line6	-0.367	-0.183	6.2	-0.3	104.5	102.9	1.6	-0.012	-0.004	0	-1.4	103	102.9	0.03
32	Line8	-0.226	-0.117	6.1	-3.3	102.9	100.4	2.48	-0.011	-0.006	0	0.1	103	102.6	0.42
33	SB T1								0.006	0.003	0	0	102.5	102.9	0.44
Sum				**16.6**	**-24**						**14.3**	**-25.1**			