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IOT based Energy Management for Hybrid Solar and Wind Energy System

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Abstract

In this paper, renewable energy-based hybrid sustainable energy sources (HSES) were proposed for utilizing different renewable energy sources for various applications, particularly in the independent power generation system. The renewable energy sources such as solar photovoltaic and wind energy can be used to supply load effectively by the accessibility of power demand, to improve the dynamic conduct of the hybrid system by balancing AC/DC bus and upgrading the nature of the generated power. This work proposes a strong control unit dependent on DC bus control and power management by fuzzy logic techniques. The controller is also supported by the Internet of Things (IoT) for the efficient selection of renewable energy sources. The choice of operation is given by an energy management system with a fuzzy logic decision-maker. The information from the load side and renewable energy source can be determined by fuzzy logic techniques to meet the power demand. The proposed system was tested and the energy efficiency achieved is about 27% higher than the conventional system.

Index terms- *Hybrid sustainable energy source (HSES), fuzzy logic, energy management system, solar photovoltaic, wind energy system, ATOA*

1. INTRODUCTION

In recent years, the electrical energy generated by conventional sources like coal, diesel, gas, and nuclear fuel is depleting every day. Solar and wind energy are the most suitable alternative energy sources and are always available at all conditions. The renewable energy sources are unlimited and do not cause any environmental pollution. The renewable energy sources, viz., solar and wind energy sources are the most promising power generation system, as they are freely available, omnipresent, omnipotent and environmentally friendly [1-3]. Many advantages are there in using PV solar panels and wind turbines together [4,5]. The main objective is to attain maximum power in varying environmental conditions. Similar to PV solar panels and wind turbines, several studies were conducted related to power flow and energy management in various hybrid electrical power systems [6-8]. Energy sources such as wind turbines, solar panels, diesel generator, and fuel cell can be used both as hybrid or stand-alone energy sources. Various hybrid power generations were implemented such as wind/fuel, wind/PV, PV/wind/fuel cell, PV/grid and PV/wind/battery [9]-[12]. These studies tend to increase energy sustainability, power quality and stabilize the frequency and amplitude of the voltage on a definite value on the load side.

Apart from energy management, a very essential part of the studies associated with renewable source utilization schemes [13]. In renewable energy systems, energy management deals with each source and user side control problems to keep the operation of the overall system efficiency. [14,15]. A

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Maximum Power Point Tracking (MPPT) controller implemented in a hybrid renewable system is defined with more effective controls of converters to run the system continuously so that the wind system will work with utmost efficiency [16–22]. This study suggests that there is an MPPT intended in a dissimilar way, which constantly and accurately calculates the maximum power from wind turbines and PV panels. The energy generated from the non-conventional energy sources viz., solar and wind are controlled independently and concurrently depending upon the in-service conditions and energy demand. IoT is used to control and monitor the power supply from solar and wind energy systems.

2. ENERGY MANAGEMENT SYSTEM

The sustainable energy management system consists of wind and Photovoltaic (PV) power generating units are shown in Fig.1. Over the desired converters, these two generating systems are linked to a DC power bus. A backup battery cluster is additionally connected to the Photovoltaic system, to store the extra power generated by the solar system, when the power generated from the photovoltaic system is not delivered to the load. In the system, AC load types are considered, which is linked to the AC power bus that is fed from the common DC power pool. The collected data from the load side and source side is transfer to the PC and it is to be estimated for the decision making the procedure of the energy management system. Then for this multi-objective and multi-input system, a simple fuzzy logic-based choice-making algorithm with IOT based energy management system is developed.

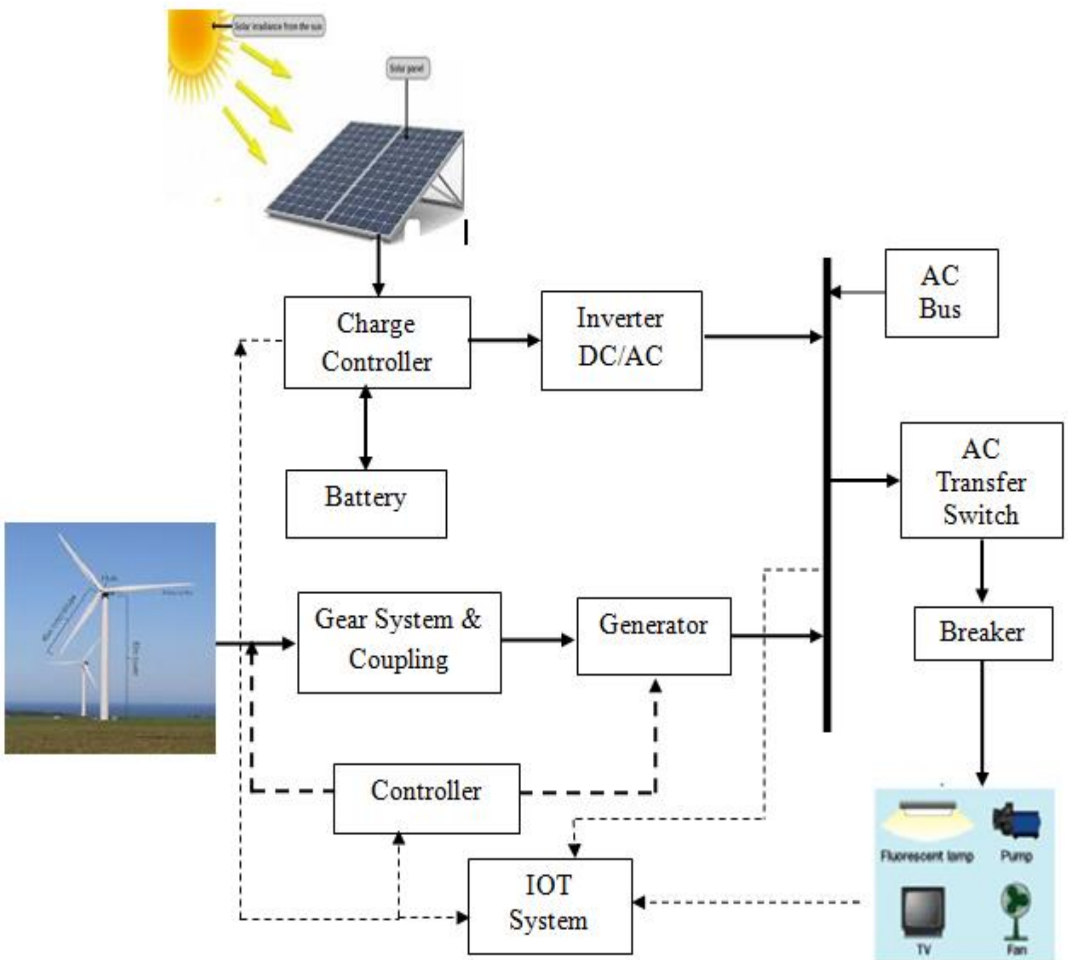

Fig.1 Proposed Power Management Systems

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3. WIND ENERGY SYSTEM

The mechanical energy which is produced by the wind turbine is changed into electrical energy by the wind generator. The wind turbine model is developed to assess the power characteristics in principle by the steadiness of the turbine. By coupling two squirrel cage asynchronous machines together, the emulator of wind energy system is set up. The power of the prime mover is selected as 5KW and the generator is 3KW. Therefore the generator can also be performed, yielding at overpower conditions to extend the analysis of the operating cases. The prime mover which is placed on the left side of machine represents the wind turbine and it is regulated with a voltage/frequency speed controller. The generator output voltage changes between 320V and 400V according to the wind speed. By using a step down transformer, a 3 phase voltage magnitudes acquired from the generator is condensed to a lesser level. So, the transformer output voltage changes up to 38V and the output of full bridge rectifier changes up to 50V. The variable voltage is converted to a constant voltage with a help of DC chopper, which is to be connected to a DC bus. The curve fit equation of the power curves of any wind generator that can be expressed as the following equation.

$$\begin{bmatrix} 0 & (v < v_{in}) \\ a_1 v^2 + b_1 v + c_1 & (v_{in} \le v < v_1) \\ a_2 v^2 + b_2 v + c_2 & (v_1 \le v < v_2) \\ a_3 v^2 + b_3 v + c_3 & (v_2 \le v < v_{out}) \\ 0 & (v > v_{out}) \end{bmatrix} \text{--} \quad (3.1)$$

Where,

Pw (t) is the wind generator output at wind speed,
v is the wind speed is at hub height,
v_{in} and v_{out} is cut- in and cut-out wind speed of wind turbine generator,
(a_1, a_2, a_3), (b_1, b_2, b_3), (c_1, c_2, c_3) are variables.

The hourly output of the wind turbine generator can be obtained by using equation 3.6 and describes the actual power curves of wind generators and average wind speed.

The wind turbine model is developed to assess the power characteristics in principle by the steadiness of the turbine. An emulator of the wind energy system is coupled with two squirrel cage asynchronous machines. The prime mover is selected as 5kW, and the generator is 3kW. The prime mover, which is connected on the left side of the machine, represents the wind turbine, and it is regulated by a voltage/frequency speed control method. The generator output voltage varies between 320V and 400V according to the wind speed.

The transformer output voltage changes up to 38V and the output of the full-bridge rectifier converts up to 50V. The variable voltage is converted to constant voltage with the help of the DC chopper, which is connected in a DC bus.

To produce the reactive power, the energy provided is sent to a 3-stage voltage chopper and converted to 48V and then coupled to a typical DC bus. An inverter is used to convert 48V to 230V AC. The voltage and current data on the chopper input voltage, the loads and output current are figured and exchanged to the system. The wind turbine power can be calculated by using equation 3.2,

$$W = \begin{cases} 0, U\partial \\ \frac{1}{2}.\partial.\pi.P^2 \quad .U^3, U_d \le \partial \\ Qn.\mathrm{Vin} \le \mathrm{U} \propto \end{cases} \text{--} \quad (3.2)$$

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Where,

W=power in watts
U=speed in velocity
∂=air density in kg/m^3
P= limits of rotor
V_d=wind speed in velocity
V_{in}=measured speed in velocity
Q_n=actual power in watts

At that point, power generation of the wind executes the speed of the wind turbine. The wind turbine power (PWT) is expressed as in Equation 3.8,

$$W=\begin{cases} 0 V(t) \leq V_{cut}-\text{in or} V(t) \geq V_{cut}-V_{in} \\ P_r \frac{(V(t)-V_{out}-\text{in})}{V_r=V_{cut}-\text{in}} Vcut_{in} < V(t) < V_r \\ P_r V_r < V(t) < V_{cut}-\text{out} \end{cases} \text{-- (3.3)}$$

Where,

V = speed of the wind,
P_r= rated wind power,
$V_{cut}-V_{in}$ = cut_{in}speed,
$V_{cut}-out$= cut_{out} speed,
V_r =rated speed of the wind turbine
N_{wind}= number of wind turbine

The total energy generation is PWT (t) = N_{wind}_PWT (t).

4. SOLAR PHOTOVOLTAIC SYSTEMS

The PV cell and the PVES are modeled in such a way to assess their characteristic features. The PV cell voltage-current equation is based upon the photocurrent of a P-N junction. The photocurrent is a purpose of change with the temperature and solar irradiation. The external current maximum value is the short circuit current and it is unspecified to be equal to the photocurrent generated. It is noticed that the cell gets heated which results in decreased terminal voltage, as the cell current improved. In commercial applications, the PV panels are joined together in parallel and serial combinations and fabricated such as PV modules, to be used efficiently. The PV module current is decided by several parallel branches and PV module voltage is decided by series-connected PV cells. To acquire the needed load power, the PV modules are attached in series to form PV arrays and the PV arrays are linked in parallel.

PV cell is formed with a thin layer of p and n-type semiconductor materials due to which they behave like a diode. The PV cell converts solar radiation into electrical energy. PV module is capable of creating high current and low voltage which can be stored easily. In this PV cell demonstrates the character of a current source. The numerical connection within the perfect PV cell and current-voltage is calculated as,

$$P_{solar} = V_{pv} I_{pv} \text{-- (4.1)}$$

Where,

P_{solar}= solar power in W

The supplied current to the solar PV panel I_{pv} is given as follows;

$$I_{pv} = \rho_p I_{ph} - \rho_p I_{rs} \left[\exp\left(\frac{q}{KTA}\frac{Vpv}{\rho s}\right) - 1\right] \text{---(4.2)}$$

Where,

I_{pv} = solar panel current
ρ_p= parallel connection of solar panel

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I_{ph} = phase current of PV is communicated in Amp.
I_{rs}= reverse saturation current
q = electron charge
V_{pv} = solar panel voltage
K = Boltzmann constant
T = solar panels surface temperature
A=area of solar panel
ρ_s = series connection of solar panel

In Equation 3.4, the reverse saturation current characteristic of I_{rs} is varies with temperature as,

$$I_{rs} = I_{rr}[\frac{T}{Tr}]^3 \exp\left(\frac{qE_q}{KA}\left(\frac{1}{Tr} - \frac{1}{T}\right)\right) \text{--(4.3)}$$

Where,

I_{rs}= reverse saturation current
I_{rr}= solar panel invert immersion current at the temperature T_r in k
T_r =Solar panel source temperature in k
E_q = energy band gap of the semiconductor

The solar PV phase current is calculated using Equation 4.4,

$$I_{ph} = [I_{scr} + \propto (T - T_r)]S/100 \text{ --4.4)}$$

Where,
I_{scr} = short circuit current
$\propto$=Temperature coefficient current of the solar panels
T_r= reference temperature and sunlight based insulation indicated at 0.85 kW/m^2
S=solar insolation in (kW/m^2).

5. FUZZY LOGIC TECHNIQUES

Fuzzy logic algorithms are normally used in fuzzy logic decision-makers that discover applications in systems that need a conclusion from indefinite input data. The power produced from the wind energy system becomes indefinite including the utmost generated power because the wind conditions are not easily predictable and are not definite. So a fuzzy reasoning algorithm is used to decide the utmost power produced by wind systems. Fig. 2 shows the block diagram of the fuzzy logic decision-maker. A fuzzy decision maker generally estimates them in the base rule system and obtains an input that is established earlier, representing the input and output relations of the indefinite system in terms of fuzzy rules and fuzzy membership functions. The fuzzy rule is the estimation of the rules to produce fuzzy conclusions from its interactions. Therefore, to utilize by the controller, these values can be integrated with a value range and then it can be expressed. Additionally, it becomes a group member which has clear boundaries and they are fuzzified to fuzzy values. Correspondingly, by the process called defuzzification, the fuzzy outputs concluded and converted to crisp values, if the output is needed as crisp value.

To decide the value of power demand, which is delivered from the wind/PV sources and the collected data, transferred to the computer. Fuzzy decision-maker uses the wind system quantities to calculate the utmost generated power by wind system. In the power management system, the utmost power values of both PV panels and wind systems are used. It is noticed that the wind speed lower limit is to be equal to voltage lower limit. The needed energy conversion is not adequate, which is below the voltage lower limit. Fuzzy decision making output is the output power space which estimates the utmost power value supplied by the wind energy system. The power produced by the Wind system varies as its functions. Thus relying on the wind speed levels, the utmost power was gained from the wind system changes and should be decided for distinct speed levels

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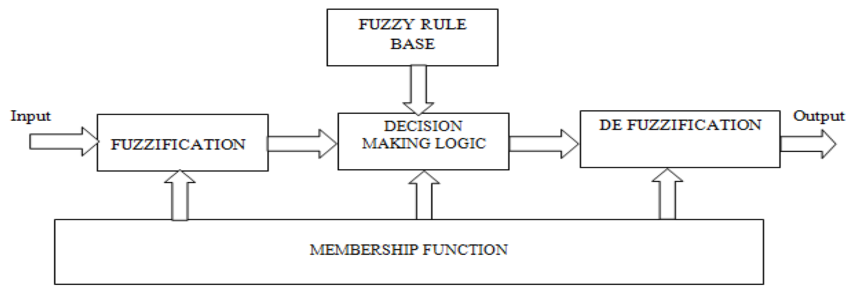

Fig.2 Fuzzy Logic Decision Maker

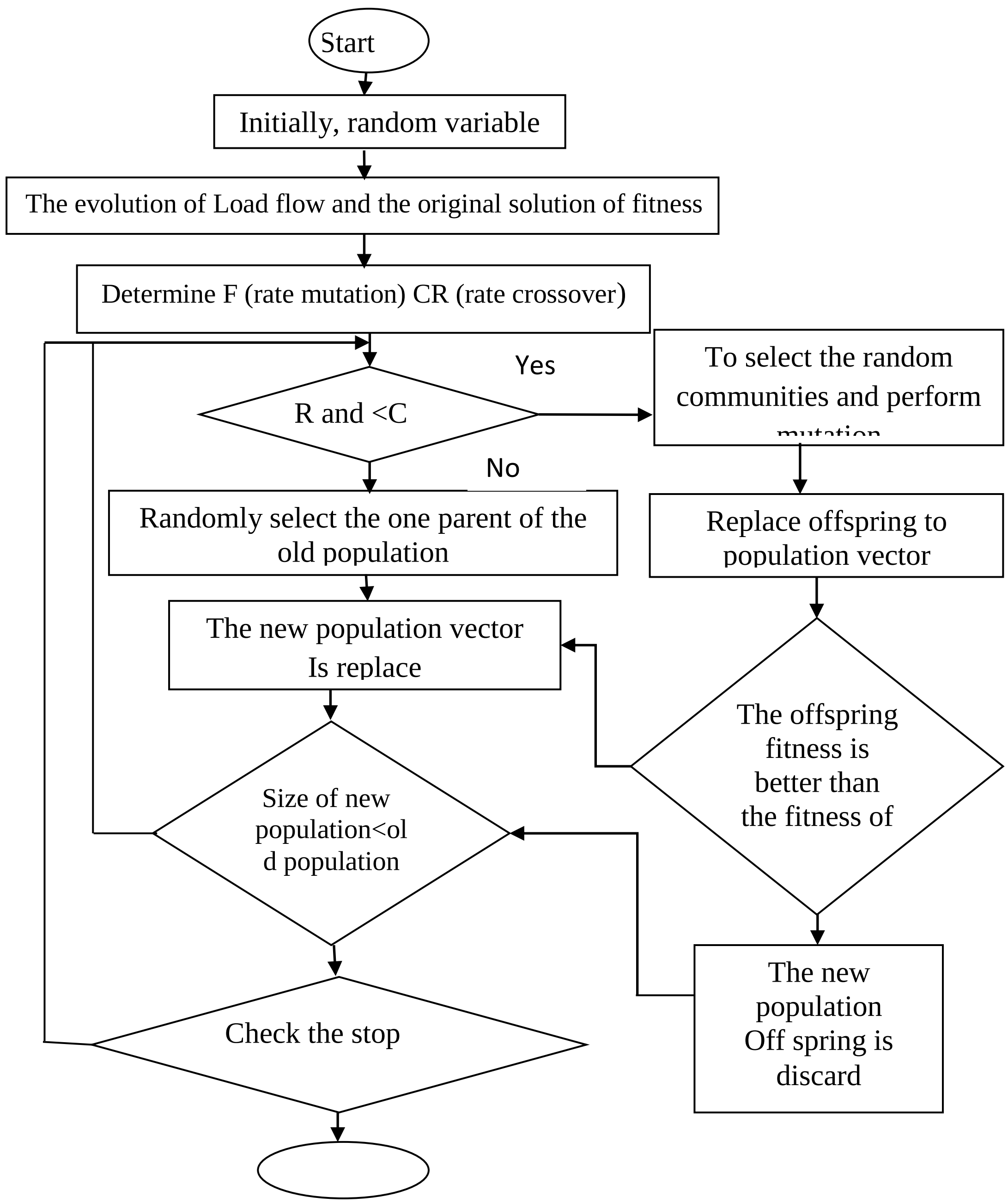

Fig. Erreur ! Il n'y a pas de texte répondant à ce style dans ce document. **Flow chart for ATOA**

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- Fuzzy reasoning algorithm is utilized in the direction of attaining the utmost wind power generation under varying environmental conditions.
- The voltage and current from the wind system are the inputs to the fuzzy decision-maker. The calculation of the utmost power is determined by voltage and current. The power produced is directly proportionate to the wind speed. As a result, if wind speed changes then its corresponding voltage and current also changes.
- The voltage and current are converted into fuzzy values in which the triangular membership function is used.

In this system, the power produced by using solar and wind turbines. The utility is stored as an additional source which can be used when required. The ATOA based energy management system algorithm steps are given below.

Step 1: Compute and measure the required amount of energy and power with respect to time.
Step 2: Prompt the customer to enter time and date.
Step 3: Calculate the breaking point of a battery, power, and energy from the PV system, wind power, battery, and a power grid.
Step 4: Compute the power harvested from the hybrid system and demand power on each day for every 30 minutes.
Step 5: Compute remaining power = Power required (demand) **-** Harvested hybrid (solar/wind) power.
Step 6: control the charge and discharge rating of the battery.
Step 7: Check that the Charging rate of battery is equal to total power energized =Grid power (800W) – Optimized power
Step 8: Observe the discharging: Power required = Remaining demand **-** Battery power.
Step 9: Store all the parameters like demand power and source power.
Step 10: Evaluate loss of power supply probability and loss of load probability.
The main principle of the operating system as follows:
(a)At first, the system starts with both solar and wind energy.
(b) According to the load condition, the PV solar panel system or wind system will be kept on working, and after the transients are over. If there is an unsuitable environmental condition for wind system or PV system, they are essential to operate one by one or they can perform together.
(c) The wind system will work it can handle the charging power requirement only to charge the PV solar panel batteries that are connected.

6. RESULTS AND DISCUSSIONS

The system comprises solar panels and wind energy with a control system; it has a control mechanism or management system, which entirely operates in open mode. In the hybrid system, solar irradiance, wind speed, optimal value, time complexity, and battery cost have taken into consideration for sensitive and efficient purposes. The proposed adaptive transformational optimization techniques are more efficient than other conventional methods. The optimization issues of the PV-wind hybrid energy system are solved by using the fuzzy logic control under MATLAB/ SIMULINK software is shown in Fig. 3.

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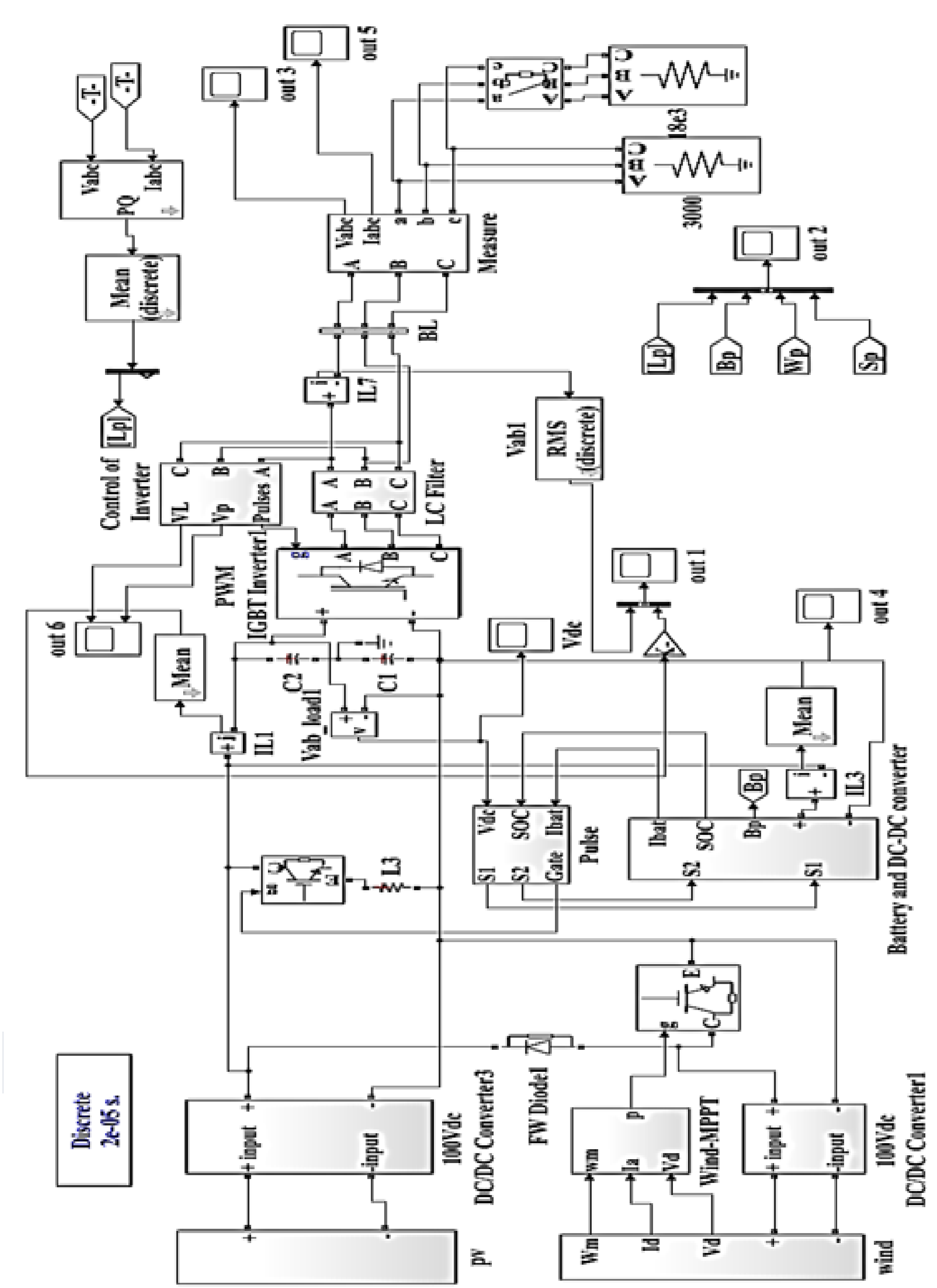

Fig.4 Simulation Model of Proposed System

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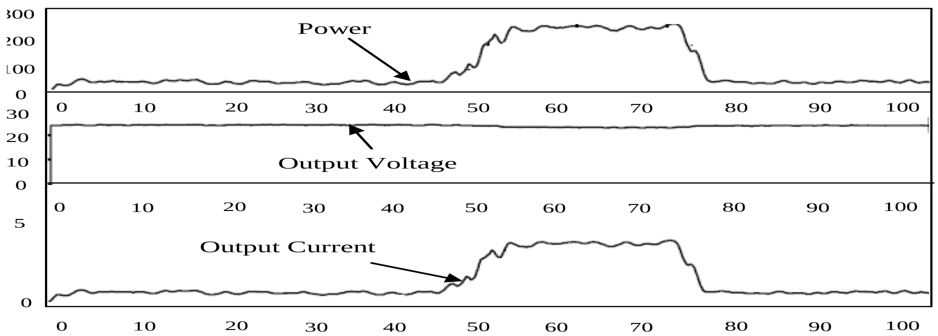

Fig.5Voltage, Current and Power variations of a solar system

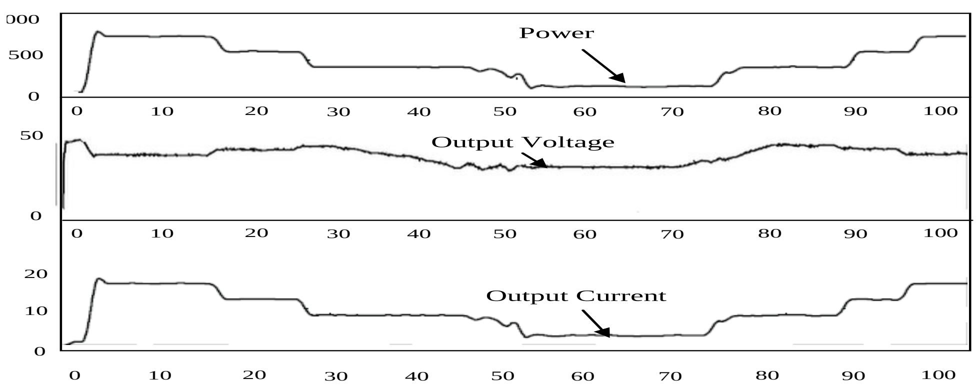

Fig.6Voltage, Current andPower variations of the wind system

It is to be noted that when a load power is on, both PV and wind systems cannot supply the loads at certain duration, so the system cannot operate appropriately. The result of this state is shown in Fig.5 and 6. Discontinuation of power occurs even after the system has generated enough power. This can be eliminated by utilizing both solar and wind applying an appropriate power management system. The power discontinuity can be avoided on loads by introducing a decision-making system. The proposed energy management system can achieve this control system in an efficient manner.

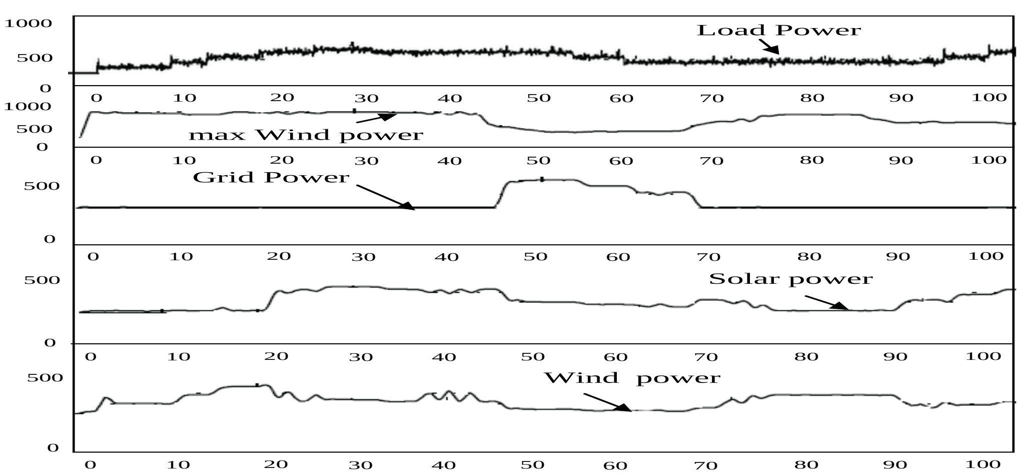

Fig.7Power variations under proposed smart power management system

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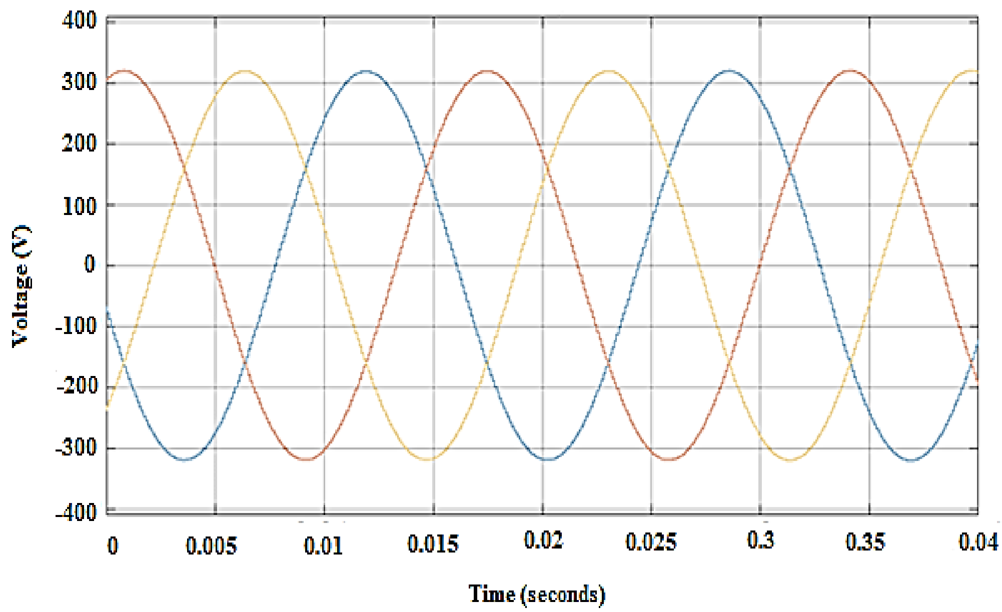

Fig.8Output Voltage on the load

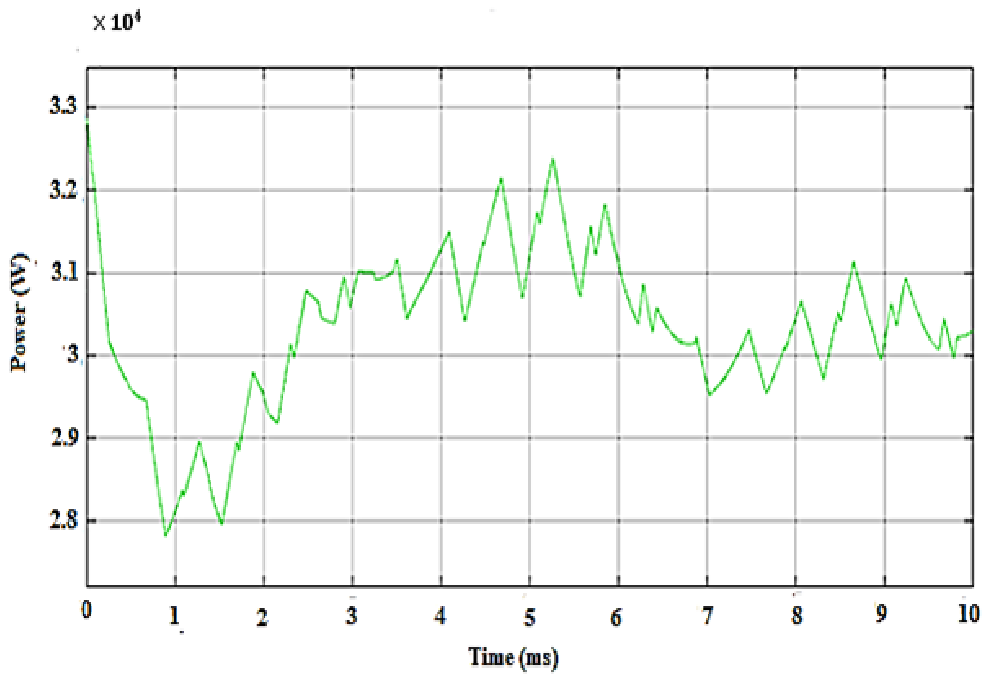

Fig.9Output Power Variation on the load

Depending upon the sudden changes, both wind and PV system operates for a short period. Since data is taken from the voltage detector, distortions are observed. Hence by adding inductive load and resistive load to the system, the system behaviour under different load conditions was observed. Fig.5 shows the PV system time variations of current, voltage and power. Since the wind system is not

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adequate, the PV system is inactive to generate essential load power. Fig.6 shows the value changes in voltage, current, and power in the wind system. Due to high wind speed reduction, the generated voltage magnitude is very low in certain levels. The utility grid supplies power for a period when both PV and wind system was switched off condition, and they do not generate adequate power. According to the load conditions, the load current varies and the load voltage is set aside as 220V. When there is higher wind speed, the power generated by the wind system is high and it is lower when there is low wind speed correspondingly.

6.1Comparative Analysis of ATOA with existing Techniques

The simulation obtained from the Hybrid Energy Management System (HRES) for an Adaptive transformational optimization algorithm (ATOA) provides better results when compared to the Genetic Algorithm (GA), Particle Swarm Optimization (PSO). The operational values of the modulation techniques are discussed in Table 6.1.

Table 1Comparative Analysis

Parameters	GA	PSO	ATOA
LOLP (%)	1.456	1.021	0.3586
LPSP (%)	1.105	0.892	0.756
Steady State Error (%)	0.7589	0.67365	0.5598
Switching loss (%)	8.9	7.63	5.1
Life cycle Cost in Lakhs	93.18	79.15	65.94

Table 1 discusses the values of the optimal parameters fetched from HRES which includes the parameters namely, LPSP, LOLP, steady-state error, switching loss, and cost in lakhs, with various existing optimization techniques, and the Proposed Adaptive Transformational Optimization Algorithm (ATOA).It is found that 16.90% of steady state error and 33.15% of switching loss are reduced on comparing PSO with ATOA.

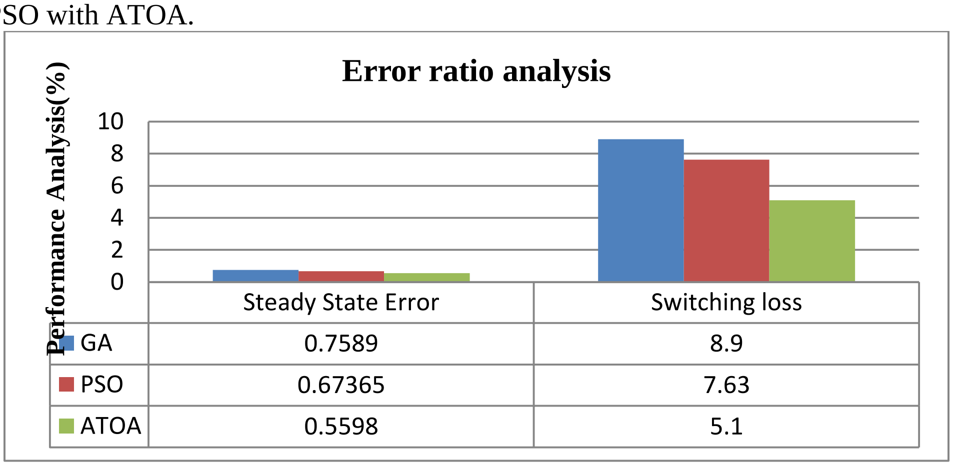

Fig.10Error Ratio Analysis

Fig.10 shows the error ratio analysis for a renewable energy system with a steady state error and switching loss of the system with a comparison among various existing methods along with proposed Adaptive Transformational Optimization Algorithm (ATOA) techniques minimizes the Error ratio of steady state Error (0.5598%) and switching loss (5.1%) for the obtained simulation result.

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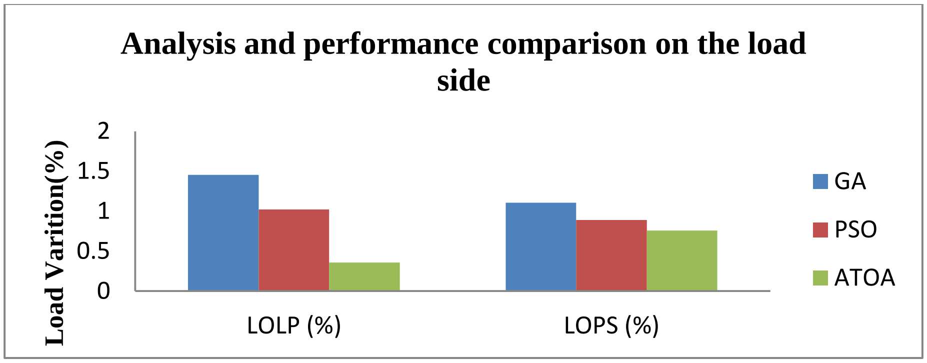

Fig.11 Load side comparative Analysis

Fig.11shows the comparative analysis of the load side variation for the parameters like Loss of Power supply probability (LOPSP), Loss of Load Probability (LOLP) with the existing techniques and the proposed ATOA techniques for the evaluation the ATOA technique which provide useful outcome values.

7. CONCLUSION

The energy management system is introduced in the renewable energy system with its energy sustainability. The smart power management system is evaluated with the help of a renewable system comprising of PV panels and wind systems. Hence the system of management is essential for its sustainability of PV and wind systems which are not reliable on the load side. In this system, the power from PV, Wind is collected at common DC bus and loads are fed without any interruption. The effects of renewable energy changes are handled by the energy management by operating PV and wind. The required and generated power information from PV and solar systems were utilized to control the overall system with the help of fuzzy logic reasoning with IoT. The proposed smart power management method will provide a feasible solution to meet out the power demand and considered as a smart operator in renewable energy applications.

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