Micro Hydro Interconnected Mini Grids in Nepal: Potential and Pitfalls

(Experience from a pilot Interconnected Mini Grid projects in rural Nepal)

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ABSTRACT

In Nepal, distributed renewable energy technologies such as Micro Hydro Mini Grids[1] (MHMGs), and Solar Home Systems (SHSs) are cost effective alternatives to electrification in many remote areas and currently provide electricity to 15% of the population. Micro hydro is a particularly appropriate alternative source for rural electrification in Nepal, as it possesses suitable terrain and water resources, and human resources and institutions with appropriate experience to support such projects. Interconnection of existing MHMGs is currently of interest, as it has the potential to further enhance the reliability, quality, and availability of supplied electricity, and the utilisation of these schemes. This paper disseminates experiences from Urja Upatyaka, where an interconnected mini grid connecting six MHMGs was developed as a pilot project in western Nepal; as well as insights from a number of other such interconnected grids at different stages of development in Nepal. Development costs for the pilot project proved relatively high, and such projects will therefore only be commercially viable if the project cost can be reduced, or if significant increases in electricity consumption and hence revenue result from the development of the interconnected mini grid. Nevertheless, assessment of the pilot project, as well as feasibility studies from the other projects reveal that these have already delivered many direct benefits, as well as providing lessons which will facilitate further development of interconnected mini grids. This paper identifies some of the key benefits of Micro Hydro Interconnected Mini Grids[2] (MHIMGs), and factors that can contribute to their successful deployment and operation.

Keywords: Micro Hydro Mini Grid, Interconnected Mini Grid, Rural Electrification

1. Introduction

Energy services play a key role in meeting basic needs and enabling productive activities. Access to affordable, reliable, sustainable and modern energy to deliver these services is therefore seen as an essential requirement for meeting sustainable development goals (UNSD, 2015). This is an urgent need, as an estimated 1.1 billion people in the world, mostly residing in rural areas, do not currently have access to electricity (UNSD, 2015). In Nepal, only around 74% of the population have electricity access, and in rural areas, where the country's poorest mostly live, access is lower still at around 70% (CBS, 2012). In Nepal the most common means of rural electrification include extension of central grid and the use of distributed renewable energy technologies including Solar Home Systems (SHSs) and Micro Hydro Mini Grids (MHMGs), depending on the available resources, distance from the grid, dispersion of the population and size of demand. Improving energy access in Nepal is being pursued via grid extension by the state owned utility, the Nepal Electricity Authority (NEA),

[1] Micro Hydro Mini Grid is defined as a local grid that supplies electricity generated from a Hydro power plant with capacity less than 100 kW

[2] Micro Hydro Interconnected Mini Grid is a local grid formed after interconnection of more than one Micro Hydro Mini Grid

and via smaller distributed off-grid renewable energy technologies, administered through the Alternative Energy Promotion Centre (AEPC).

Both approaches have their respective advantages and limitations. Under current tariff arrangements, grid extension can provide electricity supply at a lower cost to consumers than alternatives, provided that adequate generation and network capacity is available to supply the area. However, the actual cost of grid extension into these remote areas can be prohibitive due to difficult geographical features and sparsely populated settlements, resulting in low returns on investment for the utility. In addition, even in dense urban areas of Nepal's cities, the grid is unreliable, with load shedding of 14 hours in the dry season due to inadequate generation capacity. This is, of course, typical of many utilities in the developing world given the challenges they face (Bhattacharyya and Palit, 2014). The unfortunate reality is that many rural and remote locations in Nepal are very unlikely to gain access to the central grid in the short to medium term, so alternative options should be explored to expedite electricity access in rural areas. Distributed renewable energy technologies such as MHMGs and SHSs have been used as a more cost effective alternative to grid extension for the past five decades, and currently provide electricity to around 15% of Nepalese households (Dhital, 2015). SHSs are modular and robust solutions in deployment, and have been largely successful in basic service provision. However, they are fundamentally limited in application and are insufficient to operate larger household or commercial loads. So while certainly making lives better, they are not sufficient to drive necessary rural economic growth (Bhattacharyya, 2012).

MHMG technology is particularly appropriate for rural electrification in Nepal, due to suitable terrain and water resources and cost effectiveness. In addition, MHMGs can provide significant levels of reliable and high quality electricity if designed and operated properly. Nepal has already made significant progress in terms of developing the technology, policy, institutions, and organisational and management capacity required for MHMGs since their initial deployment in the early 1960s. As a result more than 400,000 rural households in Nepal are provided with electricity through MHMGs (World Bank, 2015). Typically these schemes are community owned, and supply a relatively small region through a local network.

While MHMGs have certainly proven a suitable option for many parts of rural Nepal, there are some limitations of MHMGs including, often, low Capacity Factor (CF), poor reliability during maintenance, and limitations on operation of larger commercial loads. A potential solution that can overcome some of the limitations of individual MHMGs is the formation of a local grid by interconnecting multiple MHMGs in an area.

Interconnection of Renewable Energy Technologies (RETs) to form a larger local grid is not a new practice in other countries and the literature indicates that this can have many potential benefits, including improved electricity service, lower operating costs, and enhanced reliability of the electricity supply (Chmiel and Bhattacharyya, 2015, Hazelton, *et al.*, 2014, Mohammed, *et al.*, 2014). AEPC has already developed two pilot MHIMG projects in Nepal, and additional projects are in different stages of development. This paper presents a study undertaken to assess the potential benefits and challenges of MHIMG, and key factors for improving their viability. This assessment is based on a detailed review of outcomes for a pilot MHIMG in Nepal and analysis of feasibility studies carried out for a number of other projects currently under development.

The remainder of this paper is organised as follows. Section 2 provides more detail on the particular opportunity offered by MHIMG in Nepal, relevant MHIMG activities and the specific research questions addressed in this paper. The study methodology is described in Section 3. A detailed case study of the Urja Upatyaka MHIMG in Nepal provided in Section

4 and key benefits of MHIMG are presented in Section 5. An analysis of feasibility studies to identify the key factors that affect the financial viability of MHIMG projects is presented in Section 6, followed by discussion and conclusions in the final Section.

2. Opportunities for Micro Hydro Interconnected Mini Grids in Nepal

While MHMGs have been a successful rural electrification option in Nepal due to their robustness and often being the least cost option (World Bank, 2015), there are some issues that have recently limited their success. Firstly, the current demand estimation method for MHMG has been influenced by a Government subsidy policy that was based initially on an 'allowance' of 100W per household, mostly focussing on meeting their lighting load. While this allowance has now been increased to 200W per household (World Bank, 2015), there is still a lack of detailed demand or energy service assessment during the feasibility study phase. Since future load growth depends on a range of factors such as income level, population growth, emerging market and road access, it is not uniform throughout Nepal's rural areas (Gautam, 2015). The lack of detailed energy needs assessment, has led to inadequate planning, and has created the problem of both underutilisation and overutilization of MHMGs in different particular contexts. Underutilisation, particularly during off peak times, has resulted in an average CF of around 20% for some MHMGs, and as a result, many of these plants have difficulties generating revenue to meet even their operating costs (Shakya, 2012). Conversely, many other MHMGs are struggling to meet the growing electricity requirements in rural areas where population and income levels are growing rapidly. If MHMGs are interconnected to allow the transfer of spilt energy from one area to another, more productive uses can be supplied while the increase in overall CF can also improve overall system economics (AEPC-RERL, 2012).

Furthermore, due to the present lack of coordinated rural electrification planning between the two responsible organisations, the AEPC and NEA, another emerging issue is encroachment by the central grid into areas served by community-owned MHMGs. This has resulted in divisions within the community between people who want grid electricity and those who want to keep the MHMGs in operation (Baral, *et al.*, 2012). According to the AEPC, the central grid has already encroached on around 11% of the established MHMG catchment area and about 27% more will be affected within a few years (AEPC-RERL, 2012). The NEA has followed a practice of not interconnecting hydropower plants of less than 100 kW to its system, as it considers management of such plants cumbersome and their technical standards inadequate (AEPC-RERL, 2012). As a consequence, MHMGs have been purchased and shut down by the NEA when the grid is extended to areas they have been serving. The AEPC and the Renewable Energy for Rural Livelihoods (RERL) Programme have recently successfully lobbied the NEA to interconnect MHMGs to the central grid if it is financially viable, but this commitment is yet to be realised in practice.

It has been recognised that the interconnection of MHMGs to form larger MHIMGs can help to overcome some of the challenges faced by MHMG, including enhancing reliability and utilisation of off peak electricity to improve the financial viability of MHMGs. Consequently, AEPC has started promoting MHIMGs. Two pilot MHIMGs have been installed, one in Baglung and another in Gulmi. One MHIMG in Taplejung is in the implementation stage, and detailed feasibility studies have been completed by AEPC for a further six potential MHIMG projects (Gautam, 2015).

The World Bank recently published a report presenting an analysis of AEPCs feasibility studies from the six potential MHIMGs, highlighting that while these MHIMGs could generate enough revenue to meet their operating cost, they would not generate a net profit. The report suggested that more projects need to be assessed to better establish the technical and financial potential of MHIMGs (World Bank, 2015). AEPC is now in the process of assessing the findings from their pilot projects in order to set its future policy on MHIMGs (Gautam, 2015).

Existing studies on MHIMGs in Nepal provide project and technical descriptions, and describe some of the benefits and issues encountered (Baral, et al., 2012, Koirala, *et al.*, 2013, Pokharel, 2103). However, these studies do not comprehensively explore the driving factors behind the success or failure of MHIMGs. This paper draws on experiences from MHIMGs during different stages of project development, and seeks to contribute to a better understanding of the factors that impact on the financial viability and overall benefits of MHIMGs.

3. **Methodology**

A case study on the development of, and experiences with, Urja Upatyaka MHIMG is provided in this paper, based on the lead author’s field experiences and discussion with community members during the construction and monitoring of the project from 2010 to 2014, when working for the Renewable Energy for Rural Livelihood (RERL) Programme. Survey data collected before the installation of the Urja Upatyaka MHIMG (Pandey, 2010) and post data collected for the project techno-socio-economic report for AEPC (ECoCoDE, 2013) were also analysed. The case study provides insights into the process of developing a MHIMG, highlights some of the benefits and challenges, and provides a basis for a broader survey of a number of MHIMG projects at various stages, from feasibility to operation. A range of articles reports related to rural electrification using MHMGs and MHIMGs were reviewed, including the above mentioned World Bank study on “Scaling up electricity access in Nepal” (World Bank, 2015), which assessed AEPC feasibility reports from six MHIMGs. Detailed feasibility reports from two MHIMGs, one in Baglung (Mega Power, 2014) and another in Taplejung (ME Solutions, 2014), were also analysed along with a report from one additional completed MHIMG in Gulmi (IMIREN, 2013). The locations of the MHIMG projects reviewed are shown in Figure 1.

Figure1. Location of nine MHIMG projects assessed for this study (Maps of World, 2014)

4. **Case Study: Urja Upatyaka MHIMG**

The Urja Upatyaka MHIMG project in Baglung connects six existing MHMGs. This project was developed as a pilot project and commissioned in 2012, with the support of the United Nations Development Programme (UNDP)/RERL programme, and with active involvement from the Community. Eight km of 11kV network was used to interconnect the existing systems. The capacity of the micro hydro generators ranges from 9 to 26 kW, with total generation capacity of 107 kW. All of these are fed by the river Kalung Khola. Urja Upatyaka MHIMG provides electricity to 1200 Households (HHs). A control system synchronises individual MHMGs, allowing them operate in parallel (Pokharel, 2103). Previously three of the MHMGs could not meet peak demand in their areas, and the other three had excess generation capacity. The connection of the six MHPs allowed for sharing of generation, ensuring the peak demand of all MHMGs could be met (Pandey, 2010).

The central grid has already been extended near to the area, which posed a threat to the MHMGs as consumers moving to the central grid reduce the income to the community-owned MHMG. As the MHMGs were all less than 100 kW, there was a risk of abandonment of the MHMG infrastructure before its economic life if the villages were interconnected to the central grid, resulting in wastage of resources and efforts from the community as well as Government. In addition to increasing generation capacity, interconnecting the six MHMGs has achieved increased power quality and reliability (ECoCoDE, 2013), by balancing the surplus electricity of one or more MHMGs with others in deficit. Additional positive impacts include a doubling of the MHMGs net capacity factor, an increase in total income for the MHMGs, the potential to supply larger commercial loads, and changes in the outlook of the community towards electricity use (ECoCoDE, 2013, Shakya, 2012).

A cooperative was formed as a new entity responsible for electricity dispatch, transmission and distribution of the Urja Upatyaka MHIMG. The management structure of the cooperative is based on an Individual Power Producer (IPP) model. In this model all six MHMGs act as an IPP and sell their generated electricity to the cooperative. The cooperative then distributes the electricity to the loads within the MHIMG. The cooperative purchases electricity from the IPPs at 4.5 US cents/kWh and sells it at 7 US cent/kWh and upwards (ECoCoDE, 2013).

In addition to the benefits for consumers, due to the increased reliability and power quality the MHIMG will be more likely to be considered for connection to the central grid by the NEA, which would allow retention of the community-owned infrastructure and income from selling surplus electricity, either within the interconnected MHMGs, or to the national grid (Shakya, 2012).

However, some technical, institutional and financial issues need to be addressed, in order to foster the new technology. Institutional strengthening and capacity building of the communities involved is required. There are also more challenging private sector needs, such as provision of people qualified to provide services for MHMGs, including designing these systems, installing them, and providing after sales service (ECoCoDE, 2013, Shakya, 2012). The project development cost also proved relatively high, and such projects will therefore only be viable if the project cost can be reduced or significant increases in electricity consumption and hence revenue result from the development of the MHIMG (Shakya, 2012).

5. Benefits of MHIMGs

The successful operation of the pilot project Urja Upatyaka MHIMG has created considerable interest. In response, AEPC have already developed one more pilot MHIMG project, and additional projects are in different stages of development.

Several papers have highlighted benefits of MHIMGs in the literature, including Pandey (Pandey, 2010), Shakya (Shakya, 2012), ECoCoDE (ECoCoDE, 2013), Pokharel (Pokharel, 2103) and World Bank (World Bank, 2015). These benefits are summarised in Table 1, grouped into technical, financial and social categories.

Table 1: Summary of Benefits after MHIMG

Technical	Financial	Social
• Reliability, quality and availability of electricity enhanced • Capacity factor increased • Overall safety and safety to operator during operation enhanced • Possibilities to operate large load • Facilitates interconnection with central grid • Operational performance of Micro Hydro generators and commercial equipment increased • MHMG's operator's capacity enhanced • Computer education, internet service became possible	• Increase in income of Individual MHMGs • Increase in income of entrepreneurs due to availability of electricity • Increase in number of commercial loads • New job creation	• Community perspective towards electricity use changed • Community confidence increased through operation of complex system • Increased ownership of electrical appliances • Unite the community

Source: Summarised from (Pandey, 2010), AEPC/ RERL conference proceedings (Shakya, 2012), Techno-socio-economic study of Urja Upatyaka MHIMG (ECoCoDE, 2013), Comprehensive study of Mini Grid (Pokharel, 2103), World Bank report (World Bank, 2015)

Through the survey of MHIMGs projects for this paper, potential benefits have been identified by the author which are additional to those found in the literature, including:

- Partial scalability: MHIMGs can be expanded to include more MHMGs if demand grows. For example, the Urja Upatyaka MHIMG is planning to add a new 40 kW micro hydro generator to meet peak demand. In addition, Tikhedhunga and Chhomrong are also interested to install new micro hydro generators and connect into the MHIMG to meet peak demand.
- Infrastructure for grid extension: The high voltage and low voltage network developed to form a local grid for a MHIMG can be a useful transition to national grid extension. There are many examples of mini grid extension into a local grid and later interconnection to the central grid in India and China (Bhattacharyya and Ohiare, 2012, MEC Consultancy, 2007).
- Reduction in wear and tear of the MHMG: In a single generator mini grid, the generator must run at all times to meet the load. Reduced generator runtime can be achieved in MHIMG systems, especially in the off peak period, protecting the plants from additional wear and tear.
- Potential to increase electricity access: MHIMG could provide surplus electricity to nearby non-electrified areas. For instance, Taplejung MHIMG aims to supply electricity to nearby Phungling Bazar, where a diesel generator is currently in operation.

6. Factors influencing the success of MHIMGs

According to the World Bank, the viability of MHIMGs depends primarily on (World Bank, 2015):

1. Distance between individual MHMGs, and
2. Market for excess energy

While a number of other factors that are of general importance for rural service delivery, such as existing infrastructure and the community's purchasing capacity are also identified as important by the World Bank, this paper focuses on the factors that are of specific importance to MHIMGs. From the analysis of the MHIMG projects listed in Table 2, a number of other important factors have been identified, including:

3. Potential for inter-system power transfer

4. Integrated Planning Approach
5. Distance from Central Grid
6. Community Engagement
7. Favourable Support Policy
8. Capacity Assessment

The reminder of this section discusses each of these factors. First, in order to discuss the importance of factors 1-4, Table 2 lays out the relevant information from nine MHIMG systems assessed for this study. In Table 2, the peak period excess power is the minimum surplus capacity available between 17.00 and 22.00 from the average daily load curve. The off peak period excess capacity is the maximum surplus power available from 9.00 to 17.00. Incremental capacity factor (CF) is the percentage increase in CF after interconnection. To estimate incremental CF of Gulmi and Taplejung MHIMG, it is assumed that 75% of surplus off peak energy will be consumed in productive end use and 100% of peak period available surplus energy will be consumed after interconnection (rest were taken from feasibility report of Individual MHIMG and the World Bank report). Incremental energy is the estimated increase in energy consumption after interconnection. It is calculated multiplying the capacity of the MHIMG by the incremental CF. These quantities are estimated for all MHIMGs, except for the existing MHIMG system at Urja Upatyaka, where they are based on measured data.

Table 2: Summary of different factors affecting MHIMG

Name of the MHIMG, Location	Number-Capacity kW	Distances between MHMGs, km	Excess power, kW		Estimated total project Cost, USD	Increment of Capacity Factor (CF) %	Incremental Energy MHIMG (kWh)
			Peak Period	Off peak Period			
1. Urja Upatyaka, Baglung[P]	6 MHPs-107 kW-	7.7	10 (3 MHMGs in deficit)	70	150,295.00	17	159,300
2. Gulmi, Gulmi[P]	2 MHP-217kW	1.5	35 (1 MHMG in deficit)	100	128,000.00	15	285,100
3. Taplejung, Taplejung[I*]	8MHPs-660kW (12 MHPs-569kW)	43 (65)*	492** kW (229 kW)	600 (400)	570,000.00 (1,307,000.00)	32	1,850,100
4. Gaudi khola, Baglung	6 MHPs-104 kW	4.5	21 (4 MHMGs in deficit)	91	225,400.00	25	227,800
5. Bongadovan, Baglung	10MHPs-416 kW (8 MHPs-344 kW)	18	159 (2 MHIMG in deficit)	300	477,900.00	45	1,639,900
6. Girindikhola MHIMG, Baglung	8 MHPs-267 kW	12	119 (4 MHMGs in deficit)	220	443,700.00	13	304,000
7. Tikhedhunga, Kaski	2 MHPs-80 kW	0.04	1 (1 MHMG in deficit)	33	57,600.00	12	84,000
8. Ghandruk, Kaski	4 MHPs-161 kW	3.5	13 (1 MHMG in deficit)	76	153,500.00	9	126,900
9. Chhomrong, Kaski	3 MHPs-67 kW	0.60	0 (3 MHMGs in deficit)	26	80,200.00	8	46,900

(Source: Extracted from feasibility report of individual MHIMG and from the World Bank report(World Bank, 2015), AEPC/ RERL proceeding (Shakya, 2012), Ms R. Pandey MSc. Thesis (Pandey, 2010))

[P]Pilot Project already installed

[I]Project currently in implementation phase

*In Taplejung, a second feasibility study was carried out due to high estimated project cost. The figure in brackets represents the design from the first feasibility study

** including two new MHMGs of 90 kW in installation stage and 244 kW in planning stage

1. *Distance between individual MHMGs*

The distance between MHMGs is a crucial factor, as it is a significant component of the cost of the infrastructure. For instance, in Urja Upatyaka MHIMG the 7.7 km transmission cost comprised around 35% of total project cost. The distance also impacts technical design and performance factors, including transmission voltage (resulting in higher costs where high voltage transmission is required) (AHEC, 2011). It can be seen in Table 2 that for five out of the nine projects reviewed, the end to end distance between MHMGs is less than five km. In the Bongadovan and Taplejung projects, which join MHMGs that are more than 10 km apart, there are plans to sell excess electricity not only within the schemes themselves but also to nearby markets in order to increase the financial feasibility of the project.

2. *Market for excess energy*

Low utilisation of energy from MHMGs harms their financial viability. The World Bank (2015) found that five out of six MHIMGs reviewed could generate sufficient profit to meet operation costs but when depreciation and capital costs (20% of the total) were taken into account, none of the six projects were financially viable. In Table 2, it can be seen that almost all of the pre-existing MHMGs in this study had excess capacity available during the low demand period. The interconnection of Bongadovan and Taplejung MHIMG will allow these MHIMGs to sell excess electricity to the nearby market centres to increase their CF significantly above the other MHIMGs and enhance financial returns. The presence of larger energy consumers such as commercial loads or a nearby market centre that consume off peak electricity can be crucial factors for the viability of a MHIMG (World Bank, 2015). The increased viability of projects with possibilities of higher electricity consumption and hence sales may also increase attractiveness to private sector investment in the project.

Although the average capacity of MHMG plants in Nepal has increased up to around 30 kW (World Bank, 2015), generators of this size can still be inadequate for the reliable operation of larger commercial loads, particularly those that require a large in-rush current during motor starts. The operation of such commercial loads can be made possible by interconnecting MHMGs. This experience at Urja Upatyaka MHIMG highlighted the opportunity to run a stone crusher that demands 40 kW, which was not possible to supply without interconnection (ECoCoDE, 2013). In addition, access to the road network or other infrastructure and growing purchasing capacity within communities also creates a market for excess energy.

3. *Potential for inter-system power transfer*

Depending on the location and economic conditions, some MHMGs have difficulty meeting peak demand, whereas others have spare power, even during the peak demand period. From Table 2, it can be seen that the peak demand period excess capacity varied from 0-492 kW across the MHMGs. Potential for inter-system power transfer is perhaps the major reason for the development of MHIMGs, as electricity can be transferred from an under loaded MHMG to an overloaded MHMG. In Urja Upatyaka, Gulmi, Gaudi Khola, Girindi Khola and Ghandruk MHIMG, prior to interconnection, some of the existing MHMGs were in deficit during higher demand periods, while others had spare power to share. Tikhedhunga and Chhomrong, however, were almost at peak capacity with no power for sharing during high demand period. As well as improving the ability to serve peak demand, interconnection improves the CF of the interconnected system in comparison to the weighted average CF of individual MHMGs (World Bank, 2015), and therefore ensures better financial viability of the project. Prior to development of a MHIMG, there should be an assessment of demand and supply whether the surplus electricity can be consumed in overloaded MHMGs area or not. On the other hand, whether the surplus electricity is enough to meet the demand of overloaded MHMG or not is also need to be assessed for viability of the MHIMG. In addition, the age and condition of MHMGs also play a major role in determining whether they can supply electricity for the economic life of a MHIMG.

4. *Integrated Planning Approach*

An integrated planning approach taking into account other possible MHMGs and existing infrastructure during the planning phase will have significant impacts on the long term outcomes as well as financial benefits of MHIMG. In the Taplejung MHIMG project, consideration of appropriate MHMGs which could contribute significant energy during peak and off peak times, the shortest possible routes between individual MHMGs, utilisation of an existing 11 kV network in some MHMGs and consideration of other potential MHMGs, already present or under construction, resulted in a carefully crafted development proposal. In the initial detailed feasibility study, 12 MHMGs were considered with a peak power surplus capacity of 229 kW, off peak surplus power of 600 kW, and 65 km of 11 kV network was proposed, with a proposed total cost of USD 1.3 million (CED, 2014). In a revised study, interconnection of 8 MHMGs was proposed, including two new MHMG which are being installed and planned respectively, resulting in 492 kW surplus power in peak hour and only 43 km of 11 kV transmission network rather than 65 km (ME Solutions, 2014). In addition, out of 43 km only 17 km of this was new 11 kV network, as the proposal utilised 26 km of existing 11 kV network to reduce the cost by more than half i.e. US$577,000 (ME Solutions, 2014) . This highlights the value of better integrated planning processes.

5. *Distance from Central Grid*

Central grid extension to areas near to MHMG distribution areas can present a threat as well as opportunity to the MHMG. In this situation, consumers usually opt to be connected to the central grid where possible, resulting in division of consumers moved to the central grid and those remaining on the MHMG. This threatens the economic status of the MHMG, which is usually community owned. MHIMGs may be better placed to successfully integrate into the central grid than standalone MHMGs because of the larger ‘aggregated’ scale that they provide in terms of technical and institutional management of the distributed generators. The central grid can act as effective storage for the MHIMG, to provide the required electricity during peak demand periods and consume the surplus electricity from MHIMG during off peak demand periods, improving the ability to meet peak loads without excess generation capacity. The central grid has extended very near to Urja Upatyaka and Gaudikhola MHIMGs, and one of their main reasons to develop MHIMGs in those cases was to enable connection to the central grid.

6. *Community Involvement*

Community willingness and commitment is another crucial factor to ensure the sustainability of MHIMGs. In Nepal almost all MHMGs, as well as Urja Upatyaka MHIMG are owned by the community, so further development is impossible without community willingness, and clear benefit to the community must therefore be demonstrated. Typical benefits sought include access to more reliable electricity and financial benefit from selling excess electricity. The community contributed 1% of the cost of total project in local material and labour during construction in Urja Upatyaka MHIMG. The local contribution results in enhanced community buy-in towards the project, which improves sustainability outcomes. It also represents a secure capital investment for the community.

7. Favourable support policy

Favourable policy for utilisation of renewable energy and sustainability has been a major driver for the promotion of MHIMGs. AEPC is trying to harness the maximum benefit of innovation in the renewable energy sector, which is why pilot studies on MHIMGs are being carried out. Without favourable policy, the development of MHIMGs would not currently be possible as significant investment and intensive technical support is required to implement these projects. In the pilot projects, the significant investment is covered by subsidy. Of course, grid extension to remote communities is also effectively subsidised by the utility and hence government.

8. Capacity assessment

Local capacity to provide service during design, construction and operation as well as equipment supply plays major role in minimising costs, as well as successful operation of the MHIMG. In Urja Upatyaka MHIMG, an international supplier delayed the installation of the project, putting it at risk. Without local after sales service, service times can be extremely long, affecting the reliability of the system. In addition capacity development of the operator and cooperative plays major roles as the successes depend on their effectiveness.

7. Discussion and Conclusions

There is a growing interest in interconnecting MHMG systems in Nepal to overcome limitations such as low capacity factor, poor reliability and inability to serve larger commercial loads. This paper reviews a range of published work, and draws on the author's field experience to identify the potential benefits of MHIMG systems, and the factors that most influence the financial viability of MHIMGs.

MHIMG can certainly have positive impacts, as outlined in Section 5. Having said that, a number of issues with MHIMG have been identified in the relevant literature. Some of the major issues include the limited benefit of MHIMG over MHMG, the potentially high costs of construction, system complexity in terms of technology and management, and lack of skilled labour to operate the system (ECoCoDE, 2013, Shakya, 2012, World Bank, 2015).

The World Bank (2015) assessed potential options for scaling up of rural electrification in Nepal (World Bank, 2015), including MHIMG. The report recommended that the MHMG should be one of the more favored options considered for rural electrification. It further advised that NEA has agreed to interconnect MHMGs of less than 100 kW with potential impacts, good and bad, on the potential scope of MHIMG deployment. The report also recommended that when designing an MHIMG, a singular larger MHMG is more appropriate than a MHIMG with same capacity established via interconnection of number of smaller MHMGs.

Due to its cost effectiveness, the availability of service providers to design, install and operate MHMGs and the predictability of hydro resources, MHMGs are one of the most appropriate sources of electrification. In addition, NEA's decision to connect MHMGs to the central grid is encouraging for MHMGs located close to the central grid.

For cases where a collection of MHMGs are located too far from the central grid to be considered for connection, and when combining the generation of individual MHMGs would result in better overall power reliability for a planned MHIMG, interconnecting the MHMGs to create an MHIMG is appropriate.

The potential success of an MHIMG is site specific. Its success depends on a number of factors, including distances between MHMGs, possibilities to inter system energy transfers between MH schemes during high and low demand periods, community involvement, integrated planning approaches for capital and operational cost reduction, and methods for maximising operating revenue, such as identifying potential market ensure the success of MHIMG.

At this time, two MHIMGs are in operation. However, impact studies have largely focussed only on Urja Upatyaka MHIMG and it is likely still too early to draw firm conclusions. Further experience and analysis will be required to assess whether interconnected MHMGs are an appropriate solution to be used at scale to overcome the limitations faced by the large numbers of isolated MHMGs in Nepal.

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