A STUDY FOR THE IMPLEMENTATION OF MICROGRIDS AND A CASE STUDY OF BIHAR

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Introduction

Electricity has long been considered one of the fundamental requirements for an improved standard of living, economic development and social enterprise. The absence of electricity affects basic needs such as cooking, access to clean water, proper sanitation and causes daylight limited working hours which impacts health and productivity, a very important consideration for a community heavily dependent on subsistence agriculture. Typical substitute energy sources used are diesel, wood and kerosene. These solutions for lighting and heating are not only costly but have an adverse effect on health and the environment when burnt.

This report reviews the extent to which these fuels are still used and considers other available options presented by current technology. With countries such as China and India quickly entering developed status, determining new and more sustainable methods of electrification becomes important before inefficient and unsustainable networks are implemented. This report focuses on electrifying communities where connecting to an electrical grid is difficult, of which there are three acknowledged methods: actual extension of the existing transmission and distribution network; individual purchase and installation of photovoltaic (PV) systems to generate personal electricity; and the implementation of a microgrid.

Microgrids offer a promising solution to total electrification. They are very flexible to the use of renewable energy sources and will also cater to small load factors, two key characteristics for sustainable electrification of remote communities. Several cases of successful microgrid implementation can be found in both developed and developing nations. Learning from these past case studies this report will analyse and propose a method of sustainable microgrid implementation for rural communities in Bihar, India where only 20% [1] of rural villages have been electrified.

Learning from Past Case Studies

To further understand the challenge of electrification of remote communities several past solutions have been studied. These have, in general, involved the deployment of small scale diesel generators which can supply energy to any community. However, diesel is not normally readily available and as such must be imported at high costs. For this reason, the continued use of diesel generators is not a viable long term solution and instead an alternative should be considered.

Renewable energy sources happen to be the most prominent solutions. These sources require no extra fuel costs and can be easily scaled to a community's individual needs, making them very attractive alternatives. Some of the most informative case studies found are reported below.

Fair Isle, Scotland

Fair Isle is one of the most remote islands in the UK and as such is not connected to the main UK transmission system. Prior to 1982 [2] electricity was supplied by two diesel generators which provided electricity only for a limited number of hours in the day. In addition, as with many cases, the cost to buy and import diesel became far too steep for Fair Isle to maintain its electricity supply at minimal cost; therefore, alternative energy sources were studied.

Wave, wind and hydroelectric power were all considered to support the island's diesel system. After testing, it was concluded wind was the only viable alternative due to average wind speeds of over $9ms^{-1}$ [3] (above the UK's average [4]). In 1982 the first wind turbine (rated at 60kW) was installed and a second turbine (rated at 100kW) was added in 1996.

Currently, Fair Isle's microgrid consists of the two wind turbines with additional support from the preinstalled diesel generators for back-up. A double network system is used to allow greater control over the energy consumption and distribution within the island. The two separate networks are services and heating; where the heating load is always regarded as second to the services load. Thus, if wind strength diminishes the heating load will be forced to reduce as to maintain the integrity of the electricity supply to the primary services load.

The Fair Isle example demonstrates how successful renewable energy sources implemented into a microgrid can be. The use of a microgrid has allowed the island to successfully electrify significantly earlier than connecting to the main UK transmission grid. Furthermore, the implementation of the renewable energy sources has helped reduce the cost of electricity, funds spent on fuel and CO_2 emissions. The overall result of this microgrid is a sustainable electricity supply for the future.

Ontario, Canada

Canada's population is very low for a country of its size. The majority of Canadians live in close proximity to the southern border, where the climate is milder. However, there are a very large number of communities across the rest of the country, many of which are too small or too far apart to viably connect to an electrical grid.

An example can be found in northern Ontario where many communities are reliant on diesel generators. It has been established through mathematical modelling and analysis that microgrids using renewable energy sources, if planned and built correctly, can significantly reduce costs in comparison to a diesel-only set-up in addition to reducing CO_2 emissions [5]. Implementation of a carefully planned wind-diesel microgrid reduces the lifetime costs of the entire system due to lower operating costs caused through decreased diesel consumption.

Although not an inexpensive method of electricity generation, diesel generators are, for many communities, the only method by which they can maintain electricity supplies, despite having access to other natural and free energy sources. As diesel prices continue to rise [6][7] and import costs face increased uncertainty, it becomes essential to start thinking where and how renewable technologies can be integrated into the remote communities found in every country of the world.

Evaluating Renewable Energy Sources in Bihar

The state of Bihar is a landlocked region of northern India. Mainly constituted of plains, the Ganges River and its tributaries, the state is abundant in fertile farming land, resulting in an economy relying on agriculture. Rainfall, averaging at 1205 mm/year [8], frequently leads to flooding; [9] therefore, construction (and power system) designs must be adapted. Temperature variance is extreme in Bihar: summers can heat up to 45°C while winters can [10] cool down to as low as 5°C [11]. The geographical position of Bihar means the area is exposed to little wind; wind speeds rarely exceed 4 m/s^{-1} [12]. Using these characteristics, consideration of the appropriate sources of energy for Bihar can occur.

The potentially successful implementation of microgrids in Bihar can be considered partially due to recent technological developments increasing the exploitation of renewable sources of energy. Most renewable sources of energy can be harnessed at the local level (e.g. by small-size generators), and thus are easy to integrate to a microgrid. By exploiting Bihar's natural resources there may be no requirement to import fuel to the generator location, which is a huge advantage over traditional fossil fuel generators. However, renewable generators must be deployed strategically through Bihar to maximise efficiency. As demonstrated in Fair Isle, the decision on what combination of renewable energy sources to use must consider weather conditions in addition to cost and available space.

Solar Power

Light can be converted into electricity using photovoltaic cells. The electricity generated by these cells is DC, meaning an inverter is required to convert the supply to AC, as most appliances will be unable to run off DC electricity.

PV cells are robust, with an average lifespan of 25 years, require little maintenance and can be deployed at the household level; consequently, they may be ideal for microgrids. However, they have a very low efficiency typically ranging from 10-15% [13] and are still relatively expensive compared to fossil based plants, with production costs ranging from Rs[1] 15-30 per unit compared to thermal energy costs of around Rs 2-6 per unit [14]. Despite this, PV cells still offer a viable alternative to traditional fossil fuels in Bihar because of its high insolation, which averages to

[1] Indian Rupees

5.22 kWh/m^2 per day, even inefficient cells can harvest large amounts of power. Furthermore, in 2009 the government launched the National Solar Mission [15] to promote the development of PV across the country, using incentives to encourage investment in PV cells.

Wind Power

Energy can also be harvested from the wind, and India is one of the leading nations in wind power development. Ambitious plans to increase India's wind power production capacity are under way [16]. Wind turbines range in sizes varying from a few hundred kilowatts to several megawatts. However, they usually generate 20-40% of their theoretical capacity throughout their lifetime (this is known as the capacity factor) [17]. Because Bihar is not exposed to a lot of wind, this capacity factor would be further reduced and thus using wind turbines in Bihar would be highly inefficient. Nevertheless, wind power could be considered for villages in different states such as Tamil Nadu or Karnataka where the average wind speeds are considerably higher.

Micro Hydroelectric Power

Micro hydroelectric generators (MHG) extract mechanical energy from flowing water and then convert it into electricity. MHG are small-scaled generators with a capacity not exceeding 100kW that can be run off-river, avoiding the use of dams and reservoirs, as they only require a small fraction of the available water flow to operate. MHGs do not require fuel and have a very long lifespan, low maintenance costs, a high efficiency and capacity factor. MHG systems therefore seem extremely suited to Bihar, with its many streams and rivers sourced all year long from the Himalayas.

Biomass Power

Another alternative way to generate electricity is to exploit biomass: the carbonaceous waste resulting from human activities and natural processes. Biomass uses the same technology as fossil fuels to generate electricity and hence may be easier to adapt to; the technology is already widely available and thus cheaper. As biomass can be produced from domestic or agricultural waste, remote communities could generate their own fuel, minimising fuel costs. Biomass exploitation is independent of the weather and therefore can more easily be matched to demand. As a result, the generator can be relied upon, which is not the case for dependent sources such as PV and wind turbines. However, the waste has to be processed before being exploited as a fuel by the burners. Thus, some costly installations are necessary.

Bringing Electricity to Bihar

It can be established that demand for electricity in rural areas exist. Studies show that villagers' currently spend about 10% of their monthly income on fuel for cooking and heating purposes [19]. Their willingness to pay for electricity depends on their household income and the availability and reliability of the proposed energy supply. Surveys conducted on poor households across six states of India indicate that the price they are willing to pay ranges Rs 15-20 /kWh, [19] approximately four to five times more than the typical grid price for a reliable electrical connection.

Bihar has only achieved rural village electrification of approximately 20% (6,287 villages electrified) [1]. The region faces many challenges with electrification; it is one of the poorest states in India with a GDP per capita of Rs 6610 [20]. Currently, there are only three power generation plants in Bihar [21] and thus investment has focused on providing enough generation to the electrical grid to meet the current demand.

There are three acknowledged methods of bringing electricity to villages in inaccessible areas:

1) Extending the existing transmission and distribution network;
2) Individuals purchase and install PV home systems to generate their own electricity;
3) Implementation of a microgrid.

Centralised electricity networks have lower long-run average electricity generation costs. However, for villages, the initial cost of extending the electrical grid is more than the rural population can afford to pay. For any location that receives electricity through a grid, the cost of electricity comprises of the following components [22]: costs of generation of electricity at the centralised plant; cost of transmitting through the transmission network; and costs of distribution.

Generating electricity from a typical Indian coal thermal power plant is estimated to cost Rs 1.71/kWh [22]. High transmission and distribution losses further inflate the cost; Bihar reported 35% transmission and distribution losses for the year 2009 [23]. For a village in more inaccessible, mountainous terrain requiring a grid extension is estimated to cost Rs 0.928/kWh per km whereas, in comparison, a village on flat terrain is estimated to cost Rs 0.756/kWh per km. Furthermore, villages only requiring electricity for domestic lighting in the evenings and daily cooking, have a very small load factor increasing the estimated grid extension cost to Rs 9.928/kWh per km; an amount that makes electricity unaffordable to the population. It is obvious that the distance and load factor are influential in assessing the feasibility of grid extension. Further challenges presented by grid extension are the cost and feasibility of installation, operation and maintenance in more inaccessible areas.

PV modules are available commercially and are relatively easy to install on an individual’s roof. However, the problem with such home systems is that access to electricity within the village is restricted to those who are able to afford them and is hence only used for household consumption. Community services such as clinics and schools may be unable to access this electricity provision without villages voluntarily funding it. Communal access to electricity is very important for alleviating poverty. For example, the installation of irrigation pumps can be directly linked to the financial health of a farming community [24]. As Bihar has one of the lowest GDP per capita in India, the installations of home systems are unlikely to happen.

Microgrids are able to utilise local resources to meet local electricity demand. The installation of a microgrid eliminates the problem of large transmission losses, distribution losses and possibly even electricity theft (in 1999 23.8% of generated electricity was unaccounted for [25]). This will help to further reduce the cost of electricity for the local area. Demand for electricity is less in rural areas than in the cities. As a result, grids tend to expand outward from urban areas, targeting the most densely populated and higher income population, saturating the markets to the well off rural areas first before reaching poorer and more remote parts of the country [26]. Microgrids are proposed for poor rural areas by Bihar’s government to achieve greater rural electrification.

The most viable solution to electrify remote and inaccessible villages is through the use of a custom microgrid, specific to the location. A microgrid will supply electricity to the entire community and thus protect clinics and schools from power cuts. If the system is more cost-effective, supply no longer needs to be limited only to daylight hours. Through the support of Bihar’s government, a viable price plan is likely to be laid out, strengthening the microgrid as economically viable to communities. In the following section, a power system simulation software has been used to simulate the cost of a microgrid in a village in Bihar.

HOMER

The software simulation tool HOMER is used to determine the best microgrid architecture for an isolated community in Bihar. The design uses the following data and estimations:

1) For an average sized village in Bihar the population is 2000 people or 333 households with 6 individuals with 6 individuals per household [27].
2) An estimated load factor in the range of 0.2-0.3 [28].
3) A peak consumption of 675W per household [29] and a services load (school, clinic) appropriate for this village size.
4) The performance and cost of various generators and their associated equipment, including wind turbines, PV cells, batteries, inverters, biomass and diesel generators.
5) The availability of resources in Bihar: diesel, biomass, stream flow and meteorological data of Bihar [12] (using the latitude: 25.61, longitude: 85.128).
6) The capital cost of grid extension estimated to be 8,000-10,000$/km, and the cost of materials for grid extension to be an additional 7,000$/km [30].

7) 1 USD ($) = Rs 45.60 (Feb 2011) [31] [2].

In the simulations, wind, solar, hydro and biomass were considered as the main sources of energy, in addition to the potential use of batteries and a diesel generator to ensure electricity supply to essential loads is maintained at all times. Figure 1 summarises the results from HOMER, and highlights the best solutions.

The Results

System Architecture	Net Present Cost* ($)	Cost of Energy ($/kWh)	Operating Cost ($/year)	Excess Electricity (%)	Distribution of Power Generation	Breakeven Grid Extension Distance (km)	DG operation (hrs/yr)
1) 100kW MHG, 25kW Diesel and 200kW Biomass Generators	**406,362**	**0.057**	**21,486**	25.4	**MHG: 74%** **DG: 1%** **BMG: 25%**	**-3.18**	789
2) 100kW MHG, 25kW Diesel and 200kW Biomass Generators	559,995	0.078	33,503	13.5	MHG: 58% DG: 3% BMG: 40%	1.98	1929
3) 50kW MHG, 25kW Diesel and 200kW Biomass Generators	895,614	0.125	60,540	**8.89**	MHG: 30% DG: 9% BMG: 61%	13.2	4537
4) 50kW Diesel and 200kW Biomass Generators	1,135,521	0.159	79,698	21.2	DG: 1% BMG: 99%	21.3	315
5) 30kW Wind Turbine, Diesel 50kW and Biomass 200kW Generators	1,196,205	0.167	82,450	22.3	DG: 1% BMG: 97% WT: 2%	23.3	302
6) PV Array 25kW, Converter 25kW, Diesel 50kW and Biomass 200kW Generators	1,236,397	0.173	79,708	22.8	DG: 1% BMG: 94% PV: 5%	24.7	**239**

Figure 1: Simulation results from HOMER. [19][22][24][35-43]

*Net Present Cost: Present value of all the costs that the system incurs over its lifetime minus the present value of all the revenue the system earns during its lifetime.

MHG is the most cost-effective renewable source of energy, followed by biomass, wind and solar. Solution 1 demonstrates that MHG should be implemented whenever possible: the cost of electricity for solution 3 (0.125$) is two-thirds more than solution 2 (0.078$). The difference is that in solution 2 MHG has twice the share of total electricity production with 58% in comparison to solution 3, which has 30%. The efficiency and cost-effectiveness of hydropower explains why 25% of India's total power [32] depends on this source. Furthermore, in the simulation results, MHG has low costs in comparison to diesel or biogas generators (see Figure 2), while providing the majority

[2] HOMER works with dollars.

of the power for the top two solutions. Nonetheless, if MHG is not a possibility, then the stand-alone systems based on biomass, wind and solar become financially viable at over 20 km from the grid.

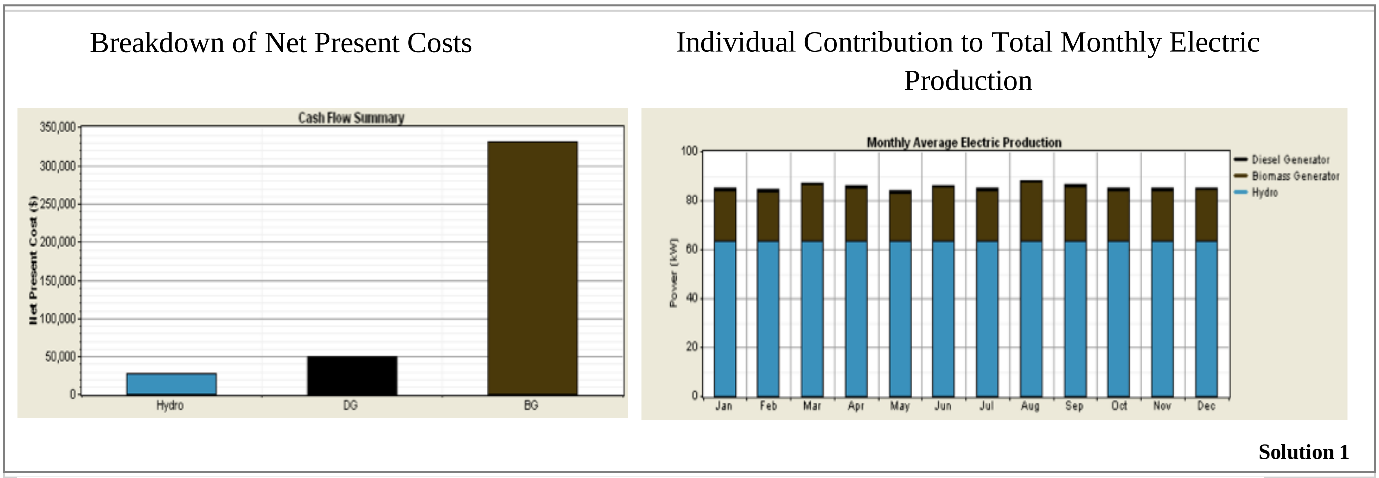

Figure 2: Graphs demonstrating the cost for solution 1 and the individual contribution of each source of energy to the total electricity production. [19][22][24][35-43]

The primary food crops grown in Bihar are paddy, wheat, corn and pulses [10]; typically, the waste products are disposed off in landfills. A recent Greenpeace report estimates that Bihar alone generates 1.8 billion kilograms of rice husk a year, and approximately 50kg of rice husk, costing less than 1Rs/kg, can power a 32kW generator for one hour [33]. Implementing a microgrid mainly powered by biomass utilises these otherwise useless resources, converting them into communal electricity for the villagers and modernising the agricultural society.

Although HOMER indicates that the combination of wind, diesel and biomass power is more cost-effective than the PV solution, solar energy may be a better long term investment. Bihar is a land locked state with low average wind speeds, hence Bihar cannot fully utilise wind turbines. As shown in Figure 1, in solution 5, wind power contributes to 3% of the total power, while solar energy generates 5% in solution 6. Furthermore, in the solar option, the diesel generator operates for the least number of hours. Hence, a solar energy solution, in spite of its greater costs, would still be a more sustainable solution compared with the installation of wind turbines.

After considering the different solutions, for rural electrification in Bihar, the renewable sources of energy can be ranked according to their potential and cost-effectiveness:

1) MHG
2) Biomass
3) Solar
4) Wind

Microgrids with MHG are more cost-effective than grid extension at very short distances away from the existing electrical grid. In addition, while diesel generators provide a minority of the power in all the presented solutions, they are necessary to provide steady and reliable electricity to the most critical applications. Hence, this report recommends the installation of MHG (if the village is sufficiently close to a river), biomass and diesel generators to electrify an isolated community in Bihar. As the demand for electricity increases, PV panels could be added and generators upgraded. Figure 3, shows how these different technologies could be integrated to create a microgrid.

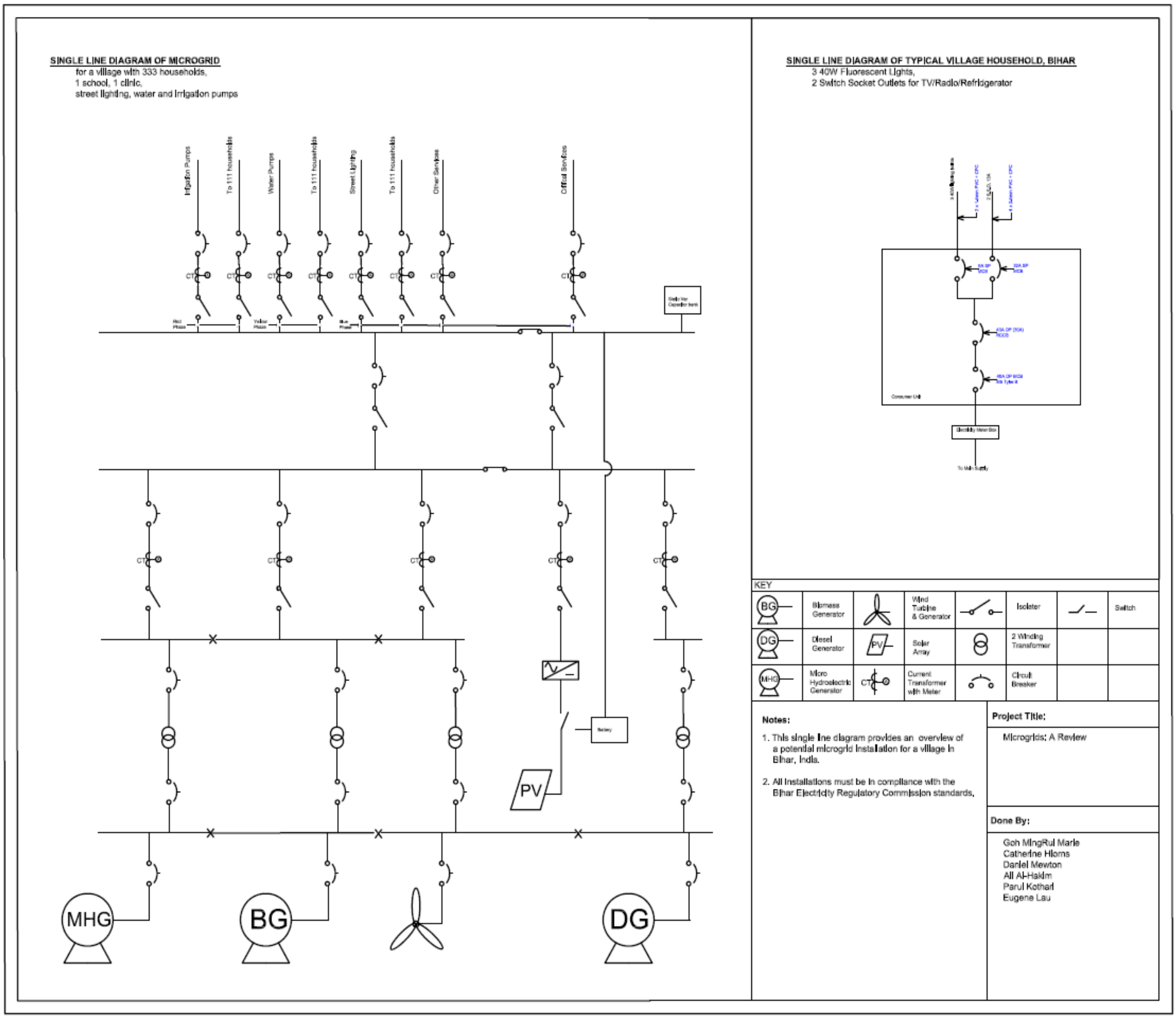

Figure 3: Two single line diagrams. The left diagram shows the integration of renewable source of energy on to the microgrid. The right diagram shows the household requirements.

Analysis Limitations

The simulations done in HOMER have several limitations due to the data used in the program and due to the software itself.

Firstly, the data used in the simulations was amalgamated from a variety of sources, which inevitably leads to discrepancies and errors. Secondly, one of the features of HOMER is its ability to accept a range of possible values for an input and compute the results for each of those particular cases. For instance, the simulations for the 100kW MHG were carried out with two "sensitivities": in one case, the MHG would generate on average 75% of its total capacity, while in the other it produces 50%. However, a sustained generation of 75% of full capacity throughout a year is impossible; this figure is too ideal. Therefore, solution 2 and solution 3 (see Figure 1) are a closer approximation to the actual performance of MHG, and consequently may be more reliable if implemented. Nonetheless, solution 1 clearly demonstrates the potential of MHG.

The main limitation in the software is the fact that the version of HOMER that is used does not consider any transmission or distribution losses from the main electricity grid, due to non-ideal transmission lines [34], and electricity stealing [28]. Modelling these losses would show additional benefits to microgrids, particularly since these losses are quite large in Bihar. Hence, standalone systems are more feasible at shorter distances away from the main grid than what has been shown in the results above. Note that transmission and distribution losses in the microgrid are not taken into account either; however, these are much smaller compared with the main grid.

Conclusion

There are several challenges with the implementation of microgrids in developing countries. To ensure that these grids can be managed and maintained, specific skill sets are required to be deployed to the area or training of the local population needs to occur. Furthermore, in areas such as Bihar consideration of the impact of flooding on investment will need to be investigated to ensure that money is simply not wasted. The electrification of any rural area poses many challenges that need to be resolved before any infrastructure should be invested in.

The complete simulation for a village in Bihar can be applied to a specific location with specific data, this would allow cost analysis for a specific area, establishing the most cost efficient way to electrify a village. Alternatively the principles from this report can be applied to a different area of the world, when that location is considering the best way of electrification of villages. A vital principle that can be gained from this report is that while cost analysis is vital to investment in microgrid, other factors such as reliability of fuel supplies and sustainability of developments should be considered.

Microgrids have a significant role in the electrification of rural communities in both developed and developing countries. When investigating the best way of providing electricity to communities, microgrids are an important consideration. They are particularly important for areas where there is the potential to use renewable sources of energy. As renewable energy technology becomes more refined and widely used, the investment costs will decrease, making microgrid implementation more cost-effective.

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