2022 IEEE Nigeria 4th International Conference on Disruptive Technologies for Sustainable Development (NIGERCON) | 978-1-6654-7978-3/22/$31.00 ©2022 IEEE | DOI: 10.1109/NIGERCON54645.2022.9803082

An Overview of Configurations and Dispatch Strategies in Hybrid Energy Systems

Saheed Ayodeji Adetoro
Department of Electrical and Electronics Engineering
Federal University of Technology Minna,
Minna, Nigeria.
adetoroayo@gmail.com

Lanre Olatomiwa
Department of Electrical and Electronics Engineering
Federal University of Technology Minna,
Minna, Nigeria.
olatomiwa.l@futminna.edu ng

Jacob Tsado
Department of Electrical and Electronics Engineering
Federal University of Technology Minna,
Minna, Nigeria.
tsadojacob@futminna.edu.ng

Solomon Musa Dauda
Department of Agricultural and Bioresources Engineering
Federal University of Technology Minna,
Minna, Nigeria.
smdauda@futminna.edu.ng

***Abstract*— Growing concern about the exhaustibility of fossil fuel, in addition to its harmful effect on the environment, has led to a rise in the involvement of renewable sources such as solar and wind in energy production. Although these sources are sustainable and environmentally friendly, they are also intermittent by nature, varying depending on the weather. As a result, the power available to loads can be unpredictable. Therefore, a single renewable energy generator may not consistently meet the energy demand of a given geographic location. This uncertainty can be minimized by an optimal combination of different but complementary renewable energy resources. However, integrating multiple generation units, with different output characteristics, adds complexity to the renewable energy system operations; therefore, a proper energy management strategy (EMS) is necessary to ensure optimum utilization of renewable sources and cost-effectively meet energy demand. Significant approaches adopted in past literature on configurations discussed and a combined dispatch strategy suitable for renewable energy systems connected to an unreliable grid is proposed in this paper.**

Keywords— Hybrid Renewable Energy Systems (HRES), hybrid energy system coupling, hybrid energy system configuration, Energy Management System (EMS), dispatch strategy.

I. INTRODUCTION

Combinations of various but complementary renewable energy systems, sometimes mixed with a dispatchable conventional energy source like diesel/gasoline generator as backup, is known as Hybrid Renewable Energy System (HRES). This has been proposed as a reliable and cost-effective solution to the unreliability and high lifetime cost of the single-source renewable energy system [1]–[3]. The optimum design of the HRES reduces the impact of uncertainties associated with the intermittency of renewable energy resources. Renewable energy systems such as photovoltaic, wind turbine, hydro, and biogas systems all work together in combination with some sort of energy storage system, compensating each other to satisfy a particular load demand. In designing a stand-alone HRES for a location that has a load profile with a peak load that needs to be met for a short period, it is cost-effective to incorporate a dispatchable energy unit, like a diesel/gasoline generator into the energy system that can readily be activated to meet the peak energy demand—this is known as the peak shaving strategy [7]. As fossil fuel-based power generation pollutes the environment, therefore it is necessary to carry out a greenhouse gas emission analysis of such a HRES with diesel/gasoline backup [2]. For a reliable and cost-effective system, a proper component selection and optimum sizing of the different HRES constituents becomes necessary. In addition, an efficient EMS is vital to ensure optimum power management of the whole HRES [4]. This strategy determines the most economical energy flow throughout the system, creating synergies among the HRES component. Making these system components work together holistically can be very complex; thus, it is necessary to know the most essential factors in order to develop a suitable EMS that ensures the best result economically and technically [5].

The energy management strategy is usually integrated with optimization of the system with the aim of ensuring continuity of power flow in all situations, minimizing the overall cost of energy production and protection of the system components. Thus, EMS refers to the methodical procedures to economical dispatch and control the HRES. This paper presents an extensive review of the approaches offered and adopted in recent times by various authors on HRES configurations and management strategies. Different HRES topologies comprising various combination of renewable energy sources, energy storage and backup systems that have been implemented in literature is presented in Section 2. The third section briefly discusses the functions and importance of EMS. A combined energy dispatch strategy for determining the most economical power flow among components of a HRES connected to an unreliable grid was proposed in Section 4. Finally, Section 5 is the concluding remarks.

II. HYBRID ENERGY SYSTEM CONFIGURATIONS

HRES can be categorized into two main configurations: stand-alone/off-grid and grid-connected/on-grid system [6]. In an on-grid HRES application, energy can be bought or sold to the utility grids at a particular tariff whenever there is energy excess or energy deficit from the HRES respectively. This type of central grid-linked system is adopted to help reduce the stress on the central grid to meet growing energy demand. Also for those that are conscious of the environment

978-1-6654-7978-3/22/$31.00 ©2022 IEEE

and prefer cleaner sources of energy to power their homes, the national grid can serve as a backup system, eliminating the cost of expensive battery banks [7]. The off-grid application has been shown to be cost-effective for rural electrification. Hence, it is suitable for providing electricity to remote locations, which are not connected to the utility grid [8]. As HRES comprises of multiple energy technologies that have different output characteristics, therefore a standard procedure is essential for incorporating renewable energy sources. Generally, the schemes used to interlink the energy sources to the hybrid system can be categorized into direct current (DC) coupled, alternating current (AC) coupled, or hybrid DC/AC coupled schemes. The appropriate scheme typically depends on the kind of energy source and connection bus voltage; AC or DC [9]. A fraction of the input power is lost due to converters' inefficiencies, therefore it is better to use output directly, without transforming from one type to the other. Hence, DC-bus coupling is appropriate if most generations and loads are DC. Likewise, AC-bus coupling is suitable for a hybrid energy system with mostly AC generation and loads [10]. If the power sources of the HRES are a fair mixture of AC and DC output power, then a hybrid ac/dc bus system design is appropriate.

A. *DC-Coupled Scheme*

In a DC-coupled system, different energy sources are linked to a DC bus directly or through electronic power converters as shown in Fig. 1. It is more efficient to use DC-bus coupling if most generation and loads are DC; moreover, no synchronization is required [11]. AC loads and the central grid can also be interfaced to the DC bus through a power converter, designed to condition and facilitate the flow of power [12], [13]. González et al. [7] proposed a DC-coupled HRES comprising solar PV, biomass, wind turbine and the national grid that could be set up in an agrestic community of over a thousand residences. Suganya & Arivalahan [13] developed a model on MATLAB/Simulink for power management of HRES, using DC/DC converter to couple all energy sources to the main DC bus bar.

B. *AC-Coupled Scheme*

In this integration configuration, different generation sources are synchronized and linked to the AC-bus through the appropriate power electronic circuitry. As shown in Fig. 2, the battery bank can also be connected to the AC-bus through a bidirectional converter to store excess power or supply power to the AC load in times when the renewable energy sources can not meet the energy demand [14]. In the AC-coupled configuration, DC loads can be fed directly from the battery storage or via AC/DC power converter [15].

C. *Hybrid (AC/DC) -Coupled Scheme*

This type of scheme is suitable if the HRES has an equitable number of AC and DC power generators. Instead of converting and linking all the generator sources to a single DC or AC distribution bus as discussed in the previous schemes, this configuration allows for the connection of AC and DC energy sources directly to an AC and DC distribution bus, respectively as shown in Fig. 3. This is a more efficient way to integrate energy sources into the HRES; as a fraction of input power, depending on converter efficiency, is lost every time it is converted from one power type to another. Also, the high cost of electronic power converters can be avoided [9], [16], [17]. However, the complexity of energy management and control of this type of configuration may be more complex as compared to the DC-coupled and AC-coupled schemes [18].

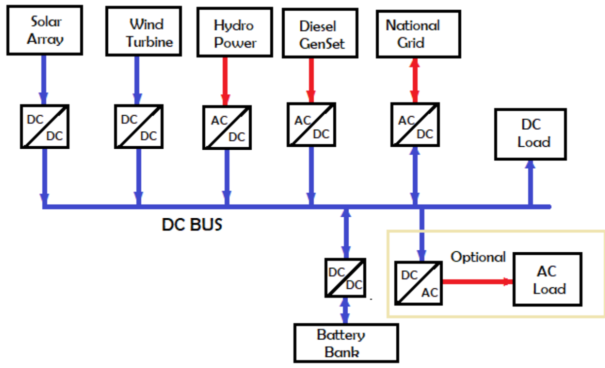


Fig. 1. DC-coupled energy system configuration

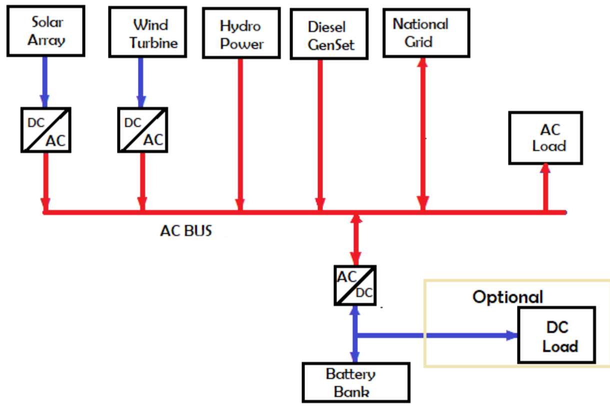


Fig. 2. AC-coupled energy system configuration

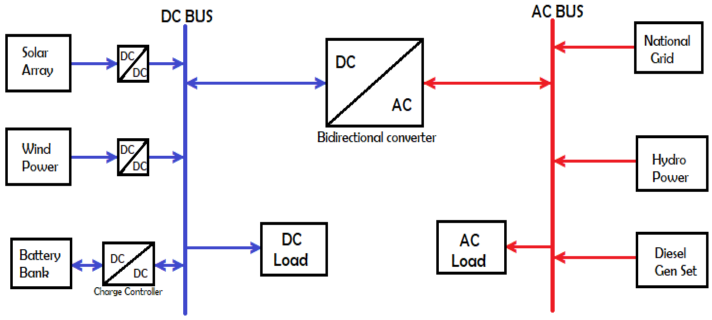
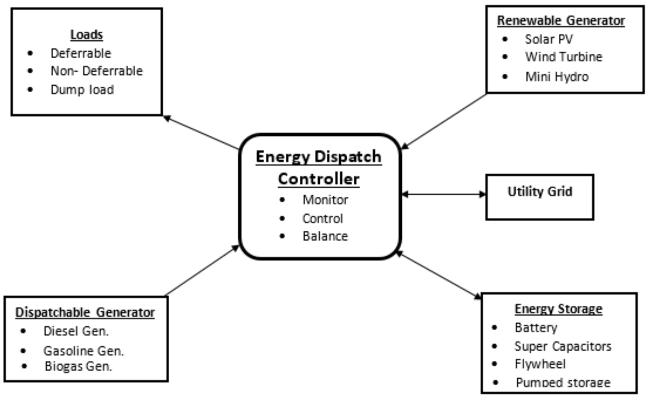


Fig. 3. Hybrid AC/DC-coupled energy system configuration

III. ENERGY MANAGEMENT SYSTEM

The cost-effectiveness of HRESs depends on proper sizing of the individual component and appropriate dispatch strategy. Most studies on the optimisation of HRESs focus on the techno-economic parameters with little or no consideration of the actual operational energy dispatch [18]. EMS is an essential element of HRES as they are entrusted with the economic dispatch of energy sources, component operation and protection. The dispatch controller is the hub of the EMS as shown in Fig. 4. Controlling of HRES can be done on two distinct levels: (1) dynamic control, which deals with the regulation of the frequency and magnitude of the system output voltage and (2) economic dispatch control, which deals with the optimal flow of energy among various system component. The economic dispatch strategy for a HRES is a control algorithm for determining the most economical combination of power sources to meet the load demand and protect the system component from overload. The analysis is usually carried out on a time step of minutes to hours in which conditions are assumed to be constant [19].



Fig, 4. Block diagram of the Energy Management System

The EMS is vital for the protection of the system components from overloading and optimal apportioning of generating units to meet the energy demand at a particular time. Energy dispatch strategy refers to the aspect of an energy control algorithm that has to do with the optimal flow of energy among the main components of the HRES. Since the power output from renewable sources is difficult to predict, therefore cannot be dispatched at will but has to utilize when available or stored for later use. Several distinctive dispatch strategies can be used with any combination of renewable energy sources, utility grid, energy storage and conventional power generators to economically meet a load requirement. Priority is generally given to renewable energy sources in order to minimize operational costs and greenhouse gas emissions. Typically, when the energy demand by the load is minimum, the power generating technology with the lowest cost of energy (COE) is deployed first. Progressively more expensive energy sources are engaged as the demands increase. Hourly energy output from renewable sources is deducted from load energy demand to ascertain the netload as expressed in (1).

$$E_{Netload}(t) = E_{Load-demand}(t) - E_{Renew}(t) \quad (1)$$

Where $E_{Netload}(t)$the deficit energy is after power is supplied by the renewable energy sources at time t, $E_{Load-demand}(t)$ is total load energy demand at time t and E_{Renew} is the total energy supplied by the renewable energy source at a particular time t.

IV. PROPOSED COMBINED ENERGY DISPATCH STRATEGY

Usually, in grid-connected HRES the national grid is considered a reliable backup/storage system, where deficit or excess energy can be drawn or injected as the case may be [20]–[21]. This type of scheme would be a challenge for many developing countries, where the grid supply can be unstable. The following sub-section discusses proposed combined dispatch strategies to meet the net energy demand after supply from the primary sources (renewable energy sources) have been used to service the load demand at a particular time step. A strategy is presented for every possible scenario with the grid considered stochastic, suitable for locations with unreliable grid supply. Fig. 5 illustrates the flow chart for the combined dispatch strategy, in a typical hybrid AC/DC-coupled energy system.

A. Battery Mode Strategy

A battery bank mode is used to either absorb excess energy or supply energy deficit during high or low power output from renewable energy sources respectively. Hence, this strategy can operate in either battery charging mode or battery discharging mode.

- **Battery charging strategy:** Battery charging strategy may be used when the total energy produced from the renewable energy generators surpasses the load demand at a particular time i.e. the netload is negative.

$$E_{Renew}(t) > E_{Load-demand}(t) \quad (2)$$

  The battery bank is used to store the excess energy, provided the predetermined maximum SOC of the battery is not reached. In a condition when the battery is fully charged, then the excess power is absorbed by the dump load (usually water pump and heater). The energy is directed to the battery storage until one or both of these conditions are met: (1) Netload becomes positive (2) Maximum SOC of the battery is reached.

- **Battery discharging strategy**: In a scenario when the energy required by the load exceeds the accumulated energy produced by renewable sources, then the Battery discharging strategy can be used to supply the whole or part of the netload. In a particular time step, if the renewable energy sources are not sufficient to meet the load demand, then the stored energy from the battery bank may be deployed to supply energy deficit until at least one of the following conditions is met: (1) lowest battery SOC is attained (2) power from the renewable energy source is equal or exceeds the load demand, in other words, when the net load is zero or negative.

B. Grid Supply Strategy

In a grid-connected HRES, at a particular time step when power from the grid is available and the load demand exceeds the sum of the energy produced by renewable energy sources and the energy stored in a battery bank (i.e., when the expression in (3) and (4) are both true) then supply may be taken from the national grid.

$$E_{Grid}(t) > 0 \quad (3)$$

$$E_{Load-demand}(t) > E_{Renew}(t) + E_{Batt}(t-1) \quad (4)$$

Where $E_{Batt}(t-1)$ is the total energy stored in the previous time step and $E_{Grid}(t)$ is the energy available from the grid.

This strategy continues until the power output from renewable sources is just enough to meet the load requirement (i.e. net load is zero).

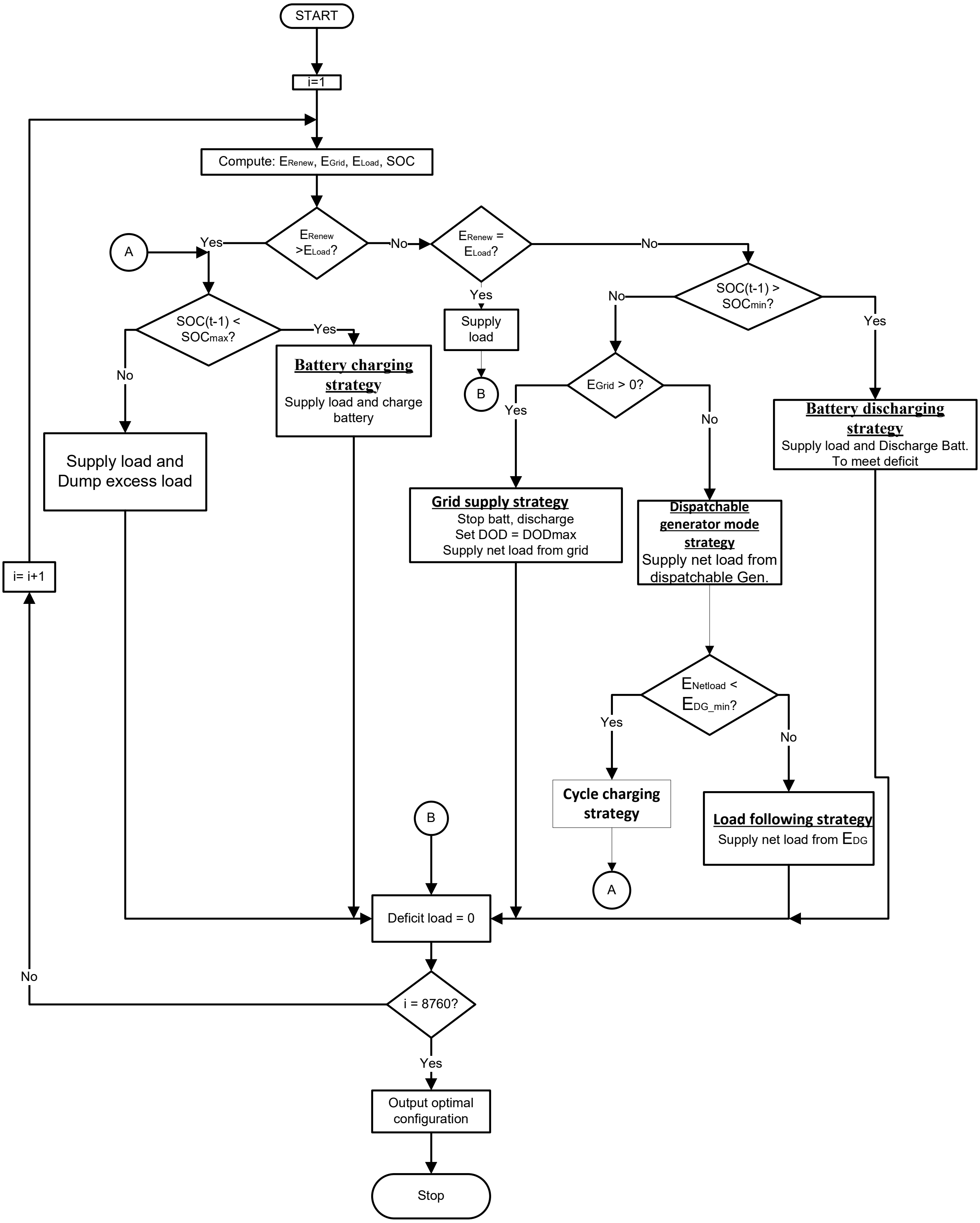


Fig. 5. Flow chart of the proposed combined dispatch strategy for HRES connected to an unreliable grid

C. Dispatchable Generator Mode Strategy

When the power output from renewable energy generators and energy stored in battery bank cannot completely meet the load demand also no supply from the national grid (in case of grid-connected HRES) in this situation a dispatchable power source (usually a diesel/gasoline generator) may be activated to meet just the netload. The generator can either be operated in load-following mode or cycle charging mode.

- **Load following strategy:** In load-following mode, the diesel/gasoline generator can be operated to meet just the netload and not charge the energy storage system and it keeps running until the energy from renewable sources is enough to at least meet the load requirement. The dispatchable power generator is prescribed a minimum run time in order to moderate the generator's start/stop frequency, therefore minimizing the rotating cost associated with diesel/gasoline power generators.

- **Cycle charging strategy:** In this strategy, the diesel/gasoline generator starts when required and operates at maximum set capacity to meet the net load and -surplus energy is then used to recharge the energy storage system. Once the diesel/gasoline generator is activated, it continues operating for its preset minimum run time, after that, the generator is deactivated when: (1) the predetermined maximum SOC point has been reached or/and (2) the energy from renewable sources is enough to at least meet the load requirement. The cycle charging strategy has some advantages as well as disadvantages. The use of diesel/gasoline power to charge the energy storage system during cycle charging strategy have the following benefits: (1) allowing the generator to run at higher power output, thereby maximizing diesel/gasoline fuel efficiency and (2) minimizing the diesel/gasoline start frequency. On the other hand, the demerits of cycle charging strategies include: (1) shortening of battery service life (2) lost opportunities for storing energy from renewable sources in the batteries and (3) electrical losses during power conversion and in the battery.

V. CONCLUSIONS

Different approaches for HRES configuration and energy dispatch strategy have been discussed in this paper. Although, HRES are been shown to be a viable solution to mitigate the stochastic nature of renewable energy sources. A proper control system is crucial to achieving the highest system efficiency and reliability. Therefore, major HRES design paradigms and dispatch techniques have been discussed and compared with one another. A combined dispatch strategy was thereby proposed in which the utility grid is considered stochastic. This is suitable for most developing countries like Nigeria with erratic power supply from the grid.

REFERENCES

[1] O. Krishan and S. Suhag, "Techno-economic analysis of a HRES for an energy poor rural community," J. Energy Storage, vol. 23, no. April, pp. 305–319, 2019.

[2] M. Hossain, S. Mekhilef, and L. Olatomiwa, "Performance evaluation of a offgrid PV/diesel/wind/battery hybrid system feasible for a large resort center in South China Sea, Malaysia," Sustain. Cities Soc., vol. 28, pp. 358–366, 2017.

[3] L. Olatomiwa, S. Mekhilef, A. S. N. Huda, and O. S. Ohunakin, "Economic evaluation of HES for rural electrification in six geo-political zones of Nigeria," Renew. Energy, vol. 83, pp. 435–446, 2015.

[4] E. M. A. Mokheimera, A. Al-Sharafia, M. A. Habiba, and I. Alzaharnah, "A Study for Hybrid Wind/ PV off-Grid Power Generation Systems with the Comparison of Results from Homer," Int. J. Green Energy, vol. 12, no. 5, pp. 526–542, 2015.

[5] I. Riverón, J. F. Gómez, B. González, and J. A. Méndez, "An intelligent strategy for hybrid energy system management," no. 17, pp. 550–554, 2019.

[6] A. Maleki, M. A. Rosen, and F. Pourfayaz, "Optimal Operation of a Ongrid HRES for Residential Applications," Sustainability, vol. 9, pp. 1–20, 2017.

[7] A. González, J. Riba, and A. Rius, "Optimal Sizing of a Hybrid ongrid Wind-PV-Biomass Power System," Sustain. 2015, vol. 7, pp. 12787–12806, 2015.

[8] C. Ghenai, T. Salameh, and A. Merabet, "Technicoeconomic analysis of stand alone PV-Fuel cell energy system for residential community in desert region," Int. J. Hydrogen Energy, pp. 1–11, 2018.

[9] M. H. Nehrir et al., "A Review of HRES for Electric Power Generation: Configurations, Control, and Applications," IEEE Trans. Sustain. ENERGY, vol. 2, no. 4, pp. 392–403, 2011.

[10] E. Vossos, "Optimizing Energy Savings From ' Direct Dc ' In U.S. Residential Buildings," San José State University, 2011.

[11] A. Abdelka, A. Masmoudi, and L. Krichen, "Assisted power management of a stand-alone renewable multi-source system," Energy, vol. 145, pp. 195–205, 2018.

[12] S. Al-Sakkaf, M. Kassas, M. Khalid, and M. A. Abido, "An Energy Management System for Residential," Energies, vol. 12, pp. 1–25, 2019.

[13] B. S. Suganya and R. Arivalahan, "Power Management of HRs Integrated with Energy StSrage System," Int. J. Innov. Res. Electr. Electron. Instrum. Control Eng., vol. 3, no. 2, pp. 123–128, 2015..

[14] Q. Tan, S. Mei, Q. Ye, Y. Ding, and Y. Zhang, "Optimization model of a combined PV/wind/thermal dispatching system under carbon emissions trading in China," J. Clean. Prod., vol. 225, pp. 391–404, 2019.

[15] B. B. Naik and M. Rambabu, "Energy Management by Using Renewable Energy Sources," Int. J. Innov. Technol. Explor. Eng., vol. 8, no. 8, pp. 315–322, 2019.

[16] S. Singh, P. Chauhan, and N. Singh, "Capacity optimization of grid connected solar / fuel cell energy system using hybrid ABC-PSO algorithm," Int. J. Hydrogen Energy,, 2020.

[17] A. Serpi, M. Porru, and A. Damiano, "An Optimal Power and Energy Management by Hybrid ESS in Microgrids," Energies, vol. 10, no. 1909, pp. 1–21, 2017.

[18] H. Qiu et al., "Multi-interval-uncertainty constrained robust dispatch for DC/AC hybrid microgrids with dynamic energy storage degradation," Appl. Energy, vol. 228, no. June, pp. 205–214, 2018.

[19] B. Soudan and A. Darya, "Autonomous smart switching control for off-grid hybrid Solar-battery-diesel power system," Energy, vol. 211, pp. 1–16, 2020.

[20] V. Khare, S. Nema, and P. Baredar, "International Journal of Sustainable Optimisation of the HRES by HOMER, PSO and CPSO for the study area," Int. J. Sustain. Energy, no. March, pp. 37–41, 2015.

[21] P. Rullo, L. Braccia, P. Luppi, D. Zumoffen, and D. Feroldi, "Integration of sizing and energy management based on economic predictive control for offgrid HRES," Renew. Energy, vol. 140, pp. 436–451, 2019.