

## Comparative Analysis of an Optimal Perturb and Observe Control Scheme for Efficient Energy Management of Hybrid Power System using Aquila Optimization Algorithm

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### ABSTRACT

Renewable energy systems are now seen as a better alternative means of generating energy than the fossil fuel generators due to their availability and minimal or near zero negative impact on the environment. However, the continuous increase in the demand of electrical energy, has makes it difficult for these sources to meet the demand especially during unfavorable weather conditions. As such a suitable solution to this problem is the usage of hybrid power systems. However, there is need to effectively control this hybrid systems to ensure that energy from this system are readily available, affordable and reliable. This work therefore seeks to develop a hybrid power system comprising of solar PV, wind system, diesel generator and battery energy system to solve the problem of inability to provide electrical energy in special weather condition. Furthermore, the solar PV MPPT strategy will be modified to ensure that the hybrid system obtain significant energy from the sun. Excess energy will be stored while power shortages will be prevented by using diesel generator at critical times. The effectiveness of the perturb and observe MPPT strategy in the solar PV will be improved by using Aquila optimizer to ensure that maximum energy is tracked from the solar PV system. Lastly, Aquila optimization algorithm will be used to solve the optimization problem of the hybrid system using levelized cost of energy and loss of power supply probability as performance metrics.

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### INTRODUCTION

The world's primary energy supply is majorly from fossil fuels. However, the adverse effect that emanates from generating energy from fossil fuel such as: increase in CO<sub>2</sub> level, volatile organic compounds, toxic heavy metals make its usage less attractive (Pookpant, 2019). These disadvantages coupled with the volatility of fuel price and exponential continuous increase in energy demand has led to researchers/ government looking for better alternative mean of generating electricity. Renewable energy sources (RES) such as hydropower, solar PV, wind, biogas and solar are now seen as better alternative to the conventional generators (Kumar *et al.*, 2020). This

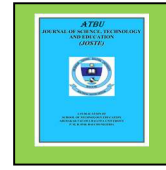
is because generation of energy from the sources guarantees reduction in environmental pollution stemming from the conventional means of generating energy. The exponential growth in the usage of RES to meet the load demand is encouraging, however, there are challenges associated with their wider adoption. Firstly, energy from these sources is largely dependent on the geographical location and weather locations. Furthermore, their inherent intermittent nature can cause power mismatch between supply and demand, network constraints and power quality issues (Le *et al.*, 2023). Photovoltaic systems remain one of the most widely used RES. Energy from PV system is clean and less harmful

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to the environment (Mustafa *et al.*, 2020). However, like outputs from other RES, power generation from PV system highly depends on weather conditions (solar irradiance and temperature), such that the power output fluctuate due to the stochastic weather condition (Maheshwari *et al.*, 2023). As such, to ensure the availability of power supply at all times, there is need to develop a means of maximizing extraction of energy from the solar PV. Maximum power point tracking (MPPT) algorithms can be employed with such RESs to solve the problem of unavailability of power supply. As an operational strategy, the RESs running at the set points recommended by the MPPT, however, occasionally cannot supply the precise amount of power committed based on the forecasted power taking such unpredictable inputs into account (Hafis *et al.*, 2023). As such researchers are modifying the MPPT strategies to address the issue. Also, storage elements are also incorporated into the system to improve the reliability. These components have the capacity to deliver the required power while meeting specific requirements that differ depending on the type of storage element (Khatri *et al.*, 2023). And when there is excess supply from the RES, the battery will be switched to charging mode. The RES generation should be equipped with properly sized BESS for optimizing the cost of operations for profitability (Kamal *et al.*, 2023). As such, combining energy storage system with RES to form an hybrid system will ensure generation of power supply that is dependable, effective and economical (Kumar *et al.*, 2020). When RES power systems are highly unreliable due to climate and meteorological circumstances, a hybrid system that combines solar and wind power sources optimally attenuates significant power variations. On the other hand, hybrid storage systems paired with off-grid micro-grid hybrid renewable energy systems offer a precise remedy for power outages in isolated regions. This can be attributed to inadequate resource distribution, difficulty balancing supply and demand, and lack of access to the power grid. The optimal synchronization and interaction between demand, generating output, efficiency factors, and the

energy management approach determines the performance and dependability of HRES (Kamal *et al.*, 2023; Le *et al.*, 2023).

Several works on optimal configuration of HRES for different rural areas have been carried out in order address the negative effect of bad weather conditions on the power output. (Gabbar *et al.*, 2020) presented an optimal planning scheme for nuclear-renewable hybrid-energy system using particle swarm optimization technique. The scheme was developed in order to create a scheme that will effectively reduce the green-house gas emissions and maximize cost while generating cost effective energy that meet the load demand of Ontario tech university campus. However other algorithms with better exploration capability needs to be used because PSO suffers from having global best result not within the search space. (Islam *et al.*, 2023) also worked on economic analysis of HRES for an health centre in Bangladesh. Furthermore (Djilali *et al.*, 2024) developed an energy management technique for hybrid power system that will ensure availability of power at all times in the rural community chosen. The work focused on improving the perturb and observe (P&O) scheme of the solar PV component, which formed one of the major components of the hybrid system employed. The improvement was done by using fuzzy logic technique to ensure that solar PV captures maximum power during favourable weather conditions. However, there is need to use a better control technique that has good precision ability, to ensure that errors in tracking the maximum power at all times is improved. As such this work seek to develop an optimal energy management scheme for hybrid renewable energy system that will not only ensure availability of power during good and bad weather conditions but also at an improved cost.

Several papers has been published in the related field to mention but few among which include, (Gabbar *et al.*, 2020) used an optimization technique for the optimal planning of nuclear-Hybrid RES. (Zhao *et al.*, 2021) presented an optimal sizing of isolated micro-grid comprising of photovoltaic, wind turbine, diesel generator, photo-thermal, ESS and load. (Khan *et al.*, 2022)

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did a techno-economic analysis of island hybrid renewable system for rural applications. (Ibrahim *et al.*, 2023) optimized step-size of P&O and incremental conductance MPPT techniques in a grid connected PV system. The work focused on developing a MPPT scheme that will guarantee that maximum power is being extracted from the solar PV under varying weather conditions. (Islam *et al.*, 2023) presented a techno-economic analysis of HRES for a healthcare centre in Bangladesh. (Wali *et al.*, 2023) did an assessment of a HRES for a rural community. (Araoye *et al.*, 2024) did modeling of optimal sizing of hybrid MG RES for a rural location. (Djilali *et al.*, 2024) presented a new scheme for efficient management of hybrid power system. This is done in order to ensure the availability of electrical energy even during special weather conditions. This paper therefore is aimed at analysing an optimal perturb and observe control scheme for efficient energy management of hybrid power system using aquila optimization Algorithm. Furthermore, Aquila optimize will be applied on the hybrid system for effective optimal sizing, to minimize the levelized cost of energy and loss of power supply.

## RENEWABLE ENERGY RESOURCES

Energy forms the basis of human's everyday life (Sumathi *et al.*, 2015b). The development of any nation depends directly on the level of energy generated or consumed. Energy requirements keep increasing since the time of industrial revolution. Balancing demand and supply of energy has been a great issue that nations has been battling to solve (Jibril *et al.*, 2019). Because renewable energy sources are abundant in nature and environmentally benign (also known as "green energy"), they are gaining significant attention globally. Examples of these resources include hydro, wind, sun, biofuels, geothermal, wave, and tidal powers. According to Scientific American, all of the world's energy needs can be met by renewable energy sources alone, provided they have enough storage. By 2050, renewable resources might provide 50% of the world's energy needs, according to a different UN IPCC research. Following the recent nuclear

accident in Japan, Germany and Japan are placing a strong emphasis on renewable energy. In order to fulfill our expanding energy needs and slow down global warming, wind and solar resources—which rely mostly on power electronics for conversion and control—are especially crucial (Muller *et al.*, 2023).

## Solar PV

PV devices directly convert sunlight into electricity, using silicon (crystalline or amorphous), copper indium gallium selenide, and CdTe. After that, the generated DC is converted to AC and either used in an isolated load or fed into the grid. A battery backup energy source is typically present in an autonomous system (Sulaiman *et al.*, 2024). A typical PV system layout is depicted in Figure 1, where a PV string is made up of a series-parallel cell combination. A DC–DC converter increases the generated DC voltage before a PWM sinusoidal inverter converts it to AC. By using MPPT control, the DC-DC converter regulates the string's maximum power output. Before connecting to the AC grid, the channels are voltage-boosted by a transformer and paralleled on the AC side. Additionally, a transformer less multilevel cascaded H-bridge (CHB) connection has been suggested (Wu *et al.*, 2011). Unlike wind power sources, photovoltaic (PV) devices offer the advantages of being static, safe, dependable, environmentally clean, and low maintenance. Though it really depends on the installation cost and utilization factor, PV energy is now more expensive than wind energy as seen in figure 1.

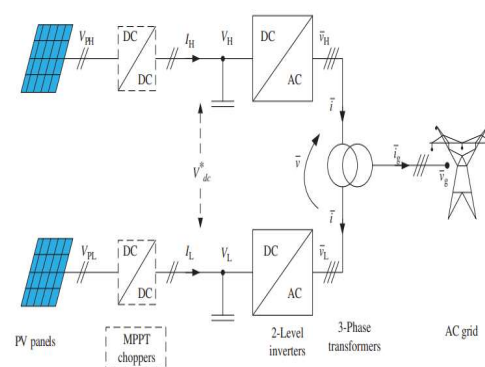


Figure 1: Solar PV Configuration Wu *et al.*, (2011).

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When weighed against the cost of PV cells, power electronics is less expensive. PV energy is now more expensive than solar thermal energy, however because to the current vigorous research trend, the price is rapidly declining to become more competitive in the future. Global PV energy consumption is predicted to rise significantly. The IEEE makes the audacious claim that by 2050, photovoltaic systems will provide 11% of the world's electricity needs (Divan & Sharma, 2024). Given the current trajectory, it shouldn't come as a surprise if PV power surpasses wind power in the future. With the widely used thin-film amorphous silicon, a photovoltaic panel's lifetime is normally 20 years, and its conversion efficiency is approximately 16%. Space applications have made substantial use of PV electricity (where cost is not a factor) (Wu *et al.*, 2011). Their uses are currently growing to include grid-connected installations, off-grid remote applications, and rooftop installations. Given that it lacks abundant natural energy supplies and that energy is expensive there, Japan is strongly committed to PV research and applications. Japan is currently shifting its focus from nuclear to photovoltaic resources in response to the recent accident at the Fukushima Daiichi nuclear reactors. Recently, China has started manufacturing PV cells quite economically. Unfortunately, like wind, PV power is likewise statistical in nature and hence requires backup energy sources or bulk storage of extra power. The recent smart grid concept can shift the power demand curve to match the available power curve, as will be discussed later. Currently there are ambitious plans to explore solar energy from the African deserts such as the Sahara and the Kalahari through extensive PV installations, and then tying this to the European grid through HVDC transmission (Divan & Sharma, 2024).

The equation used for expressing the PV module is shown in equation 1 (Pavan *et al.*, 2017).

$$I_{PV} = I_{ph} - I_D - \frac{V_D}{R_{sh}} \quad (1)$$

The diode voltage, diode characteristic and photo current equations are represented as (Sumathi *et al.*, 2015a):

$$V_D = (V_{PV} + I_{PV} R_{se}) \quad (2)$$

$$I_D = I_0 (e^{V_D/V_T A} - 1) \quad (3)$$

$$I_{ph} = I_{sc} + K_1 (T - T_{ref}) \lambda \quad (4)$$

Where  $I_0$  represents the cell saturation of dark current,  $V_{pv}$  is the thermal voltage of the of the PV module,  $T$  is the temperature,  $q$  is the electron charge,  $A$  is the diode ideality factor which largely depends on the PV technology and  $R_{sh}$  is the shunt resistance of the solar cell.  $I_{ph}$  is the photocurrent,  $I_{sc}$  represents the cell's short current at standard test which is at 1000 W/m<sup>2</sup> and 25°C,  $K_1$  is the coefficient of cell's short-circuit current,  $T_{ref}$  is the cell's reference temperature and the solar irradiance unit is W/m<sup>2</sup>.

The PV module hourly power produce can be expressed as:

$$P_{pv} = A_{pv} \times H_{t_{Av}} \times \eta_{pv} \quad (5)$$

Where:  $P_{pv}$  is the power produced,  $A_{pv}$  is the area of PV module,  $H_{t_{Av}}$  is the average global solar irradiation of the site and  $\eta_{pv}$  represents the PV efficiency (Pavan *et al.*, 2017).

### Wind System

In wind energy systems, a generator connected to a variable-speed wind turbine transforms wind energy into electrical power. Cage-type, fixed-speed induction machines are used in a lot of historical installations worldwide. At various wind velocities, Figure 1.8 displays the torque created in a wind turbine as a function of speed. When the turbine speed is raised while the wind velocity stays constant, the torque rises, peaks, and then falls (Sumathi *et al.*, 2015a). A set of peak constant power curves that are tangential to the corresponding torque-speed curves are superimposed on the family of curves. By using maximum power point tracking (MPPT) control, the turbine speed can be adjusted to generate the highest power (maximum aerodynamic efficiency)

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for a given wind velocity. As seen in the picture, the torque has typical square-law characteristics with speed while the output power has cube-law features. An example of a variable-speed wind power generation system with two-sided PWM converters and an induction generator is shown in Figure 2. To keep the excitation current or flux constant (or programmable, if preferred), the PWM rectifier provides the generator excitation. The excitation and active currents are managed by the vector control in the speed control loop (not illustrated). An MPPT control programs the speed in accordance with the wind velocity. Before being fed into the grid, the variable-frequency, variable-voltage electricity is first transformed via a DC-link converter system into a constant voltage and frequency. As demonstrated, the line-side converter is in charge of preserving the steady DC-link voltage. Although synchronous current control is also an option, a simplified control employing hysteresis-band current control is demonstrated (Sumathi *et al.*, 2015a). You can utilize a Scherbius-style drive with slip power control and a doubly fed induction generator (DFIG).

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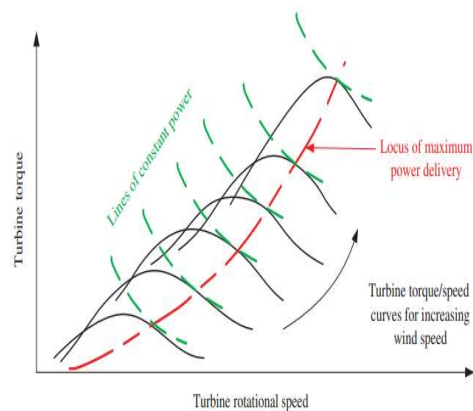


Figure 2: Torque speed characteristic for a variable speed wind turbine at different wind velocities

Alternatively, a permanent magnet synchronous generator (PMSG) with diode rectifier/boost DC–DC converter/PWM inverter or a two-sided PWM converter system can be used. The world has enormous wind energy resources, and currently they are the most economic “green”

energy. Stanford University estimates that only 20% of the available wind energy can meet all the electricity needs of the world. Recent technology advances in variable-speed wind turbines, power electronics, and machine drives have made wind energy very competitive, almost equal to that of fossil fuel power. Wind and PV energy are particularly attractive to the one-third of the world's population that lives outside electric grids (Kazmierkowski, 2014). Among the developing countries, for example, China and India have large expansion programs for wind energy. Currently, in terms of percentage energy consumption, Denmark is the leader with 25% wind energy, which is expected to rise to 40% by 2030. In terms of installed capacity, China is now the leader and the United States occupies second place (close to Germany and Spain), with a total penetration of barely more than 3% (this is because the US energy consumption is the highest in the world). The United States has the ambitious goal of increasing it to 20% by 2030 (Kazmierkowski, 2014). One drawback of wind energy is that its availability is sporadic in nature and may require backup power from fossil or nuclear power plants. Of course, surplus wind energy at high wind can be stored (storage will be discussed later) for lean-time utilization. Offshore wind farms generally offer higher energy output than onshore farms, although their installation and maintenance are more expensive (Kazmierkowski, 2014). Figure 3 present a typical Wind Power System.

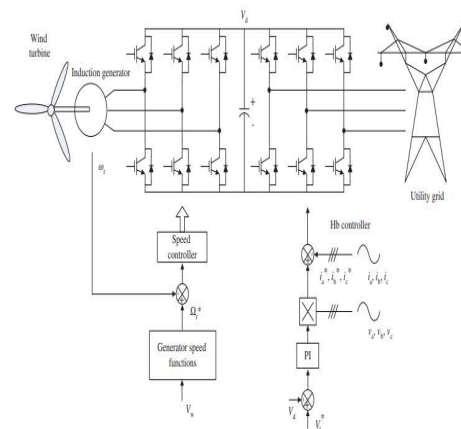


Figure 3: A Typical Wind Power System

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For a location A, perpendicular to the direction of the wind speed, the power is depicted using (Abdelli *et al.*, 2013):

$$P_t = \frac{1}{2} \times \rho \times A \times C_p \times v^3 \quad (6)$$

Where;

$P_t$  is the power

$\rho$  is the air density

$v$  is the wind velocity

$C_p$  is the power coefficient which describes the fraction of the wind captured by a wind turbine

### Tidal Energy

Another sustainable energy source is tidal energy, which harnesses the energy generated by the earth's rotation and the gravitational pull of the moon. The water level reaches its maximum level once every twelve hours, which is the 12-hour cycle time of the lunar attraction (Abu-Rub *et al.*, 2014). Three categories of tidal energy exist: barrage generators, dynamic tidal power, and tidal stream generators. The first commercial stream generator in history, installed in Ireland in 2007 with a capacity of 1.2 MW. Through the use of a connected synchronous generator, the system produces electricity using a submerged axial flow water turbine, which rotates slowly in a single direction. In a tidal barrage system, a barrage is used to hold water in a pond during high tide. During low tide, a water turbine-synchronous generator produces power due to the pond's low potential head of water. In 2011, South Korea erected the largest tidal barrage power plant (254 MW) in the world. The generation from the up-and-down water flows across the barrage is combined to create dynamic tidal power. Because of the high expense of building the barrage and pond, it becomes more expensive to explore for this kind of energy. There are no tidal power plants in the United States (Abu-Rub *et al.*, 2014).

### Geothermal Energy

Geothermal energy will be discussed to ensure a comprehensive overview of renewable energy sources. The thermal energy produced and stored within the ground is extracted to

produce geothermal energy. Volcanoes, hot springs, and other natural phenomena are examples of this energy. In the latter scenario, rainwater percolates through the ground and warms due to geothermal energy (Soltani *et al.*, 2019). The sun produced the energy that is stored in the earth, and radioactive decay of minerals within the earth produces the energy that is generated. The earth's regional geothermal heat belts are the source of the finite supply of geothermal energy. There are three different kinds of geothermal energy: direct use, often known as district heating systems, involves the energy flowing naturally on the surface of the earth; a hot spring is one example of this. Another option for house heating is a geothermal heat pump, which uses water injected into a coil of pipes, either vertically or horizontally, to absorb heat. For instance, 93% of dwellings in Iceland are heated by geothermal energy (Soltani *et al.*, 2019). Figure 4 illustrates the principle of geothermal electric power generation by a flash steam plant, which is the most commonly used method (Zarrouk & Moon, 2014).

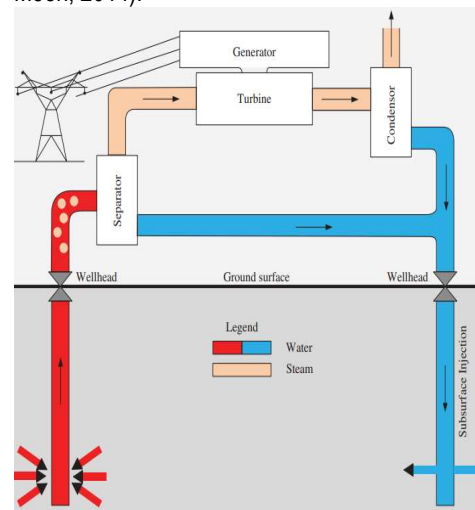


Figure 4: Principle of geothermal electricity by flash steam plant

Three types of geothermal electricity are presented here: (1) dry steam plant, (2) flash steam plant, and (3) binary cycle plant. In this method, water is injected in a pipe (which may be one or two miles deep), and steam and hot water

under pressure are collected in another pipe. The third type of geothermal electricity is generated by a turbo-generator, which operates similarly to a conventional steam power plant through a pipeline. As seen in the picture, steam powers a turbine-generator system to produce energy after the water and steam are separated by a separator and recirculated. Whereas hot water exchanges heat to a low boiling point fluid to convert it to steam for operating a turbine in a binary cycle plant, water is totally converted to dry steam in a dry steam plant. Unlike solar and wind energy, geothermal electricity is affordable, dependable, and constantly available. Usually, the cost is \$0.10/kWh and \$3.00/W. The United States leads the world in geothermal energy production, with 10.7 GW produced globally in 2010 (3 GW) (Zarrouk & Moon, 2014). It's interesting to note that Iceland produces all of its electricity from renewable sources, with 30% coming from geothermal energy and 70% from hydroelectric power.

### Diesel Generator

The diesel generator is an energy conversion system from fuel to electricity with a conversion efficiency of  $\eta_{DG}$ , so that it can be described by equation (7) (Khatri *et al.*, 2023; Vahabzadeh *et al.*, 2012).

$$E_{DG} = \eta_{DG} E_{ff}$$

$E_{ff}$  is the total energy content of oil which is roughly proportional to the volume of oil.

It is being selected based on the peak load characteristics of the load characteristics. A linear model can be assumed for the fuel consumption rate (F) in litres/hour of operation by the DG given in equation (8).

$$F = (0.246 \times P_{out}) + (0.08415 \times P_{Ngen}) \quad (8)$$

Where;

$P_{out}$  is the operating output power (kW),

$P_{Ngen}$  is the rated power of DG (kW).

The fuel cost can be calculated using the formula as in (9)

$$C_{fuel} = C_{diesel} F(R_s) \quad (9)$$

Where  $C_{diesel}$  is the fuel price per litre?

### Battery Energy Storage System

The most widely used type of energy storage in the grid has been the battery. This technique transforms grid electrical energy into DC, which is then chemically stored in a battery. The stored energy is then recovered and fed back into the grid using the same converter technology (Fan *et al.*, 2020). Although relatively convenient, with a high cycle efficiency (usually 90%), battery storage is possibly the most expensive (normally >\$0.1/kWh). Lead-acid batteries have been widely utilized in the past, but NiCd, NaS, Li-ion, and vanadium redox flow batteries are becoming more and more popular recently (Zhang *et al.*, 2018). In the Southern California Edison grid, for instance, GE installed a 10-MVA lead-acid battery storage system in 1988. The largest battery storage system in the world was installed by ABB in Fairbanks, Alaska, in 2003 (Fan *et al.*, 2020). It uses a 27 MW NiCd battery that can hold its charge for 15 minutes. Flow batteries are faster to charge and can be more cost-effective in large-scale storage, but the "chemical plant" required to maintain electrolyte through constant pumping is complex. Essentially, it is an 18-step GTO-based phase-shifted square-wave converter system with harmonic neutralization (Zhang *et al.*, 2018). Three groups of H-bridges are used to fabricate an 18-step output voltage wave, with the second and third groups having a 20° and 40° phase lead, respectively, with respect to the first group. In order to negate the harmonics (17th, 19th, etc.) and increase the output voltage, the transformer secondary connections with 15 segments create an 18-step voltage wave, which is then filtered by the capacitor bank. In order to control the bus voltage and stabilize the power system, the converter system can function as a static synchronous compensator (STATCOM), static var generator (SVG), or leading or lagging static synchronous compensator (SVC). Multilevel converters can be employed in contemporary installations (Sufyan *et al.*, 2019).

### Flywheel Storage

Through a converter-fed drive system that charges a flywheel (FW), electrical energy from the grid is transformed into mechanical energy in this type of storage. The energy is then recovered by the drive while it is in the generating mode (Olabi *et al.*, 2021). To lessen the energy loss, the FW can be submerged in a vacuum or H<sub>2</sub> medium or utilized with an active bearing. Because of the fast speed, FW can endure the strong centrifugal force by using steel or composite materials. While FW storage has been utilized previously and is more cost-effective than battery storage (\$0.05/kWh), mechanical storage has its normal drawbacks (Rufer, 2021).

### Hybrid Renewable Energy Resources

The combination of two input sources is referred to as hybrid renewable systems. Connecting solar PV to biomass, diesel generators, wind turbines, or any other renewable energy source is one example (Traoré *et al.*, 2018). Energy storage systems are typically coupled with PV systems in scenarios where they are integrated with other renewable or non-renewable energy sources. This is done to ensure that excess energy is stored when power generation exceeds load demand, and that stored energy is dissipated when load demand exceeds energy generation (Sumathi *et al.*, 2015). The ESS will only operate when absolutely necessary, and the renewable energy systems will be scaled to match the base load demand. These arrangements take into consideration the maintenance cost and reliability in choosing the renewable energy system to use at any instant. The proposed HRES's schematic diagram is displayed in Figure 5

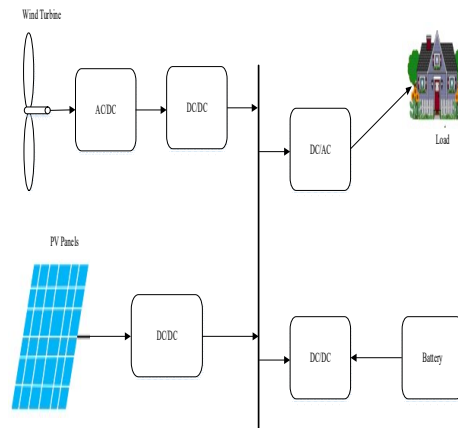


Figure 5: Schematic Diagram of a Hybrid Renewable Energy System

The DC bus is in charge of mixing the electricity generated by the PV panels, wind turbines, and batteries to provide the AC demand via an inverter. When the system is in operation, the extra energy is stored in the battery bank when the power generated is equivalent to the load. Power from the storage system will be added to the available power if at some point the load demand exceeds the generated power. However, if the energy produced by the battery and renewable energy sources is still less than the energy required for the load, the excess load must be released, which will cause a power outage in the load that is affected.

### OBJECTIVE FUNCTION

To guarantee that the HRES is economically viable, the objective function must be able to reduce the annual total cost (annual maintenance cost [AMC] and annual capital cost [ACC]) while ensuring improved reliability. The annual total cost can be calculated and expressed as follows:

$$TAC = \min \left( \sum_{j=1}^N ACC + \sum_{j=1}^N AMC \right) \quad (10)$$

Where N represents the number of optimization sample.

The design cost occurred at the beginning of the system design while the



maintenance cost occurs during the project life span. The capital recovery factor (CRF) can be used for computing the present value of the annuity. The CRF is expressed as:

$$CRF = \frac{a_r(1+a_r)^n}{(1+a_r)^n + 1} \quad (11)$$

The optimization problem of the hybrid system is to determine the right combination of PV panels, wind turbines and batteries which gives the minimum ACC and AMC. This will in turn minimize the annual total cost subject to the following constraints.

$$n_{pv-} \leq n_{pv} \leq n_{pv-max} \quad (12)$$

$$n_{Bt-mi} \leq n_{Bt} \leq n_{Bt-ax} \quad (13)$$

$$n_{wt-min} \leq n_{wt} \leq n_{wt-m} \quad (14)$$

Where  $n_{wt-max}$  and  $n_{wt-m}$  represents the upper and lower boundary of  $n_{wt}$  respectively,  $n_{pv-min}$  and  $n_{pv-ma}$  are the lower and upper bound of the  $n_{pv}$  and  $n_{Bt-min}$  and  $n_{Bt-max}$  represents the minimum and maximum boundary of the  $n_{Bt}$ .

The charge quantity of the battery bank at any time should also satisfy the constraint in equation (15) in order to improve the battery lifetime.

$$SOC_{min} \leq SOC(t) \leq SOC_{max} \quad (15)$$

Where  $SOC_{min}$  and  $SOC_{max}$  represents the minimum and maximum limits of state of charge.

### OPTIMIZATION TECHNIQUES

Meta-heuristics are simple and adaptable since they merely take into account inputs and outputs, much like biological or physical events. Moreover, one type of stochastic optimization method is meta-heuristics (Sadeeq & Abdulazeez, 2023). Their ability to efficiently avoid local optima—which typically arise in real problems—is aided by this characteristic. In the actual world, meta-heuristic optimization algorithms perform better than heuristic optimization algorithms in solving a variety of challenging and complicated optimization issues because of their benefits in simplicity, flexibility, and the capacity to avoid local optima. Meta-

heuristic optimization algorithms fall into three main categories: swarm intelligence, physics-based, and evolutionary approaches. The natural laws of evolution serve as an inspiration for evolutionary algorithms (Sharma & Tripathi, 2022). As the number of repetitions rises, the population created at random changes over the course of the following generations. Each generation of individuals is always formed by the combination of best individuals so that the population can be optimized over several generations of evolution (Sadeeq & Abdulazeez, 2023; Sharma & Tripathi, 2022).

### Aquila Algorithm

In 2021, Aquila Optimizer (AO)—a population-based meta-heuristic algorithm—was introduced by (Abualigah *et al.*, 2021). The Latin word for eagles, or birds of prey, is Aquila. These birds are considered to be among the most cunning and proficient predators, possessing strong, sharpened claws and strapping feet that allow them to seize their prey with speed and agility (Mahajan *et al.*, 2022). Aquila employs four main hunting techniques: strolling and capturing prey, contour flying with a brief glide, low flying with a slow drop, and high soar with a vertical stoop (Abualigah *et al.*, 2021). These four core Aquila hunt mechanisms served as the inspiration for the creation of the Aquila Optimizer (AO), a nature-inspired optimization algorithm that fundamentally clarifies the actions of each hunt stage. Initialization, Expanded Exploration, Narrowed Exploration, Expanded Exploitation, and Narrowed Exploitation are the five main processes that the traditional Aquila Optimizer (AO) concentrates on (Mahajan *et al.*, 2022).

The first step taken in employing AO technique to address any problem is the initialization phase. Prior to initializing the other AO parameters, a random population of solutions will be formed.

The broader exploration is step two. Expanded Exploration essentially reveals the main hunting strategy used by Aquila, which is a high ascent with a vertical stoop in which algorithms seek to determine the search pace from the high ascent. Equation (16)

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mathematically represents this strategy (Abualigah *et al.*, 2021):

$$X_i(t+1) = X_{best}(t) \times \left(1 - \frac{t}{T}\right) + (X_M(t) - X_{best}(t) * rand) \quad (16)$$

Where:

$X_i(t+1)$  is the solution of the next iteration of  $t$ , and it is created by the first search technique,

$X_{best}(t)$  is the finest solution found so far,  $\left(1 - \frac{t}{T}\right)$  controls the exploration,

$T$  and  $t$  represent maximum number of iteration and current iteration,

$X_M$  is the location mean value of current solution,  $rand$  value lies between 0 to 1.

$X_M$  is calculated as follows (Abualigah *et al.*, 2021):

$$X_M(t) = \frac{1}{N} \sum_{i=1}^N X_i(t) \quad (17)$$

Where  $N$  is the population size

The third phase is narrowed exploration, the second hunting technique carried out by Aquila that is the contour flight with short glide is projected wherein Aquila arranges the land thereby circling around the target prey to attack. Such behavior of Aquila is precisely brought to light using Equation (18).

$$X_2(t+1) = X_{best}(t) \times Levy(D) + (X_R(t) + (y - x) * rand) \quad (2.18)$$

Where:

$X_2(t+1)$  denotes solution of the next iteration of  $t$ ,

$X_{best}$  represents the best solution,

$X_R(t)$  denotes the random solution belonging to  $N$  (Abualigah *et al.*, 2021).

$$x = r \times \sin(\theta) \quad (19)$$

$$y = r \times \cos(\theta) \quad (20)$$

Figure 6 present the flowchart of the Aquila Optimization Algorithm.

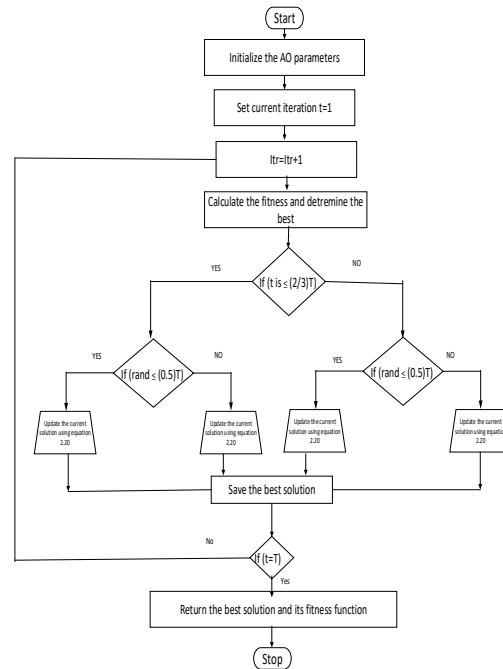


Figure 6: Flowchart of the Aquila Optimization Algorithm

## CONCLUSION

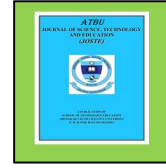
Hybrid renewable energy systems are now seen as a better alternative means of generating energy to meet load demand. As such, this paper presents an optimal energy management scheme for sustainable energy power generation. This scheme that will be developed will ensure effective control of the hybrid system comprising of solar PV, wind system, DEG and BESS to reliable and affordable energy is obtain from this system. An improved P&O mppt strategy of solar PV will be incorporated to further improve the availability of power irrespective of weather condition. An aquila optimizer will be incorporated into the system to optimized the formulated objective function. Growing demand for renewable energy systems is a reaction to worldwide concerns about global warming and sustainable growth. By combining several renewable energy sources to generate a dependable and sustainable supply of electricity, Hybrid Renewable Energy Systems have emerged as a viable alternative to address the energy demands of distant places. This study

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emphasized the necessity of optimal design of renewable energy sources to meet the rising energy demands. For this purpose, the Aquila Optimization (AO) approach is suggested. The implementation of the AO optimization will improve the reliability of the system. Moreover, this paper demonstrated a positive impact on the utilization of renewable energy sources.

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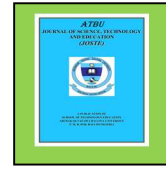
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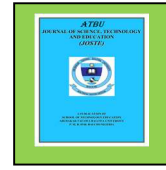
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