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Efficiency of Micro Grid with Storage Battery in Reliability, Economy and Environment Assessments

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Abstract: In this study, the Micro Grid (MG) formed from the renewable energy resources and the storage battery was analyzed and verified by multi-factors. The target MG power system was planned and installed in Kochi prefecture, Japan and it consisits of wind power turbine and solar power plant as well as micro hydro power generator. The efficiency of a stand alone Micro Grid in reliability and economy as well as environment was assessed. The system reliability is verified by the indices of Loss of Load Probability (LOLP) and Expected Energy Not Supplied (EENS). And the economic efficiency was given appraisal by Yardstick indices of the Net Present Value (NPV) and the Benefit-Cost Ratio (BCR) as well as the Payback Period (PBP). The environment efficiency was evaluated considering the amount of CO_2 discharge that was reduced by using installed MG power system renewable energy.

Key words: Renewable energy, micro grid, battery service, reliability, economy and environment assessments

INTRODUCTION

THE application of renewable energy in electric power systems is rapidly growing (Karki and Billinton, 2001). Although, Micro Grid contains the natural energies, which can produce clean energy and reduce the emission of CO_2, power generation from Micro Grid usually fluctuates due to the electric particulary of equipments. Thus, the issue of reliability should be considered with the economic and environment impacts of Micro Grid. They are so important for having a reliable power supply with an optimal operation and planning of Micro Grid. As an environment problem of the global warming, reducing the discharge of greenhouse gas such as carbon dioxides (CO_2) becomes a big objective on the world. It is necessary to introduce more renewable energy for future electric power system.

There are many kinds of alternative clean and environment friend resources, such as wind, solar and micro hydro power generation, which are very appropriate for improving our environment conditions. On the other hand, renewable energy resources driving by wind and sun are available without fuel cost. In addition, since this type of energy resources usually serve for a local load and not require for high-voltage transmission lines crossing through rural and urban landscapes (Youli *et al*., 2007). Therefore, the power loss is obviously reduced simultaneously the carbon dioxide discharge is also reduced. These characteristic of renewable energy provide the great benefit for those countries who are poor in fossil-based resources like Japan.

A renewable energy resources may be regarded as the distributed resources, however, big amount of distributed energy resources connected to a local power system may cause a stability problem of a power system. For instance, system voltage and frequency may fluctuate beyond limited margin etc. Furthermore, the reliability problem may also occur on the main grid. In order to fully utilize natural energy to increase the system flexibility and meet the system demand in reliability and security so as to avoid power outages on the main grid, systematic check of each indices is necessary. Pilot projects with some practical results have been obtained (Giraud and Salameh, 2001; Kondoleon *et al*., 2003) and some studies for system evaluation of Micro Grid have also been investigated on system reliability and economy assessment by difference ways (Chedid and Rahman, 1997; Zulati *et al*., 2006; Sun *et al*., 2006).

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In Japan, the New Energy and Industrial Technology Development Organization (NEDO) started 3 research test projects: Aomori project, Aichi project and Kyoto project in 2005 for testing the Micro Grid. These projects demonstrate the technical feasibility of Micro Grid with renewable energy, but environment and economy impacts of Micro Grid have not been done yet. In this study, an efficient methodology of a stand alone Micro Grid in reliability, economy and environment assessments are presented. The reliability evaluation of the Micro Grid is analyzed by the reliability indices such as LOLP and EENS. The economy and environment assessments of this Micro Grid are also evaluated by a simulation methodology with calculations.

STRUCTURE OF THE PROPOSED MICRO GRID

A Micro Grid is a small power network composed by various distributed energy resources and loads for electricity power supply. A Micro Grid can be used either in stand alone type or co-operating type with an existing power system and plays an important role for supplying a reliable electricity power to the customer side in case an emergency when any natural or manipulative fault is occurred in the main grid side, called islanding operation. In this study, a stand alone Micro Grid consisting of wind, solar and micro hydro power generation with storage battery are designed for a local power supply. To provide the Micro Grid with an adequate level of controllability, each distributed energy resources are interfaced with power electronic devices such as Rectifier and Inverter Controller (RIC), which provides the required capabilities.

Local weather and natural conditions: A Micro Grid proposed in this research, is consisting of electrical loads and distributed energy resources such as wind, solar and micro hydro power generation with storage battery. Figure 1 shows the geographic location map of Kochi Prefecture, Muroto city where planned to install a Micro Grid. Wind condition in this site is relatively strong together with more valid sunshine days in the year. The average wind speed is about 7.75 m sec^{-1} and the average solar irradiation is about 4.4 kWh m^{-2}. Muroto city is also famous for deep seawater energy in Japan. These available good natural resources with rich rivers close to the sea make this site be a perfect spot for installing a Micro Grid.

Structure of Micro Grid and local power system: There are about 186 households located in this region, the power consumption as a local load is given in Table 1 using hourly average load from local power system. The structure of local power system has 2 transformers, a Separation Device (SD), which is used in protection purpose when designing the Micro Grid. The structure of Micro-grid has three feeders, loads and distributed energy resources consisting of wind, solar and micro hydro power generation with storage battery as shown in Fig. 2. In the Micro Grid, there are 2 kinds of loads, traditional loads and sensitive loads. Whenever a fault occurs or power supply from the main grid is lost, sensitive loads must be isolated and met by distributed energy resources by opening SD as soon as possible and operated as an islanding operation.

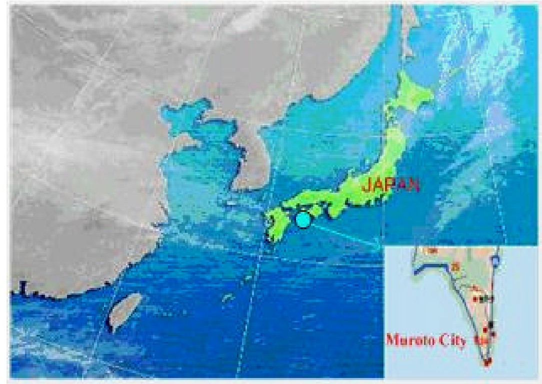

Fig. 1: The candidate region to install a Micro Grid

Table 1: Statistic value of hourly average load in local power system

Time (h)	Load (kWh)	Time (h)	Load (kWh)
0	152.00	12	252.00
1	143.00	13	266.00
2	135.00	14	268.00
3	130.00	15	265.00
4	127.00	16	262.00
5	129.00	17	247.00
6	142.00	18	241.00
7	169.00	19	231.00
8	213.00	20	213.00
9	245.00	21	197.00
10	259.00	22	184.00
11	264.00	23	169.00

In the consideration of system reliability and controllability of the Micro Grid, each distributed energy resources in the Micro Grid are equipped with power electronic devices such as Rectifier/ Inverter etc. at their interfaces which implements AC/DC/AC converter. In this research, the wind power is controlled by Rectifier and Inverter Controller (RIC); micro hydro power is controlled by Voltage and Frequency Controller (VFC) system through one transformer and the solar power is controlled by an inverter shown in Fig. 2. RIC of wind power consist of double layers circuits that convert AC into DC and again from DC into AC with simultaneous electric wave rectification; VFC of micro hydro power is with the function of frequency stabilizing and voltage regulating by tracking the load characteristics. The frequency is tracked by regulating the extra load and the voltage is regulated through excitation regulation.

Characteristics of power generation of the proposed Micro Grid: Power generation from wind, solar and micro hydro is respectively managed based on the climate data such as wind speed and irradiation data recorded for one year time (2003) and this data obtained from the National Climate Center of Kochi prefecture, where a Micro Grid planned to be install. To represent the normal condition of power generation, the average value is considered for each power unites and the daily average data was used for analysis in this research.

Power generation from micro hydro power system: The rating capacity of the micro hydro power generation is given as 160 kW (4×40 kW). The output of the power generation P is calculated based on the fiction of water discharge, water head, multiple waterwheel efficiency η_w and generation output efficiency η_g shown in Eq. 1:

$$P = 9.8QH\eta_w\eta_g = 9.8QH\eta[kW] \quad (1)$$

where:

- η = The overall efficiency, multiplied by η_w and η_g are usually considered as given between from 60-70%, which use of a propeller waterwheel. Here, the overall efficiency η is assumed as 60%
- Q = The actual measurment data collected from the installation site (Table 2)
- H = The water head given as 6 m

Therefore, the micro hydro power generation output P can be easily calculated by the Eq. 1. Figure 3 shows the power generation for the micro hydro power produced in Micro Grid.

Power generation from solar power system: The calculation of solar power generation is base on the Japan Storage Battery Company's AP-140G types module, which serial connection of 8 modules with Parallel connection of 4 modules (in total 32) are prospective install for simulation use. The amount of irradiation and irradiation time become the key factors for the solar power system. Table 3 shows the average irradiation time and irradiation density of the solar power. Figure 4 shows the power generation for the solar power system produced in Micro Grid.

Power generation from wind power system: The calculation of wind power generation is based on a characteristic curve of Vestas Company's V47 type, wind power turbine (Denmark). The rating output of this wind power turbine is 660 kW with the rating wind speed is 14 m sec^{-1}. Cut-in wind speed and cut-out wind speed are 4 and 25 m sec^{-1}, respectively. In addition, the height of the tower is 50 m and the rotor diameter is 47 m with three blades of large-sized wind turbine. The wind speed is the important factor and directly affecting the output of wind power generation shown in Eq. 2:

$$V_z = V_1(Z/Z_1)^{1/n} \quad (2)$$

where:

- V_z and V_1 = The wind speed at the height of Z (height of wind turbine)
- Z_1 = Observed height
- n = An index selected by a relative roughness of surface

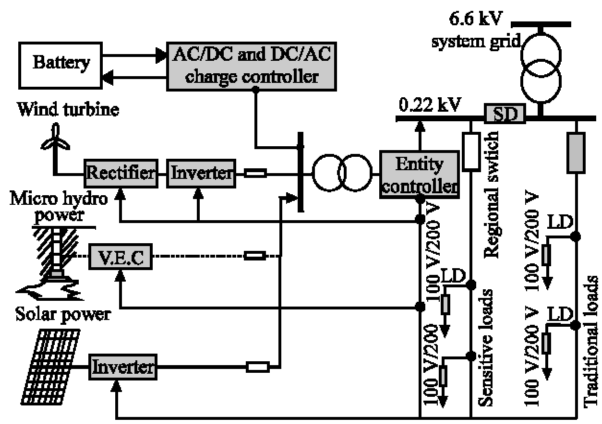

Fig. 2: Structure of local power system after installing a Micro Grid composed of wind, solar and micro hydro power generation with storage battery

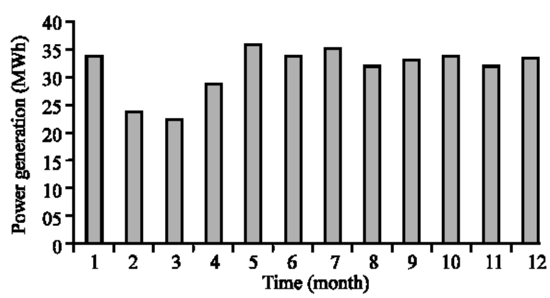

Fig. 3: Simulated power generation for micro hydro power produced in Micro Grid

Table 2: Average water discharge provided for Micro hydro power generator

Months	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
WD (L s^{-1})	1322.52	929.08	881.99	1124.65	1415	1332.44	1385.27	1260.08	1304.96	1329.44	1255.59	1319.84

Table 3: Available irradiation time and irradiation density of solar power

Months	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Ava.irradiation time (h)	6.33	6.68	7.23	6.95	9.32	5.81	4.84	7.94	8.36	7.73	5.74	7.27
Irradiation density (kWh m^{-2})	3.38	3.39	4.02	3.51	4.96	4.339	4.96	4.1	3.71	4.5	4.12	3.98

Table 4 : Monthly average wind speed in muroto region

Months	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Wind speed (m sec^{-1})	8.98	6.63	8.39	8.37	9.92	8.36	6.54	7.74	7.66	8.27	8.91	8.72

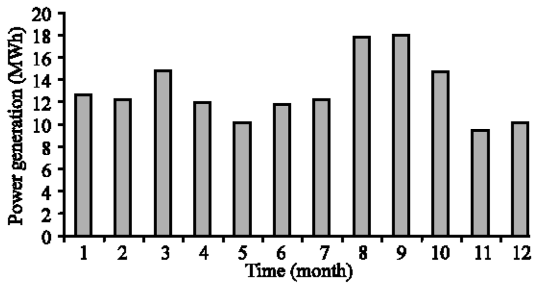

Fig. 4: Simulated power generation for solar power produced in Micro Grid

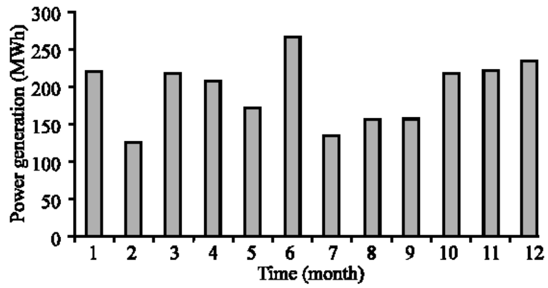

Fig. 5: Simulated power generation for wind power produced in Micro Grid

The characteristic curve between cut-in wind speed and the rating wind speed are expressed by Eq. 3:

$$Y = -0.2383X^3 + 6.6095X^2 + 0.8439X - 37.52 \qquad (3)$$

where:

Y (kW) = The output at the wind speed X (m sec^{-1})

Table 4 shows a monthly average wind speed in Muroto region, where a Micro Grid planned to be install in this region.

The yearly average wind speed in Muroto region is very strong with 8.2 m sec^{-1}. It is satisfy the usual economic feasible level with the yearly average wind speed equal to 6 m sec^{-1}. Base on the Eq. 2 and 3 and wind speed in Table 4, the possible power generation for wind power can be shown in Fig. 5.

Power serving by installing storage battery: Since a storage battery is indispensable for a power system to maintain stability and reliability, a storage battery is considered for adjusting the unstable outputs of renewable energies for charge and discharge in Micro Grid. For a grid-connected Micro Grid, renewable energy resources such as wind and solar power will find it economical to store energy locally in a battery. Because, the short-term peak demand will be meet by the battery without drawing from the main grid and paying the demand charge (Chedid and Rahman, 1997). The most importance of installing a storage battery in a Micro Grid is that the natural power generation produced by the distributed generation of Micro Grid is usually unstable and not fixity, it is difficult to control the outputting generation to responding the load tracking as well as load changes. It is necessary and needed a device such as storage battery which input/output control is easy and regarded as for a power resource for adjusting supply-demand balance in Micro Grid and improving the reliability of the Micro Grid. For this purpose, a NAS (Natrium Sulfur) battery as for a backup power resource are considered to install in this Micro Grid for charge and discharge electricity to take a supply-demand balance in the Micro Grid. NAS battery is selected because it has a significant characteristic as follows (Nakabayashi, 2007):

- A high energy density: about 3 times high energy density than that of the lead battery and operates at a high temperature of 360° Celsius with high efficiency than the others.
- Large-capacity: have a past record of 8 MW
- The charging and discharging efficiency is high (about 85%) and the self-discharge rate is almost zero, can store up electricity most effectively
- It is possible for charging and discharging battery for more than 2.250 times and has the superior long-term durability >15 years

The size of NAS battery considered here is 250 kW (5×50 kW) and its maximum capacity is 1800 kWh which can continuously supply power for 7.2 h day^{-1}. The electricity power charge/discharge to/from the NAS battery is controlled by the supply-demand equation:

$$C(t) = P(t) - L(t)$$

which:
P (t) = The electricity power generated by the Micro Grid
L (t) = The demand supplied from this Micro Grid

It is charged whenever the supply from the renewable energy exceeds the demand or discharged from batteries whenever the renewable energy is insufficient to supply the load as shown in Fig. 6. Charging and discharging process of the NAS battery is depended on the amount of P (t)-L (t), with computer monitoring by considering $P(t)>L(t)$ for change in battery and $P(t)<L(t)$ for discharge from battery. The different way for calculation of the changing and discharging battery can be also fund by the references (Chedid and Rahman, 1997; Yang *et al*., 2006). The NAS battery size considered here is depending on the maximum possible load under the worst possible weather condition that enable to control of the fluctuations in both the renewable generation outputs and the load. The maximum allowable energy taken or added to the NAS battery is considered as 10% of the capacity of the chosen battery per hour.

Reliability evaluation on proposed Micro Grid: The main purpose of power system is to supplying electricity in most economically and reliable way to customers. Reliability of a system is the measure of how adequate and security the system to supply electricity to customers. Reliability evaluation of proposed Micro Grid can be calculated by the following indices of Loss of Load Probability (LOLP) and Expected Energy Not Supplied (EENS).

Reliability analysis of Micro Grid: The methods of LOLP and EENS are the most widely used probabilistic technique for measuring the system's reliability levels that can be calculated in details as follows:

The LOLP can be referred as hourly Loss-of-Load-Expectation (LOLE) if hourly demands are used in the calculations instead of daily peak demands, it can be expressed by the following Eq. 4 (Billinton and Allan, 1984):

$$\text{LOLP} = \sum_{i=1}^{n} P_i(C_i - L_i) \tag{4}$$

where:
C_i = Available capacity on hour i
L_i = Forecast peak load on hour i
$P_i(C_i\text{-}L_i)$ = A probability of loss of load on hour i and can be obtained directly from the capacity outage cumulative probability table

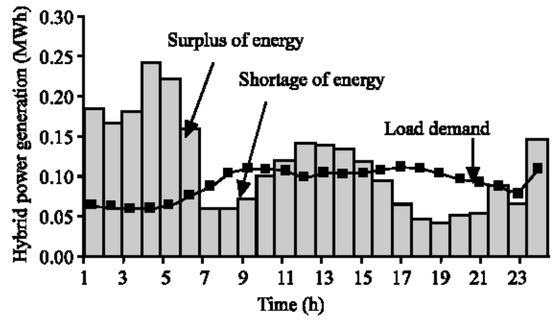

Fig. 6: Combine NAS battery to Micro Grid for supply-demand balance

The capacity outage probability can be easily obtained by using of the binomial distribution as shown in Eq. 5:

$$P(X = k) = c_n^k p^k q^{n-k} \, (k = 0,1,2,...,n) \tag{5}$$

where:
P = A Forced Outage Rate (FOR)
q = An un-forced outage rate (q = 1-P)
P (X) = A probability of capacity outage X

The EENS (kWh) is the expectation of the energy loss caused to customers by insufficient power supply, can be calculated by the following Eq. 6 (http://www.hoodong.com/wiki/EENS):

$$\text{EENS} = \sum_{i=1}^{m}\sum_{j=1}^{n_i}\sum_{k=1}^{24}\sum_{X=L_{ijk}}^{C_i}\left[X - (C_i - L_{ijk})\right]P_{ijk}(X) \tag{6}$$

where:
X = A capacity outage
C_i = An installed capacity in ith time section
L_{ijk} = A kth hour's load of jth day in ith time section
P_{ijk} = A capacity outage which is bigger than and equal to X's probability for kth hour of jth day in ith time section
m = A number of time section in 1 year
n_i = A number of days in ith time section
k = A kth hour in 1 day

SIMULATION RESULTS

Reliability of micro grid: The Micro Grid is working under normal output condition with wind, solar and micro hydro power supply. Based on the generation of wind, solar and micro hydro power generation, it is known that the hourly generation has negative number between demand and power service. Table 5

Table 5: Micro-grid generation and demand as well as the difference between Micro-grid generation and demand

Time (h)	0	1	2	3	4	5	6	7	8	9	10	11
MG generation (kWh)	183	114	53	9	45	157	264	410	482	576	610	477
Demand (kWh)	152	143	135	130	127	129	142	169	213	245	259	264
Difference (kWh)	31	-29	-82	-121	-82	-28	122	241	269	330	351	213
	12	13	14	15	16	17	18	19	20	21	22	23
MG generation (kWh)	302	241	173	246	375	363	272	166	71	75	398	448
Demand (kWh)	252	266	268	265	262	247	241	231	213	197	184	169
Difference (kWh)	49	-25	-95	-19	113	115	30	-65	-142	-122	214	279

Table 6: Simulated results of reliability related to hybrid generations in the Micro grid

Loss of Load Probability (LOLP)	0.14
Expected energy shortage in hour	3593.7 (kWh month^{-1})
Average energy shortage in hour	4.8 (kWh h^{-1})
Average period of power failures	4.28 (h)
Daily frequency without power supply	0.8 (times day^{-1})

Table 7: Simulated results of reliability related to combining nas batter™ in Micro-grid

Loss of Load Probability (LOLP)	0.06
Expected Energy Not Supplied (EENS)	1282.6 (kWh month^{-1})
Average energy shortage in hour	1.72 (kW h^{-1})
Average period of power failures	2.47 (h)
Daily frequency without power supply	0.6 (times day^{-1})

shows the service condition of the Micro Grid for 1 day supply case in January 2003. During a part of time, for instance, from the time of 1-4 (4:00 am) and 13-15 (3:00 pm), the Micro Grid generation will be insufficient to meet the demand. The reliability of the Micro Grid can be calculated by Eq. 4-6 as shown in Table 6.

Reliability of Micro Grid by combining with storage battery: In order to improve the reliability of the Micro Grid showed above, a NAS battery was combined for storing electricity by charging battery at a favorable night time when the electricity power generation is excess and discharge in the day peak time or in the shortage of energy supply. Figure 7 shows a quantity of charge and discharge of NAS battery in the Micro Grid. Table7 shows the results of the reliability of the Micro Grid with NAS battery.

From the simulation results, it can be known that the reliability of the Micro Grid has been improved 57% in LOLP and 64.2% in EENS by combining the NAS battery. Figure 8 shows an optimal operation of the NAS battery in the Micro Grid. Under the electricity shortage circumstance, the NAS battery will be discharged or otherwise it will be charged or sell the extra produced power to a power company. With this operation, the supply-demand of the Micro Grid can be controled and supplied electricity in more secure, economic and reliable way.

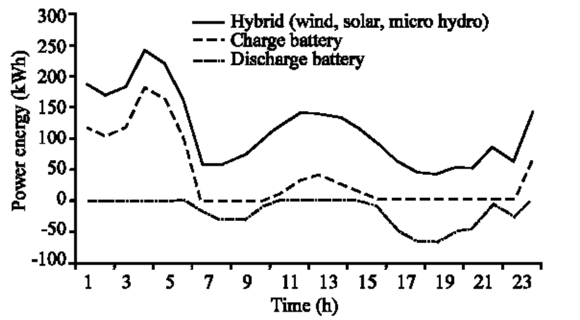

Fig. 7: Profile of charge and discharge of NAS battery in Micro Grid to improving the system reliability

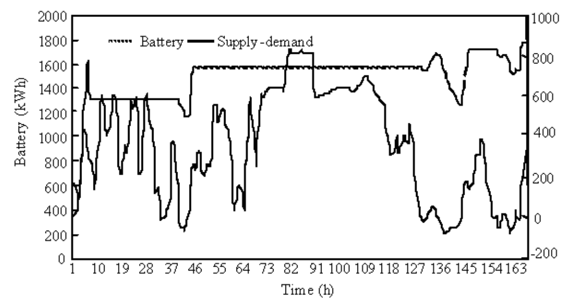

Fig. 8: Optimal operation of the NAS battery in the Micro Grid

ECONOMIC AND ENVIRONMENTAL IMPACT

Assessment of Micro Grid: In this study, we intend to assess economic and environmental impacts of Micro Grid consisting of wind, solar and micro hydro power generation. Yardstick of economic merit such as Net Present Value (NPV), Benefit-Cost Ratio (BCR) and Payback Period (PBP) are discussed in detail in this study. The environmental impact of the Micro Grid is mainly assess by the emission reduction of CO_2 by using of renewable energy resources in Micro Grid compared with the traditional fossil fuel power plants.

Economic impact assessment of the Micro Grid: The main purpose of the economic impact assessment is to provide an economic basis of deciding whether or not to pursue a certain project. Evaluation of the following measurements: Net Present Value (NPV), Benefit-Cost

Ratio (BCR) and Payback Period (PBP) (Yong *et al*., 2001) will be the key for deciding whether or not to purse the project in economic impact assessment. The computation of the total capital cost for 32 kW Micro Wind Power Plant(MWPP) is given in Table 8 and the data was based on (Mathew, 2006); Total capital cost of 10 kW Micro Hydro Power Plant (MHPP) and 10 kW Solar Power Plant (SPP) are presented in Table 9 and 10, respectively, for economic impact assessment of the Micro Grid. To calculate the yardsticks of economic merit, the electricity price generated by MWPP, MHPP and SPP are based on the electricity price that household pay to electricity company when buying from it originally, It can be assumed as 22/kWh Japanese yen (¥). The useful life of MWPP, MHPP and SPP is 25 years.

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 equation:

$$NPV = NPV(B) - [IC + NPV(A)] \quad (7)$$

where:

NPV (B) = The Net Present Value of Benefits
IC = The Initial Cost (total capital investment)
NPV (A) = The Net Present Value of Annual cost

Here,

$$NPV(B) = B[(1+I)^n - 1]/I(1+I)^n \quad (8)$$

$$NPV(A) = A[(1+I)^n - 1]/I(1+I)^n \quad (9)$$

where:

B = All benefits (annual energy sales)
A = Annual operation and maintenance cost (annual cost)
I = The real rate discount

For 10 kW MHPP to install in the Micro Grid, the NPV will be calculated as the following:

$$NPV = 27{,}161{,}849.97 - (5{,}494{,}973 + 1{,}548{,}916.9) = 2.01 \text{ (Million yen)}$$

Since NPV is >0, the supposed project is economically acceptable bringing profit to the investor.

Table 8: 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^{-1})	5.520,00
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

*¥ (Yen): The Japanese currency

Table 9: Total capital cost for 10 kW MHPP

Description	Cost (¥)
Civil works	2,500,000
Penstock (20 m pipe, ¥ 5050/m)	115,000
7 units -1.4 kW turbine-generator and Accessories (¥ 121.200/unit)	960,000
Transmission Line	172,500
Substation (step-up and step-down)	287,500
15% of electromechanical equipment	231,150
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

Table 10: Total capital cost for 10 kW SPP

Description	Cost (¥)
Tatal capital cost of project	6,666,000
Capacity factor	0.4
Rate of discount	0.05
Operation and maintenance: 1% of capital cost	66,660

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 Eq. 10:

$$BCR = NPV(B)/[IC + NPV(A)] \quad (10)$$

Therefore, for the above 10kW MHPP, the BCR can be calculated by Eq. 10 as:

$$BCR = NPV(B)/[IC + NPV(A)] = 27{,}161{,}849.97/(5{,}494{,}973 + 1{,}548{,}916.9) = 3.9$$

Since BCR is >1 then the supposed project is acceptable.

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,

$$NPV(B) = [IC + NPV(A)] \quad (11)$$

Solving for n yields,

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

Therefore, for the above 10 kW MHPP, the payback period can be calculated:

$$n = -\ln[1-(0.05\times 5{,}494{,}973)/(1{,}927{,}200-109{,}899{,}46)]/\ln(1+0.05) = 3.4(\text{year})$$

The calculation result shows the 10 kW MHPP operating in Micro-grid will start to gain the profit after 3.4 years. Under the same principle, the economic assessment on 32 kW MWPP and 10 kW SPP are given in Table 11.

It is known that the economic assessment of the installation is in relation to the local efficiency. That is, the higher efficiency it is, the investment will be sooner be recovered. From the result of simulation, it indicated the payback for MHPP is 3.4 years, MWPP is 4.6 years and SPP is 13 years. This proved the system is much more efficient than before introduce the Micro Grid. Because only 3.4 years for MHPP, 4.6 years for MWPP and 13 years for SPP are enough to recover the high cost of the installation.

Environmental impact assessment of the Micro Grid: The impact of renewable energy resources in Micro Grid is not only in economic term but environmental as well. That is, the amount of gaseous pollutants released into the atmosphere for production of power is significantly reduced when using renewable energy resources instead of traditional plants. This is particularly important issue since electricity power generation emissions contribute a significant proportional of overall emissions that cause the global warming and the greenhouse effect.

For the above mentioned Micro Grid, the total monthly supply of MHPP is 7.440 kWh and the monthly power demand is 23,379.46 kWh. It is interesting to determine the amount of carbon dioxide emission that will be reduced per month if the area where planned to install a Micro Grid taps some its electricity from MHPP. According to Tokyo Electric Power Company (TEPCO), The CO_2 emission intensity of grid power supply is 0.381 kg kWh^{-1}. For micro hydro power plants, the CO_2 emission intensity is 0.011 kg kWh^{-1}, for micro wind power plants and solar power plants, they are 0.0295 and 0.072 kg kWh^{-1} according to the NEDO. The emission intensity figures are based on life cycle analysis which incorporates the emissions from construction, operation, dismantling and disposal. Figure 9 shows a monthly amount of CO_2 emission from the Micro Grid. The total and avoided CO_2 emission by introducing of MHPP, MWPP and SPP in the Micro Grid are calculated and showed in Table 12. It can be seen that a total of 8tons CO_2 emissions can be avoided by installing Micro Grid in an average one month in this considered area.

Table 11: Economic assessment of micro grid

Item	NPV (¥)	BCR	PBP (year)
MHPP (10 kW)	20117960.00	3.9	3.4
MWPP (32 kW)	20166244.80	3.0	4.6
SPP (10 kW)	3259237.64	1.4	13.0

Table 12: Average monthly amount of CO_2 emissions reduced by introducing of micro grid

CO_2 emissions (ton $month^{-1}$)	MHPP	MWPP	SPP
From main grid		9.20	
Avioded from the above resources	2.83	1.75	4.91
Reduced by using of the above resources	30.80%	19.00%	53.40%
From the micro grid		1.20	

Table 13: Efficiency of miceo grid in reliability economy and environment assessment

Item indices	Reliability LOLP and EENS ($kWh\ month^{-1}$)	Economy energy cost (yen $month^{-1}$)	Enviornment CO_2 emissions (tons $month^{-1}$)
Main grid	LOLP = 14 EENS = 3593.7	5.3×10^4	9.2
Micro grid	LOLP = 6 EENS = 1282.6	4.2×10^4	1.2

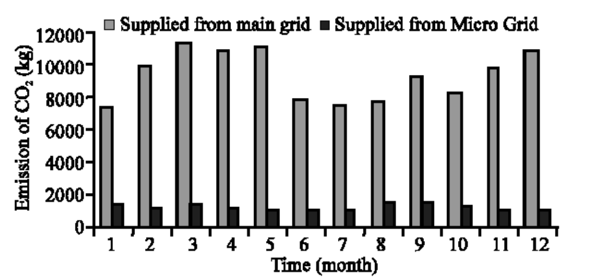

Fig. 9: CO_2 emissions from the Micro Grid compared with the traditional plants

Table 13 summarize the efficiency of the Micro Grid with storage battery in reliability, economy and environment assessments. The results indicated the important by using renewable energy resources in Micro Grid can be improve the system reliability and reduce the energy cost. Also, by reduce the CO_2 emissions, which make a great contribution to the greenhouse effect and the global warming. In this research, the economic merits of the Micro Grid are determined and provide an economic basis when deciding whether or not to pursue a certain project. This can be assist power system engineers to decide the types and renewable energy resources should be use when designing a Micro Grid. The researchers believe that the present research is very important due to the Kyoto Protocol requirements on emission reduction.

CONCLUSION

In this study, a reliability evaluation, economy and environment impacts of a Micro Grid with storage battery are presented. This research shows that the reliability of the target Micro Grid was improved 57% of LOLP and

64.2% of EENS by combining a storage battery in this Micro Grid. And the results of the economic assessment shows that the net present value became >0, the benefit-cost ratio are respectively 3.9, 3.0 and 1.4 for MHPP, MWPP and SPP. Under this condition, this Micro Grid system may start to gain the profits after the payback period of 3.4 years for MHPP, 4.6 years for MWPP and 13 years for SPP.

The environmental benefit after introducing the Micro Grid into this area is also proved by the results of 2.83 ton of CO_2 that is reduced by using of the MHPP and 1.75 ton CO_2 reduced by MWPP and 4.91 ton CO_2 reduced by SPP in each month averagely. About 96 ton of CO_2 emissions are reduced for 1 year by introduction the Micro Grid in the target area.

This research indicates that the introduction of the Micro Grid in such remote area may improve the local economy and also positive impact on environment. The founding of the preserve research is believed to be useful for many countries who, are going to take advantage of the Micro Grid to supply electricity independently according to the necessary demand for their needs in future.

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