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ECONOMIC AND ENVIRONMENTAL IMPACTS OF INSTALLING MICRO-GRID IN A RURAL AREA

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ABSTRACT

Recently, the issue of Micro-Grid has been considered as a challenge among power utilities as well as communities in many countries around the world. Pilot projects have been promoted and some practical results have also been obtained. As an environment problem of the global warming, clean energy like wind and solar power can be considered as viable options for future electricity generation. Besides being emission-free, the energy coming from wind and solar are also available at no cost. In the past, these renewable energies are no included in Micro Grids. Renewable energy resource forming a Micro-Grid is not only provides the cheaper electricity for the rural area; it also creates the potential income for the end-user in that area. This paper intends to assess economic and environmental impacts of Micro Grid which forming by renewable energy micro-wind power plant (MWPP) and micro-hydro power plant (MHPP) in a rural area. Yardstick of economic merit such as: Net Present Value (NPV), Benefit-Cost Ratio (BCR) and Payback Period (PBP) will be dealt on this study.

KEY WORDS

Micro-Grid, Economic and Environment Impact Assessment

1. Introduction

Recently, the concern of renewable energy has been growing worldwide. As a definite solution of environmental problems of the global warming, reducing of emission of greenhouse gas such as carbon dioxides (CO_2) is a big objective around the world. It is necessary to change the pattern of energy consumption from heavily depending on fossil fuels such as oil, coals etc. to introduce renewable energy resource for future electricity generation. Besides being emission-free, the energy coming from the wind and solar is also available at no cost. In addition, renewable energy provides a solution for power supply to the remote rural area that is not accessible by the Electric Power Company, this especially useful to the developing countries that are poor in fossil-based resources. Because of these advantages, the interest in renewable energy is indeed growing worldwide [1]. Distributed energy resources forming a Micro- grid are not burdened with the costs of the existing system (which can result in a cost savings) but they must reliably supply all of the demand without the benefits of a diverse set of loads and generation technologies (which can result in a cost increase). As a pre-practical project, a rural area (Yamanashi Prefecture of Japan) is chosen as a pilot area for installing a Micro-Grid. This paper intends to assess the economic and environmental impacts on installing a Micro-Grid which consisting of a 32 kW micro-wind power plant and a 10 kW micro-hydro power plant to this mentioned rural area. Yardstick of economic merit such as: Net Present Value (NPV), Benefit-Cost Ratio (BCR) and Payback Period (PBP) will be dealt on this study. Reducing of greenhouse gases particularly in carbon dioxide emission will be the main focus of the environmental assessment. From the result of economic impact assessment, NPV greater than zero, BCR 3.86 for MHPP and 2.97 for MWPP, These numbers show that it's economic feasible for installing Micro-Grid in this area. Also MHPP is expecting to gain profits after the PBP of 3.36 years and 4.58 years for MWPP. On the other hand, with the Micro-Grid supplying the needed electricity to the rural area, 3 tons of CO_2 emission is expected to be reduced for one year.

2. Install a Micro-Grid in a Rural Area

2.1 Micro-Grid Structure with its Distinguished Features

A Micro-Grid (MG) is a collection of small generators (such as wind, solar, micro-hydro generation and a storage battery etc.) which provide electricity for users in close proximity. A Micro-Grid could exist as stand alone power networks within small communities, or be owned and operated by existing power suppliers as shown in Fig.1.

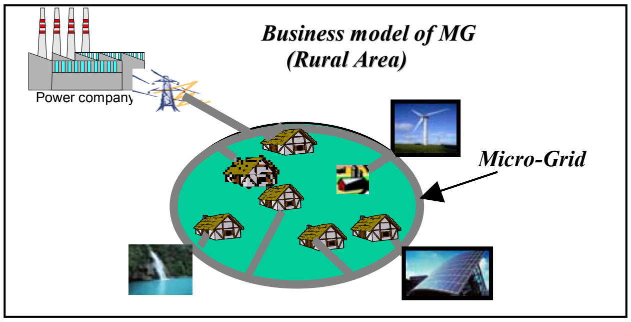

Fig.1. Business model of MG

A Micro-Grid can have various distributed energy resources. By generating electricity locally, it can avoid the transmission inefficiencies that inevitably come with power that is produced at great distance and for homeowners with these units can also sell their surplus electricity back to the national grid. From the viewpoint of social impact, MG will provide cheap electricity to the local industry and increase the income to the end-users. On the other hand, installing a Micro-Grid would not need an entirely new network to be built, as some broadband networks have dictated. It is very important and useful for rural areas which are remote from the national grid. Especially, It is huge benefit for the rural area in many developing countries which lack of resources for building the new electricity supply facility in rural area. And having generators close to demand also cuts down the cost of getting electricity from a national grid to the rural area. Distinguished features of Micro-Grid can be assumed as the following [2]:

(1) Micro-Grid provides an effective way to integrate distributed energy resources and loads in order to full utilize their abilities. Micro-Grid can supply electrical and thermal load simultaneously in effective ways even when a fault occurs on the system side.
(2) Micro-Grid can contribute to the surrounding distribution grid from the viewpoint of the utility system. This means that Micro-Grid should be a self-controlled individual entity.
(3) Micro-Grid provides a "plug-and play" capability for each distributed energy resources, which meets the customers' local loads. Customers can install their own distributed energy resources as they like however it should not harm the grid.

2.2 Geographical and Socio-Economic Features of Considered Rural Area

A rural area considered in this paper is in Yamanashi prefecture. It locates at a slope surface with complex geographical shape along the direction from east to west. There are 32 households distributed around this area, and rely on agricultural activity for their living. The rural area has no resources for building the large utility for electricity supply, hence, it rely on national grid for electricity supply in this area. Rural area in many developing countries, have similar condition as Yamanashi prefecture, which rely heavily on national grid for electricity transported. Aiming to cut down the electricity loss due to transmission line, and by utilizing the renewable energy to developing a rural area's energy supply, a Micro-Grid which consisting of a 32 kW micro-wind power plant and a 10 kW micro-hydro power plant is introduced in this rural area for supplying electricity to all residents which are remote from a national grid so far. Monthly electricity demand, electricity generated from installed micro-hydro power plant (MHPP) and micro-wind power plant (MWPP) in this rural area are shown in Fig.2, Fig.3 and Fig4. This paper is focusing on the economic and environmental impact after the Micro-Grid installed in this rural area. Some benefits of MHPP and MWPP of MG are proved by comparing the environmental and financial efficiency before and after installation of MG will be discussed in the later of this paper. It is also indicated that installation of Micro-Grid will boost further the socio-economic development in a rural area for the entire rural community.

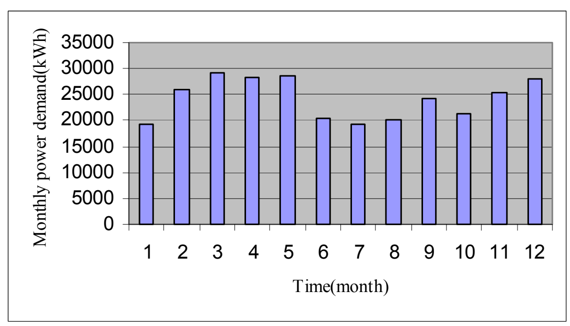

Fig.2. Monthly electricity demand of the rural area

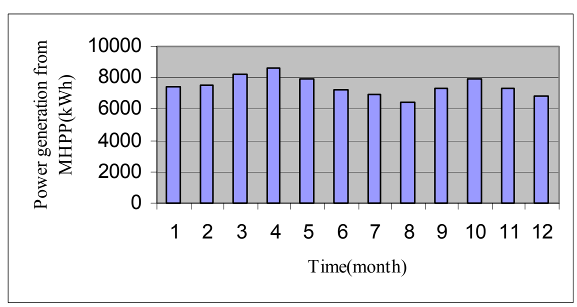

Fig.3. Power generation from MHPP

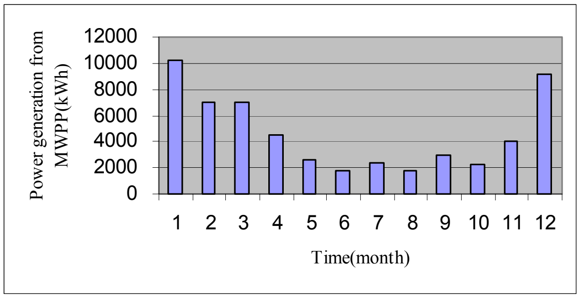

Fig.4. Power generation from MWPP

3. The Necessary of Micro-Grid Economic Assessment

A Micro-Grid with various distributed energy resources has mentioned above. Their economic characteristics are different from each other as well as their dynamics. Some of them are suitable for base load operation and the others may be good for responding to sudden load changes. In addition, several types of them have the capability to supply thermal load besides electricity. By fully utilizing their capabilities, the Micro-Grid can be operated efficiently and economically. There is an analogy of Best Mix Strategy and Economic Load Dispatch (ELD) for the bulk power system except CHP (Combined heat and power) functions. Moreover, if a contract and a regulation permit, the Micro-Grid can sell their electricity to the market through the grid. This is an incentive for investment in the Micro-Grid [2]. Therefore, the economic consideration of the Micro-Grid is important issue since it has various distributed energy resources with different characteristics and interaction with the grid should be taken into account for selling/buying electricity from/ to the utility. The economics or business case for the Micro-Grid determines the configuration and operation of the Micro-Grid. Issues of Micro-Grid economics can be roughly divided into three categories as follows [3]:

(1) The first concerns the basic economics of optimal investment and operation of technologies available to the Micro-Grid. These are problems that, at least at the distribution system scale, have received intense academic scrutiny; as a result, established and reliable tools are available to guide operation and should, with some adaptation to the specifics of Micro Grids, be effective.
(2) The second concerns some of the unique aspects of Micro-Grids that will require innovation. In general, these are areas in which micro-grid differ significantly from distribution systems.
(3) The third concerns the relationship of the Micro-Grids to the distribution system. In many ways these problems resemble familiar ones related to the interface between customers and utilities. For example, they need to provide a real-time price signal to the Micro-Grid so that optimal use of resources by both the Micro-Grid and grid can be achieved simultaneously.

4. Economic Impact Assessment of a Micro-Grid

According to International Association for Impact Assessment (IAIA), impact assessment is simply defined as the process of identifying the future consequences of a current or proposed action. It evaluates the impact of certain proposal which is very important in the process of decision making. The main purpose of the economic impact assessment is to provide an economic basis of deciding whether to pursue a certain project or not. Evaluation of the following measurements: net present value (NPV), benefit-cost ratio (BCR) and payback period (PBP) [4] will be the key for deciding whether to purse project or not in economic impact assessment. The computation of the total capital cost for 32kW MWPP in this rural area is given in table1, and the data of this table is based on [5]. Also total capital cost of 10kW MHPP presented in table2. To calculate the yardsticks of economic merit, the electricity price generated by MHPP and MWPP is based on the electricity price that household pay to electricity company originally when buying from it. In Japan, 22/kWh Japanese Yen (1$=120 Japanese Yen (\)). Also, it is assumed that the useful life of MHPP and MWPP is 25 years.

4.1 Net Present Value (NPV)

The net present value (NPV) is the net value of all benefits (B) and costs of the project, discounted back to the beginning of the investment. The benefits will be the income in selling the generated power of the community. The costs constitute the total capital investment (IC) and the accumulated annual operation and maintenance cost (A) which is assumed to be 2% of the total project cost. The NPV is given by the following formulation:

$$NPV = NPV(B) - [IC + NPV(A)] \qquad (1)$$

$$Where,\quad NPV(B): NPV\ of\ Benefits$$
$$IC: Initial\ Cost$$
$$NPV(A): NPV\ of\ Annual\ Cost$$

And,

$$NPV(B) = AES[(1+I)^n - 1]/I(1+I)^n \qquad (2)$$

$$AES: Annual\ Energy\ Sales$$
$$Where: I\ is\ the\ real\ rate\ of\ discount$$

$$NPV(A) = A[(1+I)^n - 1]/I(1+I)^n \qquad (3)$$

For 10kW micro-hydro power generator that installed to this rural area, the NPV will be calculated as the following:

$$NPV = 27{,}161{,}849.97 - (5{,}494{,}973 + 1{,}548{,}916.9)$$
$$= 20{,}117{,}960.1(\square)\square$$

Since NPV is greater than zero, the supposed project is economically acceptable bringing profit to the investor.

4.2 Benefit-Cost Ratio (BCR)

Benefit cost ratio (BCR) is the ratio of the net present value of the total benefits to the net present value of all the cost plus the investment cost. BCR is calculated by the following method:

$$BCR = NPV(B)/[IC + NPV(A)] \qquad (4)$$

Therefore, for 10kW MWPP, the BCR is calculated by formulation (4) as the following:

$$\begin{aligned} BCR &= NPV(B)/[IC + NPV(A)] \\ &= 27,161,849.97/(5,494,973 + 1,548,916.9) \\ &= 3.86 \end{aligned}$$

Since BCR is greater than 1 then the supposed project is acceptable.

4.3 Payback Period (PBP)

Payback Period (PBP) is the year (n) in which the net present value of all benefits will be equal to the net present value of all the costs plus capital investment. At the PBP,

$$NPV(B) = [IC + NPV(A)]$$

Solving for n yields,

$$n = -\ln[1 - (I \times IC)/(B - A)]/\ln(1 + I) \qquad (5)$$

Therefore, for 10kW MWPP, the payback period is calculated as the following:

$$\begin{aligned} n &= -\ln[1 - (0.05 \times 5,494,973)/ \\ &\quad (1,927,200 - 109,899,46)]/\ln(1 + 0.05) \\ &= 3.36\ (year) \end{aligned}$$

The calculation result shows that operating the 10kW MHPP after 3.36 years will gain profits up to the end of life of the plant.

For 32kW MWPP, the economic impact assessment can be also calculated by using of the same evaluation way as shown in Table3.

Table 3
Economic Assessment of 32 kW MWPP

NPV (Japanese Yen(\))	20,166,240.8
BCR	2.97
PBP (Year)	4.58

Table 1
Total Capital Cost for 32 kW MWPP

Description	Cost (¥)
Civil Works (11% of project investment)	880,000
32 kW Wind Turbine-Generator and Accessories (\180,000/kW)	5,520,000
Electrical Infrastructure (Transmission Line, etc) (9% of Investment)	720,000
Power Conditioning (7% of project investment)	560,000
Installation and Other Miscellaneous Charges(4% of Investment)	320,000
Total Capital Cost of Project	8,000,000

Table 2
Total Capital Cost for 10 kW MHPP

Description	Cost (\)
Civil Works	2,500,000
Penstock (20m pipe, \6,000/m)	115,000
7 units -1.4 kW Turbine-Generator and Accessories (\144,000/unit)	966,000
Transmission Line	172,500
Substation (step-up and step-down)	287,500
15% of electromechanical equipment	231150
20% of civil works	500,000
20% of Direct Cost and Contingencies	954,430
Sub-Total:	4,995,430
Interest: (10% of Sub-Total)	499,543
Total Capital Cost of Project	5,494,973

5. Environmental Impact Assessment of a Micro-Grid

Fig.5 shows the MHPP supply and demand profile. The MHPP energy supply for one month is obtained by multiplying the average generated power of 10 kW by 24 hours per day and is expressed in terms of kilowatt-hours (kWhr). The local electric power demand is determined by dividing general power demand into 32 households loading fitted for MHPP simulation study to yield an average demand of 32 kW. Fig.5 shows the amount of energy taken from MHPP to supply the demand of electricity which is determined for one month.

In Fig.5 the total monthly supply of MHPP is 7,440kWhr and the monthly power demand is 23,379.46kWhr. It is interesting to determine the amount of carbon dioxide emission that will be reduced per month if this rural area taps some its electricity from MHPP. According to Tokyo Electric Power Company (TEPCO), the CO_2 emission intensity is 0.381Kg/kWh. For hydro-power plants, the

CO_2 emission intensity is 0.011Kg/kWh and for micro-wind power plants, the CO_2 emission intensity is 0.0295Kg/kWh. The emission intensity figures are based on life cycle analysis which incorporates the emissions from construction, operation, dismantling and disposal. Therefore, the monthly reduction of CO_2 amount that by after installation of the MHPP and MWPP in this rural area will be calculated as shown in Fig.7 to comparing with the emission of CO_2 from load demand by before installation of the MHPP and MWPP of MG is shown in Fig.6. The total Carbon Dioxide Emissions of MHPP and MWPP will be calculated as shown in Table4.

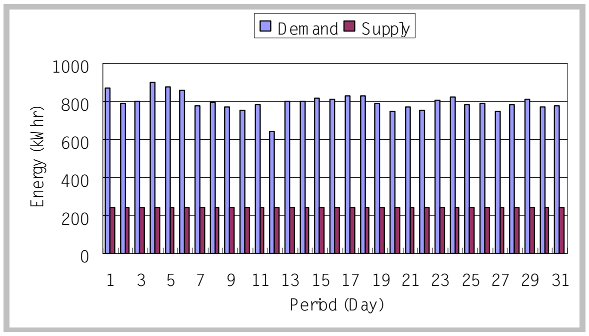

Fig.5. Demand and supply profile of MHPP

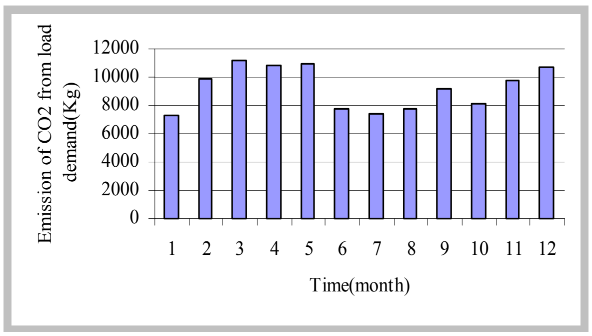

Fig.6. Emission CO_2 from load demand before install the MHPP & MWPP of MG to this rural area

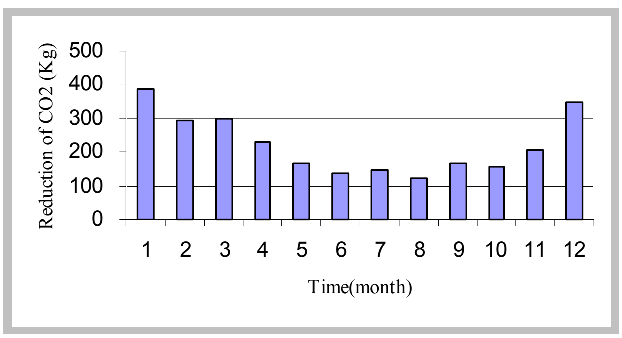

Fig.7. Reduction of CO_2 by after install the MHPP and MWPP of MG to this rural area

Table 4
Average Monthly Amount of CO_2 Emissions from MHPP and MWPP

CO_2 Emissions	MHPP(tons)	MWPP(tons)
From Grid	9.2	9.2
From resource	7.47	4.65
Reduced	1.73	4.55

From the result of Table4, the total amount of CO_2 emission that will be reduced 1.73tons and 4.55tons for the average one month when the load takes most of its energy supply from MHPP and MWPP. This is indeed a worth noting environmental impact of installing MHPP and MWPP of MG to this rural area.

6. Cost of Energy From the Micro-Grid Hybrid System

Long power transmission lines have high power loss in a certain degree. This research shows that by installation a Micro-Grid in a rural area to supply a local energy demand will be an effective way to developing the renewable energy resources that to cuts down the cost of getting electricity from the national grid and can avoid the long transmission power loss. From Fig.8 we can know that installation of a Micro-Gird with hybrid MHPP and MWPP will be economically and benefit for the cost of energy by supplying electricity to the target rural area. A certain amount of load demand will get the electricity supply from the MG resources and sometimes the supply is not only satisfy the demand but also they are used to save electricity in storage battery or selling back to the electric power company. Supposed that, the surplus electricity selling to the power company is usually considered as 8 Japanese Yen for per kWh and buying insufficient electricity from the power company is usually considered as 21 Japanese Yen for per kWh. By comparing with the conventional electric power system with the hybrid system for considering of the cost of energy, we obtained the following results shown in Fig.9.

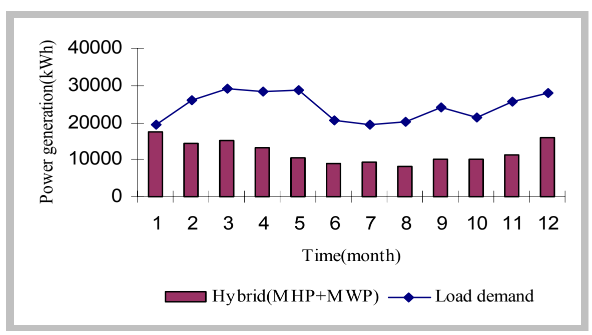

Fig.8. MG Hybrid system compared with load demand

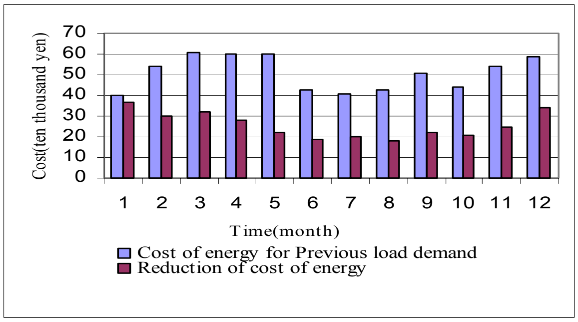

Fig.9. Comparison the reduction of cost of energy before & after installation of MHPP and MWPP of MG in a rural area

7. Conclusion

Economic and environmental impact assessment of installing a Micro-Grid is discussed in this paper. From the results of the economic assessment, the Micro-Grid is economically feasible as calculated by a NPV greater than zero. BCR of 3.86 and 2.97 for MHPP and MWPP, respectively, confirmed the merits. The MHPP is to gain profits after the PBP of 3.36 years and for MWPP after 4.58 years.

Environmental benefit of installing a Micro-Grid is also proved by the results of total amount of CO_2 emission that will be reduced 1.73 tons and 4.55 tons for average one month from MHPP and MWPP respectively. 3 tons of CO_2 emission is reduced for one year by installed MG in this rural area.

Installation the MG in a rural area paves the way to economic development and positive environmental impact to this rural area. The founding of the preserve research is believed to be useful for many countries which are going to take advantage of the Micro-Grid to supply electricity independently according to the necessary demand for their needs.

Finally, Micro-Grid will not only bring the economic and environment benefits for rural area, it also will increase the development of the social economic. For example, workforce of the local community will be increase, and awareness of environment protection of local public will also be increasing etc.

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