Design and Implementation of Energy Management System For Small-Scale Hybrid Power Plant

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***Abstract*— This paper explains the energy management system (EMS) to arrange small-scale renewable energy (RE) power plants in one affordable area. RE power plants integrated are sourced from local area such as hydro, biogas, and solar. Hydro power and biogas were built in 2014 with standalone mode, whereas solar power were built in 2015. The main problem is that the energy sources of all existing RE power plants are not continuously available (intermittent). Solar energy is only available during the day. Likewise with water energy sources that was suficient in the rainy season but drastically reduced in the summer. The source of biogas energy is very dependent on the amount of gas content produced from livestock. Therefore an energy system integration arrangement is needed to solve the above problems. The design of integration is done by adjusting the output of each generator source into a DC voltage system to be stored first in the energy storage unit such as batteries. This is due to the simpler and safer arrangement of DC source integration compared to AC source systems. Local grid designed of electrical energy distribution can also be connected with utility grid (on-grid mode) to compensate the intermittent conditions of RE power plants. Finally the design is implemented to maintain energy balance of supply - demand, reduce the grid electricity cost with RE penetration, improve efficiency, security, and reliability of the local grid.**

Keywords* — *renewable energy, EMS, energy storage, integration

I. Introduction

Renewable energy sources (RES) have been widely considered as one of the most promising alternative energy sources in addition to conventional fossil fuels [1-3]. This earth has enough generating resources to cover the increase in electrical load. Many RES have been developed by researchers, such as wind, hydro, solar, tidal, biomass, biofuel, biogas, geothermal power plants. Wind and solar energy sources are quite popular renewable energy sources that are clean and freely available. But each RES has intermittent condition [4-6]. Solar energy is only available during the day when the weather is sunny. Wind energy is available at times which are often unpredictable (sporadic) and very fluctuating depending on the weather and season. Likewise with hydro energy sources, very abundant during the rainy season and drastically reduced in the summer. The source of biogas energy is very dependent on the number of animals and the availability of feed. However, there are several sources of generation whose utilization depends on the season. To overcome this problem, it requires a combination of several renewable energy (RE) to cover the energy demand continuously called the hybrid energy system (HES) [7-10]. Hybrid techniques are widely used to combine several types of RE power plants, such as wind energy generation, solar and diesel [11-12], solar and hydro power [13], wind and solar energy plants [14-16], wind energy generation and diesel [17], solar and biogas [18] and etc. Due to intermittent renewable energy resources, energy storage facilities are an important requirement to provide uninterrupted electricity supply [19]. The energy storage such as batteries appears in answering the balance needs of energy supply and demand because if without an accumulated system, energy will be produced and used simultaneously [20-21].

In the future, the use of RE power plants is not only focused on remote areas, but also can be used in urban or rural areas where utility grid are affordable. Through microgrid technology, RE power plants can be implemented anywhere as long as their potential available. Distributed energy resources (DER) based on renewable energies can operate stand alone (off-grid) and can also be conected with utility grid (on-grid). The use of renewable energy generation such as solar, wind, hydro and others can be applied easily without being affected by intermittent conditions through proper energy management arrangements. Thus microgrid technology has more advantage compare with traditional electricity networks that are centralized because it offers stability in electricity supply, reliability, efficiency, security, reducing emissions and saving costs [22].

In supporting penetration of RE use in Indonesia, some researchers have implemented several RE power plants such as hydro, biogas and diesel. One of the pilot project locations is at Baiturrahman boarding school, a rural area in southern side of Bandung, Indonesia. Three renewable energy power plants have been built in small capacity to reduce dependence on utility grid. The renewable energy (RE) power plants installed are 5 kW biogas, 5 kW micro hydro, and 1 kW solar. Present primary electricity supply is come from the utility grid provided by PLN (Indonesian State Electricity Company) at total capacity of 36 kVA. Each RE power plant supplies only a portion of the load that operates on a stand alone basis which is not connected to the utility grid. The problem is that each RE power plant has a different intermittent period, so the load it supplies must follow the RE characteristics. Each RE power plant works independently and separately, so those three RE power plants cannot cover intermittent conditions each other's. For example, when the power generating PV does not adequately supply the load that it connects, then the load will shut down. While at the same time the generator from micro hydro or biogas produces excess energy, but the excess power cannot be transferred to the PV load. Another problem is that when all RE power plants are in the same intermittent period or being maintenance, then all the loads supplied by the all RE will shut down, so that this condition can disrupt the school activities.

In this paper, the authors conducted a study by designing an energy management system (EMS) for several RE power plants that have been installed at the pilot project, Baiturrahman Boarding School. All the RE power plants will be integrated into one microgrid and can be connected to utility grid to supply electricity in the whole school. Several factors must be considered in estimating the system energy storage which is suitable for use in systems including, specifications for power, energy, weight, size, efficiency, speed of charging and discharging, average life, etc.

II. System Design

The energy management system (EMS) designed to support existing microgrid at the pilot project that has configuration is as shown in Fig. 1. The use of local RES in one community / area is done to fulfill and maintain energy supply. The potential of biogas, hydro and solar energy can be integrated in the form of hybrids that operate on-grid or off-grid. Here, the energy management required to ensure a balance between supply and demand.

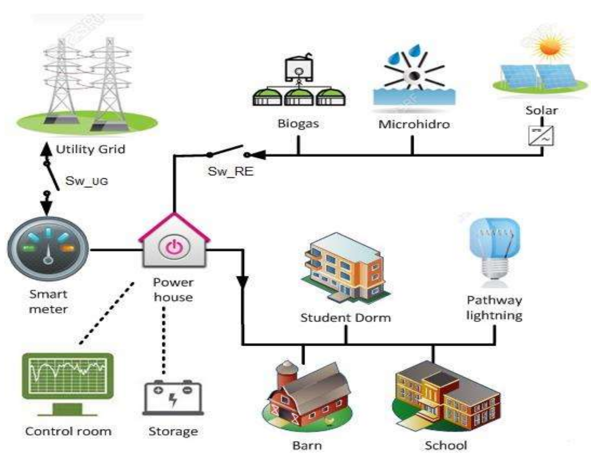

Fig. 1. The existing microgrid system configuration

A. Micro Hydro Power

Hydro power mainly uses a propeller turbine that is suitable for use in low head river flows. Fluctuations in the flow rate of the Cirasea river as potential energy that drives a micro hydro turbine can be seen in Fig. 2. The flow rate decreases when the season starts entering the dry season, which is around May-August. This condition makes this micro hydro can complement each other to produce electricity to meet load demands.

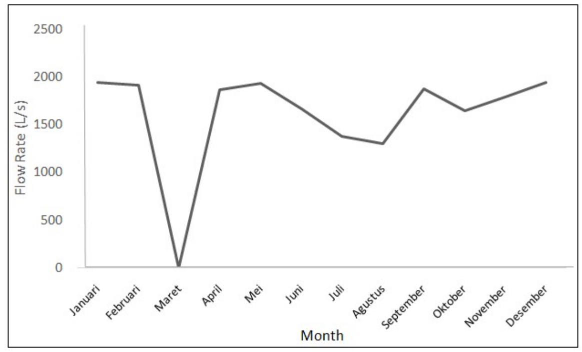

Fig. 2. Monthly flow rate fluctuations from the Cirasea river

The type of turbine used in this design is a propeller turbine shown in Fig. 3, with a capacity of 5 kW, 3 phase, 220 Vac. The nominal capacity generated is 5.3 kW. The power capacity is obtained from available head of 1.5 m with a design flow rate of 500 L/s and turbine efficiency of 72%. The minimum and maximum flow ratios are 15% and 110% respectively. The output power of the micro hydro is expected to be able to supply loads to the dormitory building continuously.

Fig. 3. The 5 kW hydro turbine

B. Biogas Power

The use of biogas power is scheduled to handle or supply electrical power at peak load times, which is around 18.00 PM to 06.00 AM. Biogas power used a biogas genset of 5 kW, one phase, 220Vac. The potential of electricity sources from biogas comes from cow dung as livestock waste. Based on the estimated electric power obtained from the Baitturahman Boarding School Electrical Division, the waste produced from 1 cow reaches 0.1 tons per day. At the farm there are 28 cows, so the amount of cow dung is 2.8 tons per day and is stored in several digesters as shown in Fig. 4.

(a) (b)

Fig. 4. (a) Digesters, (b) Biogas Generator

Based on the calculation of the potential of biogas through the Buswell equation and the Ideal Gas formula the electricity produced is 38.3 kWh/day. This value is relatively the same in monthly terms as long as the number of cows on the farm does not change.

C. Solar Power

One of the main factors affecting the output power produced by solar panels is irradiation. Indonesia is a tropical region with very large solar energy potential with an average daily irradiation of 4.89kWh/m^2 per day. Daily irradiation was obtained from NASA's Surface Meteorology and Solar Energy Database which was measured directly based on the location of the installation as shown in Fig. 5.

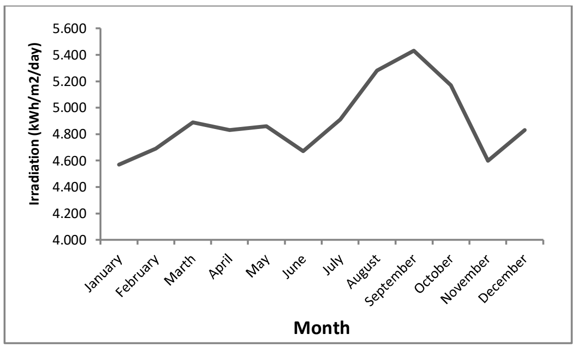

Fig. 5. Solar Global Horizontal Irradiance Resources.

Solar power was produced from 10 solar panels previously installed at local area with totally maximum power of 1000 Wp as shown in Fig. 6.

Fig. 6. Solar panel with a total capacity of 1000 Wp

D. Energy Storages

Energy storage such as battery recommended in the system to anticipate RE power shortages, because RE power is intermittent like solar panels that only produce power during the day. Conversely, micro hydro plants that work 24 hours are serving low loads, resulting in a surplus power. This power surplus then stored in the battery or supplied to the utility grid if the battery is fully charged. Meanwhile if a peak load condition occurs where all RE power capacity is low, the energy stored in the battery will cover the power shortage during the peak load. The storage system consist of 6 batteries 12 V, 150 Ah as shown in Fig. 7. All batteries are configured in 2-series 3-paralels with nominal voltage of 24 Vdc, 450 Ah.

Fig. 7. Energy storage using 6 batteries 12 V, 150 Ah

From the configuration, the total battery capacity is 10.8 kWh. Generally, energy storage required in order to control the balance of power flow more flexibly and reduce power loss when excess energy from the source occurs.

E. Load Profile

The load profile identifies the condition of energy consumption in the design object. The load profile was obtained from measurement record of the load shown in Fig. 8.

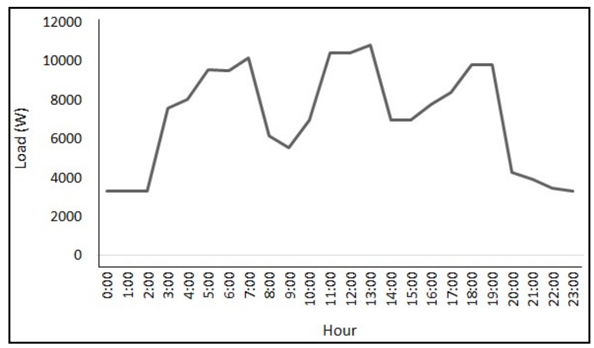

Fig. 8. The load profile at local area

The use of loads on the boarding school were relatively the same every day without any significant changes because the activities of the students were quite limited. Totally there are 14 buildings in the school area with different load characteristics consisting of school buildings, student dormitories, teacher's houses, places of worship, main halls, and computer labs.

F. EMS Design and Operation

Previously all RE power plants were connected to loads with standalone systems using conventional off-grid controls. Furthermore, all of the power plants were integrated into a microgrid that is connected to utility grid to supply electricity to the local loads as block diagram shown in Fig. 9. One of the challenges in this research was to integrate all power plants into a reliable, efficient, safe and sustainable microgrid. Hybrid controller also equipped with sensors, meters, control devices and analytical tools to automate, monitor and control the flow of energy. Power components consist of RE power plant (hydro, biogas, and solar), converter components, batteries as energy storage, synchronization components, load, and utility grid. While the control component is used to manage power components so that the process of controlling the flow of power can operate effectively, efficiently, and safely.

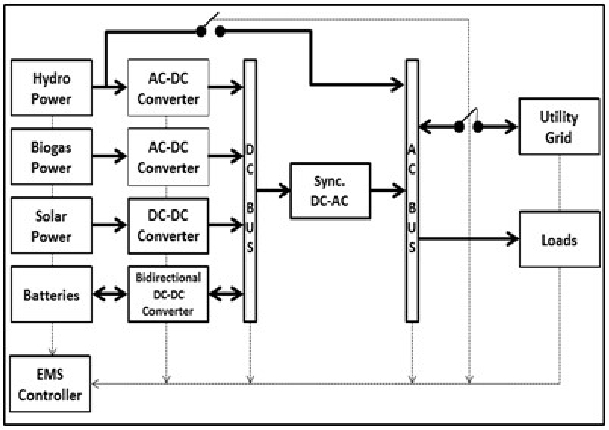

Fig. 9. Block Diagram of EMS Hybrid RE Power Plants

The block diagram above consists of power components and control components as shown in Fig. 10.

(a) (b)

Fig. 10. (a) Power components installation, (b) EMS control componentsand monitoring design

The control hardware equipped with electronic sensors that read voltage, current, frequency, power factor, etc. The reading results of these parameters are input signals that processed in the microcontroller. The output of the microcontroller produces a signal to be used for monitoring systems or actuators in the form of electronic relays to control power components.

Some scenarios considered in managing Hydro-Biogas-Solar as a hybrid power plants to create the balance, security, and efficiency of local grid are as follows:

- Hydro output power usually more stable than solar and biogas due to longer intermittent period than biogas and solar. Therefore, when the load is still low, the hydro power output can be directly connected to the AC load and charge the battery through an AC-DC converter.
- The output of solar power is a DC source, it usually fluctuates due to the influence of solar radiation so it must be stabilized with a DC-DC buck-boost converter, amplified by MPPT and then stored in the battery.
- The biogas power output often decreases due to the lower of biogas pressure that is injected into the generator combustion system. Because of the instability of the biogas power output so it cannot be connected directly to the AC load. Such as solar power setting, for more flexible integration, AC biogas power output is converted to DC through AC-DC converters, stabilized and amplified, then stored in batteries.
- Battery storage will be used to supply the load during peak loads when hybrid power plants do not adequately meet power requirements.

If Hybrid power plants including battery storage still cannot meet the load requirements, the system will automatically import power from the utility grid (on-grid mode). Conversely, at low load conditions, if RE hybrid power plants have excess power then the first priority is to fully charge the battery, the rest is sent to the utility grid.

III. Result and Discussion

The daily test results from the output of each RE power plant and its comparison with the load profile are as shown in Fig. 11. The total power needed to supply the load is 168.9 kWh per day with the peak load occurs around 07.00 AM, 10.00 AM - 13.00 PM, and 18.00 - 19.00 PM. The hydro power output is the biggest compared to biogas and solar power. The output power is relatively stable for 24 hours with an average power of 4248.3 W or 101,9 kWh per day (60% of load). Here hydro power can be used as the main grid that supplies continuous load demand.

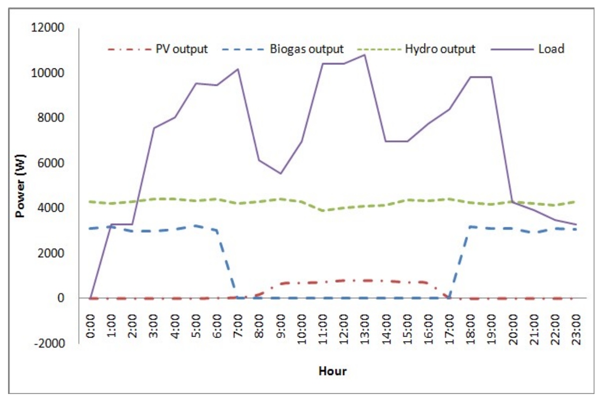

Fig. 11. RE power output and load profile

Scheduling biogas generators is considered to supply load demand during peak loads until the morning, which is around 18:00 PM - 06:00 AM. If it is operated for 12 hours the generator is capable of supplying an average of 3.33 kW, 40 kWh per day (23% of load). Many factors that affect the output of biogas power include methane content, gas pressure, losses in generator sets, etc. Solar power output produces 6,207 kWh per day (3.7% of load) starting at 6:00 PM to 17:00 PM. From the total solar PV capacity of 1 kWp, a minimum power of 22 W is produced at 6.00 PM and a maximum power of 810 W at 12.00 AM. Here the efficiency of solar panels is still low. Some of the factors that affect the efficiency of solar PV include radiation, temperature, panel type, direction, slope angle, and azimuth angle.

The daily test results from the output of Hydro-Biogas-Solar hybrid powers and characteristic of batteries charge-discharge are as shown in Fig. 12.

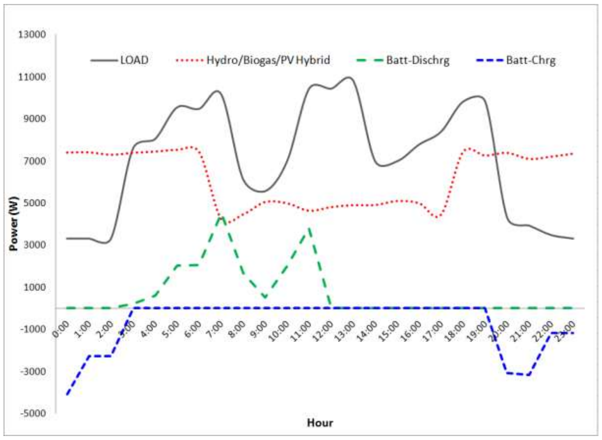

Fig. 12. Load, Hydro/Biogas/PV Hybrid Power, and Charge-Discharge Batteries

From Fig. 12, it can be explained that at 19.00 PM-3.00 AM it is the period in which the hybrid power plant supplies lower load requirements resulting in a power surplus. In this period surplus power was used to charge the batteries. From 3:00 a.m. - 7:00 p.m. is a period where the total power of a hybrid power plant cannot supply full load. So that during that period the battery will discharge its energy to increase the power shortage of hybrid power plants. The increase in load to reach the peak load occurs during the day, so most of the power used to charge the battery comes from biogas and hydro power.

The characteristic combination of hybrid power including batteries and utility grid of on grid mode is as shown in Fig. 13.

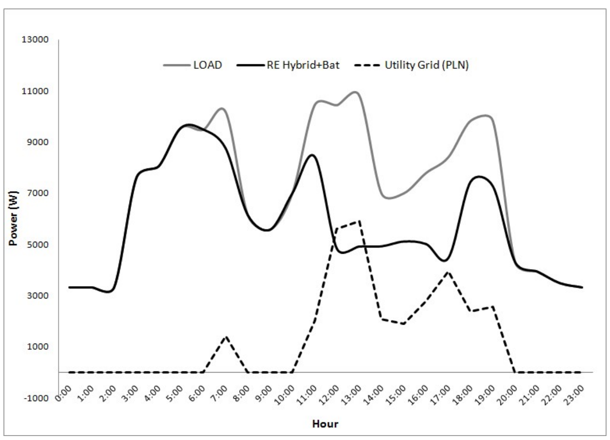

Fig. 13. Load, RE Hybrid+Batteries, and Utility Grid (PLN)

In Fig. 13, it can be explained that Hybrid power plants including battery storage still cannot meet fully load demand during peak load periods, so the system automatically imports power from the grid utility (on-grid mode). One of the advantages of RE hybrid power plant with on-grid mode at the project pilot location is that the system can maintain the continuity of the power supply so it does not interfere with school activities. The average total power requirement in a day is around 168.9 kWh, the average power supplied from RE hybrid is 148.1 kWh, and the average power imported from the utility grid is 30.6 kWh.

Some other modes that are important to be applied in RE power Hybrid systems are grid protection systems. Some of the protection modes applied in hybrid RE power are as follows:

- *Self healing*: a term used to describe the ability of an electric grid to detect, predict, anticipate and respond to disturbances that occur in the system quickly based on data or information sent by sensors that have been installed. For example, when there is a disturbance in the utility transformer, the protection system will automatically isolate the interference without waiting for the operator, so that it does not disturb other grid and does not cause blackouts.
- *Anti Islanding*: if there is a disturbance on the grid, the system will automatically disconnected the utility grid (off-grid) to ensure local grid safety and the utility operator can safely correct the problems that occur on the grid, while the load is still supplied by the local RE hybrid power system.

IV. Conclusion

The Energy Management System (EMS) has an important role in every hybrid power plant application. EMS is used in optimizing local energy sources, scheduling power plants, regulating power distribution in grid to be more efficient and reliable, optimizing continuous operation and matching all power plants to load demands. The results of the EMS design test on the smale-scale hybrid renewable energy (RE) power plant at the pilot project location indicate a decrease in the power requirements of the utility grid along with the use of local RE such as hydro, biogas, and solar as a more environmentally friendly energy source. In its development, the methods applied in EMS can vary depending on the characteristics of the power plant source, load demand, and complexity of the electricity grid.

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References

[1] K. Balachander,“ Comparative Study of Hybrid Photovoltaic-Fuel Cell System/Hybrid Wind-Fuel Cell System for Smart Grid Distributed Generation System,” 2012 IEEE International Conference on Emerging Trends in Science, pp. 462-466, December 2012.

[2] K. Handayani, Y. Krozer, and T. Filatova, “From fossil fuels to renewables: An analysis of long-term scenarios considering technological learning,” Energy Policy, ScienceDirrect, vol. 127, pp. 134-146, April 2019.

[3] Y. Lu, Z. A. Khan, M. S. Alvarez-Alvarado, Y. Zhang, Z. Huang, and M. Imran, “A Critical Review of Sustainable Energy Policies for the Promotion of Renewable Energy Sources,” Review, sustainability, MDPI, vol. 12, No. 5078, pp. 1-30, 2020.

[4] I. A. Nassar, I. M. Kassem, and M. N. Ali,“Influence of using Intermittent Renewable Energy Sources on The Power System Operation,” 2019 21st International Middle East Power Systems Conference (MEPCON), IEEE, pp. 462-466, December 2019.

[5] H. Zsiborács, N. H. Baranyai, A. Vincze, L. Zentkó, Z. Birkner, K. Máté, and G. Pintér ,“Intermittent Renewable Energy Sources: The

Role of Energy Storage in the European Power System of 2040," Article, electronics, MDPI, vol. 8, No. 729, pp. 1-18, 2019.

[6] J. Rugolo and M J. Aziz.,"Electricity storage for intermittent renewable sources", Energy & Environmental Science, 2012 (5), pp: 7151-7160.

[7] F. Bourennani, S. Rahnamayan, G. F. Naterer,"Optimal Design Methods for Hybrid Renewable Energy Systems", International Journal of Green Energy, Vol. 12/2, pp.148–159, 2015.

[8] H. H. Fathima and K. Palanisamy,"Optimization in microgrids with hybrid energy systems-A Review", Renewable and Sustainable Energy Reviews, Vol. 45 (C), pp. 431-446, 2015.

[9] H. T. Dinh, J. Yun, D. M. Kim, K. H. Lee, and D. Kim,"A Home Energy Management System With Renewable Energy and Energy Storage Utilizing Main Grid and Electricity Selling", IEEE Access, Vol. 8, pp. 49436 – 49450, 2020.

[10] M. Jariso, B. Khan, S. Tanwar, S. Tyagi, and V. Rishiwal,"Hybrid Energy System for Upgrading the Rural Environment", 2018 IEEE Globecom Workshops (GC Wkshps), December 2018.

[11] S. Linn and A. Z. Ya,"Solar/Wind/Diesel Hybrid Energy System with Battery Storage for Rural Electrification", International Journal of Scientific Engineering and Technology Research, Vol. 03, Issue. 10, pp. 2172-2176, May 2014.

[12] S. Rehman, and I. El-Amin,"Study of a solar pv/wind/diesel hybrid power system for a remotely located population near Arar, Saudi Arabia", Energy Exploration and Exploitation, Vol. 33, No. 4, pp. 591-620, 2015.

[13] J. Jurasz and B. Ciapala,"Solar–hydro hybrid power station as a way to smooth power output and increase water retention", Solar Energy, Vol. 173, Elsevier, pp. 675-690, October 2018.

[14] P. Roy, J. He, T. Zhao, and Y. V. Singh,"Recent Advances of Wind-Solar Hybrid Renewable Energy Systems for Power Generation: A Review", IEEE Open Journal of the Industrial Electronics Society, Vol. 3, pp. 81-104, Januari 2022.

[15] E. T. S. Lobo, Rombe, and M. Sau,"Testing of Solar –Wind Energy Hybrid System Small Scale", The 1st International Conference on Education and Technology (ICETECH) 2019, IOP Conf. Series: Journal of Physics: Conf. Series 1464 (2020) 012048.

[16] G .M. S. U. Al-Mamun, M. R. Hasan, M.I. Hossain, A.A. Atik, A. J. Hossain, S. M. M. D'Costa, A. Rahman, and A. S. M. S. Imam," Design and Analysis of a Solar-Wind Hybrid System", Journal of Power Electronics & Power Systems, Vol. 10, Issue 1, pp. 1-7, 2020.

[17] K. Allali, E.B. Azzag, and N. Kahoul,"Modeling and simulation of a Wind-diesel Hybrid Power System for Isolated Areas", International Journal of Computer Applications, Vol. 166(23), pp. 18-24, 2015.

[18] H. M. Mahmudul, M. G. Rasul, D. Akbar, and M. Mofijur," Opportunities for solar assisted biogas plant in subtropical climate in Australia: A review", Energy Procedia, Vol. 160, pp. 683-690, February 2019.

[19] A. Z. AL Shaqsi, K. Sopian, and A. Al-Hinai,"Review of energy storage services, applications, limitations, and benefits", Energy Report, Vol. 6(7), pp. 288-306, December 2020.

[20] T. Bocklisch," Hybrid Energy Storage Systems for Renewable Energy Applications", Energy Procedia, Vol. 73, pp. 103-111, June 2015.

[21] L. Brandeis, D. Sprake, Y. Vagapov, H. Tun,"Analysis of electrical energy storage technologies for future electric grids", 2016 IEEE NW Russia Young Researchers in Electrical and Electronic Engineering Conference (EIConRusNW), 2016.

[22] E.K. Lee, W. Shi, R. Gadh, and W. Kim,"Design and Implementation of a Microgrid Energy Management System", Article, sustainability, MDPI, Vol. 8(1143), pp. 1-19, November 2016.