International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-6, March 2020

Future Challenges in Energy Management System for Hybrid Renewable Energy System

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Abstract—Taking into consideration of continuously increasing consumption of the electricity and perturb towards environmental issues, renewable energy sources have been broadly used for generation of electricity. A Hybrid Energy System can be elucidated as systems which consist of various energy sources such as wind, solar, fuel cell, diesel generator and storage systems such as batteries to store energy are integrated and interconnected to satisfy the load energy demand. This paper infers the generation of electricity by utilizing the Hybrid Renewable Energy System (HRES). This paper presents the modelling and future challenges of the HRES.

Keywords—Hybrid Renewable Energy System, wind, solar, fuel cell.

I. INTRODUCTION

The huge increase in the electrical energy demand over the world has raised concerns over the numerous environmental impacts such as emission of gaseous and gritty substances released from the fossil fuel combustion, depletion of energy resources from fossil fuel and energy supply shortage in the future [1-3]. The development of energy systems which are sustainable, non- polluting and substitute fuels are required for increasing energy demand in the future for various applications in the industries and other sectors [4]. The lack of electrical power supply which are reliable, the high operating cost of diesel generator or AC grid installation are some of the major challenges faced in the electrification in rural areas, leading a fair number of developing countries to focus into hybrid system configuration of alternative energies [5-7].

A Hybrid Renewable Energy System (HRES) can be defined as a system which is a combination two various technologies, that is, one or more non-renewable energy sources and at the minimum of one renewable energy source [8]. Many research and development are currently focused in hybrid renewable energy systems in order to hybridize and optimize the generation of electricity.

Manuscript received on February 10, 2020.
Revised Manuscript received on February 20, 2020.
Manuscript published on March 30, 2020.

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The scientific improvement has involved various storage systems and renewable energy sources and has interpreted electrical power system as a system that utilizes more than one energy source as HRES [9-10]. The goal of a hybrid renewable energy system is to satisfy the load demand by utilizing renewable sources, and if there is a dearth it is compensated with non-renewable sources, meanwhile reducing the consumption of fuel.

The reliability of the system is improved when the productions from renewable energy are utilized together, which is most important advantage of hybrid systems. In addition to that, the storage system size can be further minimized moderately as there is less dependency on one independent energy source [11]. The optimal sizing, selection of system components and control operations are important and exigent factors in the independent hybrid energy systems lifetime [12]. For sizing of components in hybrid system and cost optimization in relation to the load demand and the energy resources accessible from the sites, various research works have been established and prosecuted using numerical methods. These methodologies engross more time and their complication level also increases proportionally with the number of energy sources taken into account in the structure of hybrid systems [13-14].

India is one among the list of countries which has been facing the same obstacle. We have massive energy demands but simultaneously there are increasing challenges in reaching those demands by means of traditional methodologies of power generation [15]. In the current trend, generation electrical energy from Solar Photovoltaic (PV) is the rapidly propagating energy resource and by 2050 it may acquire 22% of the electricity generation globally. However, due to the daily and seasonal variation of solar irradiation, the supply of solar electricity is turbulent [16-17]. The PV peak power generation are generally during noon, but the residential energy demand information implies peaks during morning and evening hours. Consequently, the supply of solar electrical energy mismatches with current demand of the load profiles. The mismatch may result in a low PV-self-consumption [18]. To overcome this, various solutions such as Demand Side Management (DSM) and energy storage systems are proposed. DSM refers to the manipulation of action of the consumer's way of using electricity in order to acquire higher efficiency and savings in the energy utilization. The energy storage system can be beneficial when the number of sporadic energy sources is incremented since it optimizes the dispatch ability of renewable energy technologies [19].

Various types of energy storage systems can be utilized and implemented, such as batteries and super capacitors for storing the electrical energy during the peak hours.

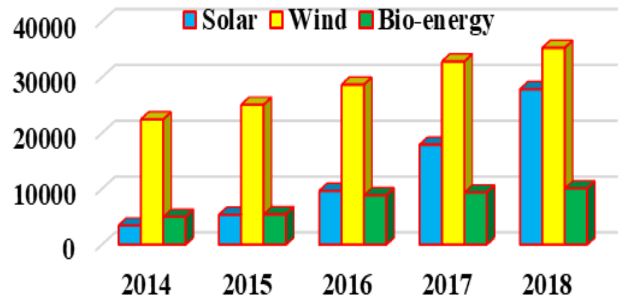

Fig. 1.Installed capacity of various renewable sources

A diesel generator set which is feeding an isolated load is commonly robust and stable system. However, the system can reach to instability if it is connected in parallel combination with a constantly differing energy source such as wind power generator. A well organised model of diesel plant can significantly optimize the analysis stage preceding the design of the hybrid wind-diesel system and also various other parameters such as performance prediction control and diagnosis processes [20-21].

The cumulative installed capacities of different renewable energy sources such as solar, wind and bioenergy present in the world, implies that solar and wind energy resources have the rapid expansion rate when compared with certain other renewable energy sources, which is clearly shown in Fig. 1. Solar energy with a capacity increase of 94 GW occupies the first position, right after which the wind energy has an increase of 47 GW. By new installations of the solar and wind power plants, the capacity of the renewable energy expands [22]. The above analysis depicts that a hybrid system which utilizes the renewable sources like solar and wind can optimise the performance of a system effectively and economically.

II. HYBRID SYSTEMS

The electrical power generated by the renewable energy sources can be differentiated depending on its variability. The solution is to form a hybrid system by coupling the sources of energy supply. Several classifications have been proposed by taking consideration of well-defined parameters. Fig. 2 illustrates the classification of hybrid system depending upon certain criteria.

Hybrid system Based on structure Mode of operation Renewable energy used Presence/ Absence of convention source Presence/ Absence of storage Grid connected Isolated from grid

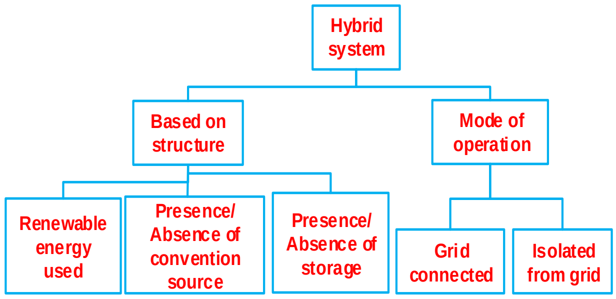

Fig. 2.Classification of hybrid system

While considering the mode operation, hybrid system can be further classified into two groups. The first group represents grid connected hybrid systems. The operation of grid connected system occurs in parallel with network. The grid connected systems are always linked to the network. In the second group, the hybrid systems are isolated from the grid. This type of systems does not have links with the networks.

The architecture of the hybrid energy systems can be grouped into three types as given below:

- **Existence of conventional source:**

A hybrid energy system can consist of certain conventional energy sources like gas turbine and diesel generator in order to reach energy demand.

- **Existence of storage capacity:**

The existence of a storage device is important for non-grid connected hybrid systems. The storage compensates the load if there is any insufficiency in the primary source. There are various means of storage devices, the flywheels of inertia and rechargeable batteries.

- **Renewable source of energy used:**

It is mandatory to have renewable source of energy such as a wind generator or PV system or combination of PV and wind generator, in a hybrid renewable energy system. For choice of the energy source, the currently available energy potential is very necessary.

Hybrid energy system consisting of conventional source can be grouped depending upon various arrangements:

- **Photovoltaic system with convention source:**

This type of systems can be installed in locations where the climate is very hot or where the sunshine is more.

- **Wind systems with conventional source:**

This type of systems can be installed in the locations with high wind speed. Storage systems such as batteries and fuel cells are mandatory if the hybrid system operates under the stand-alone mode.

- **Hybrid photovoltaic / wind / diesel system:**

These systems are widely installed and utilized in the locations where the solar potential and the amount of wind speed is appropriate. The ultimate objective of this system is to minimize the amount of fuel consumption from the system.

A hybrid system which does not consist of conventional energy source can be classified as following:

- **PV system with energy storage:**

In order to satisfy the load demand, the PV system should consist of another energy source during the absence of sunshine. For installing autonomous photovoltaic systems, the energy storage capacity is very important to feed the load during the inoperative condition of energy source.

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DOI:10.35940/ijrte.F7436.038620
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- **Wind generator system with storage:**

The combination of wind energy system with storage device can be used to store energy for long period for an independent system. For a hybrid system connected to the electrical network, it can be used as a buffer.

- **Hybrid photovoltaic / wind / storage systems:**

The systems mentioned above consist only one renewable source of energy production, which is a demerit for systems where large amount of energy is required. Due to this, a continuous supply of energy to the load cannot be guaranteed, which also increases the cost of production. These problems are rectified by utilizing a system of PV and wind generator hybridized with the energy source.

III. MODELLING OF HYBRID SYSTEM

A.Solar PV system

Solar photovoltaic system generates electrical energy by following the principle of photovoltaic effect. The electrical energy is generated in the solar panel when the solar radiation is incident on it. A solar panel consist of a set of solar cells which are connected either in series or in parallel combination in order to supply the required amount of output voltage and current.

Even though, many solar cell models were proposed, the one diode electrical equivalent circuit is widely utilized for the analysis of the cells or modules. The equivalent circuit comprises of current source, diode, a series and parallel resistance. The photo-current is generated by the current source. The photo current is produced due to the solar radiation incident on the cell. Voltage loss is observed in the solar cells when it is connected to external circuits. The series resistance (RS) is a representation of this voltage loss. The equivalent circuit for a photovoltaic generator is represented in Fig. 3.

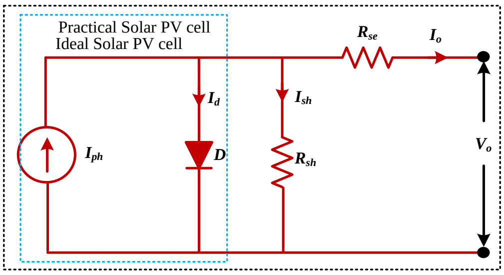


Fig. 3.Equivalent circuit for a photovoltaic generator

Where,

v= PV module voltage

i= PV module current

i_{ph}= photocurrent

R_{sh}= shunt resistance

R_s= series resistance

P_{PV} is the output power of the module, IT refers to the total solar radiation on the module and η refers to the efficiency of the PV module. Output power is given by,

$$P_{PV} = I_T \eta A_{PV} \quad (1)$$

$$P_{PV} = \eta_{\text{mod}} \eta_{PC} P_f \quad (2)$$

Where,

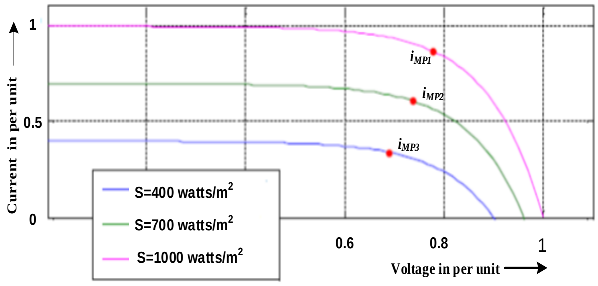
η_{PC} = efficiency of power conditioning

P_f = packing factor

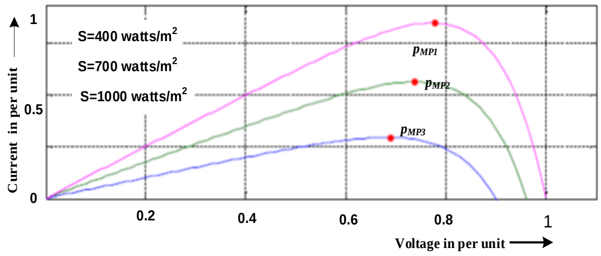
A_{PV} = area of solar array

Under standard test conditions the solar PV power is given by

$$P_{PV} = P_{STC}\left(\frac{IR}{IR_{STC}}\right) \times \left[1 + a_p (T_{\text{mod}} - T_{\text{mod\_STC}}\right] \quad (3)$$



(a)



(b)

Fig. 4.(a)I-V Curves of PV Array with different radiation levels (b) P-V Curves of PV Array with different radiation levels

Where, *P*STC is the solar photovoltaic power under standard test conditions STC; the DF factor refers to reduction in PV power due to building up of dust on the solar modules, wiring, and shading losses; Solar irradiance is denoted by *IR*; coefficient of power is denoted as ; and the temperature of the solar PV module is denoted by .

The efficiency of the module is given by,

$$\eta_m = \eta_r [1 - \beta(T_c - T_r)] \quad (4)$$

Where,

η_r= module reference efficiency,

β = temperature coefficient of array efficiency,

T_r= reference temperature for cell efficiency,

T_c= average monthly cell temperature.

The efficiency of the solar module in standard test condition at its maximum power point is represented by:

$$\eta_{m,STC} = \frac{P_{m,STC}}{A_{PV} R_{STC}} \quad (5)$$

Where the solar PV panel area [m2] is denoted by A_{PV}.

The PV modules of IV and PV characteristics under different irradiations have been presented at 25 0C in Fig. 4 (a) and (b), respectively.

B. Wind Energy System

Wind energy system consists of turbine converts the kinetic energy generated due to the wind into rotational energy. When the wind turbine and generator coupled, due to the rotational energy in turbine, electrical energy is generated in generator. The output power of the system is dependent on velocity of wind, density of air, power coefficient and area swept by blades. The output energy generated by wind can be mathematically represented as follows

$$P_w = \frac{1}{2}\rho_a A C_P V^3 \qquad (6)$$

Where,

ρ_a =density of air

C_P = power coefficient

A = area swept by blades

V = velocity of wind

The output power of wind turbine is associated with wind speed in a cubic ratio. J is the first order moment of inertia a friction based dynamic model for the wind turbine rotor and also a first order model for the permanent magnet generator is used. The dynamics of the wind turbine due to its rotor inertia and generator are added slightly under-damped system by considering the wind turbine response as a second order. By this simple approach, the modelling of small wind turbine dynamic is as follows.

$$\frac{P_g(s)}{P_{wt}(s)} = \frac{0.25}{S^2 + 0.707 + 0.25} \qquad (7)$$

C. Fuel Cell

The operation of a fuel cell is to generate electrical energy from chemical energy. Generally, analytical and empirical modelling approaches are utilized widely. The analytical model of fuel cell is related to the electrochemical equation analysis which describes the working of fuel cell. This type of modelling approach necessitates large computation and vast information regarding geometrical and electrochemical specifications like internal humidity level, catalyst layer thickness and transfer coefficients. The accuracy in this type of approaches completely relies upon approximation and assumption made in the analysis. In the absence of geometrical and chemical variables, empirical approach of modelling is widely followed. This type of approach is based on data fitting and black box approach. The accuracy in the empirical type modelling relies on various factors. These factors affect the accuracy at each stage of modelling process. The generator which consists of hydrogen as its prominent fuel is used for modelling of fuel cell. The SOFC's (solid oxide fuel cell) electrical efficiency is given by:

$$\eta_{m,STC} = \frac{P_{FC}}{m_{H_2} HH_{H_2}} \qquad (8)$$

Where (kg/s) and are respectively the H2 mass flow rate and heating value.

The PEM (Proton Exchange Membrane) is most widely known fuel cell and is commonly utilized for various requirements. It can be utilized as a substitute for the internal combustion engines in various applications in the transportation sector. The porous carbon electrodes in the Proton Exchange Membrane are bonded to very thin sulphonated polymer membrane.

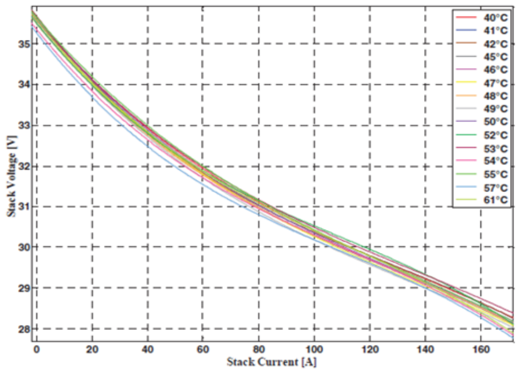


Fig. 5.set isothermal steady-state V-I curves

D. Diesel Generator

When the diesel engines are connected or coupled with a generator, it forms a diesel generator. Diesel generators have the capability for generating a nominal power. The surfeit amount of energy generated by the diesel generator can be utilized to charge the battery bank. The diesel generators generally modelled to operate at eighty to hundred percent of its kW rating, during its operation along with battery bank or other renewable energy sources. The energy generated (E_{DG}) by diesel generator can be represented as given below.

$$E_{DG} = P_{DG}\eta_{DG}t \qquad (9)$$

Where output is power and is the efficiency of the diesel generator.

The output voltage of the AC diesel generator is generally equivalent to AC bus voltage. Due to this, most of the diesel generators do not have a series connection. In order to match the system current requirements, diesel generators connection can be made in parallel combination

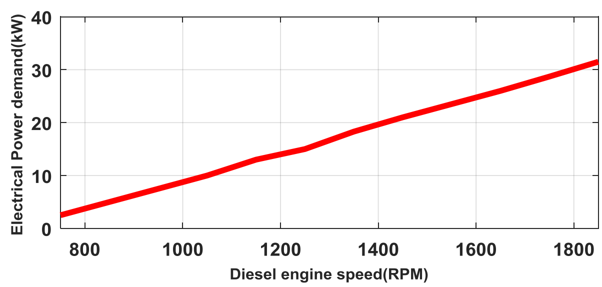


Fig. 6.Plot electrical power versus diesel engine speed

The instantaneous output current from diesel generator relies upon parameters such as size or type of diesel generator. The instantaneous output current can be represented as:

$$I_{DG} = I_{DG,max} X_{DG\%} \qquad (10)$$

Where, the output current of the diesel generator is I_{DG}, which represents the percentage of the maximum diesel generator current.

The maximum nominal diesel generator output current is denoted by $I_{DG,max}$.

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The diesel generator output decision variable between [0, 1] is $X_{DG\%}$. 1 is maximum diesel generator output and 0 is no diesel generator output.
Below graph illustrates the fuel efficiency power of 30kW. It is entirely appropriate to use diesel engine in modelling and simulation, even though the performance parameters of diesel engine differ because of the ambient condition changes.

IV. IMPORTANCE OF ENERGY STORAGE SYSTEMS

Energy storage is used to store surplus electrical energy in order to utilize it when there is no other power source. It is also used as an alternative source of energy. To ensure the stability in the power system, batteries and super capacitors are used in hybrid energy storage system. Battery-Super capacitor is used hybrid storage system in order to increase the life of battery bank. This can be achieved by reducing the stress level and size of the battery. This system also minimizes the overall capital cost of system.
The goal of optimization of energy storage is to enhance reliability, minimizing overall cost and emissions.
Hybrid stand-alone systems widely use lead acid batteries as energy storage system. Lead acid batteries are preferred because of high efficiency, lower capital and installation cost. Lead acid batteries have efficiency about eighty-five to ninety percent, whereas the Li-ion battery has an efficiency of up to ninety percent. Li-ion batteries are used very less in stand-alone hybrid systems, even though they have high energy density, long operating life and low self-discharge rate.

The excessive energy is utilized to charge battery bank until battery state of charge occupies its peak value. For a stand-alone system, the extra energy is dumped if it reaches peak of state of charge of battery bank. The excess energy is supplied to the grid, for grid connected hybrid system.

Super capacitors consist of pre-defined threshold values which imposes limits on its charging and discharging operations. The super capacitor is utilized as the primary storage which supplies the power to load. When the SOC of super capacitor falls below the pre-defined thresholds, the battery is used recharge the super capacitor.

V. POWER FLOW CONTROL IN HYBRID SYSTEM

To achieve voltage and power regulation in grid connected and stand-alone systems, the hybrid energy sources should be controlled using particular power converter control strategies. The converters in source side are accountable for applying the maximum power from the RES and DC bus voltage regulation. Due to this, power converters in the system need a simple algorithm for controlling. The load side converters are accountable for regulation of voltage, real and reactive power, frequency and harmonics for sustaining the quality of the power.
The optimum point at which the module operates at its peak power is known as maximum power point (MPP). In solar PV systems, the commonly applied MPPT (Maximum Power Point Tracking) algorithms are Perturb and Observe (P&O) and Incremental Conductance (INC) algorithm. The intention of the P&O algorithm is to analyse and find out the load current's changing direction. The figure below shows the flowchart of the MPPT algorithm using P&O algorithm.

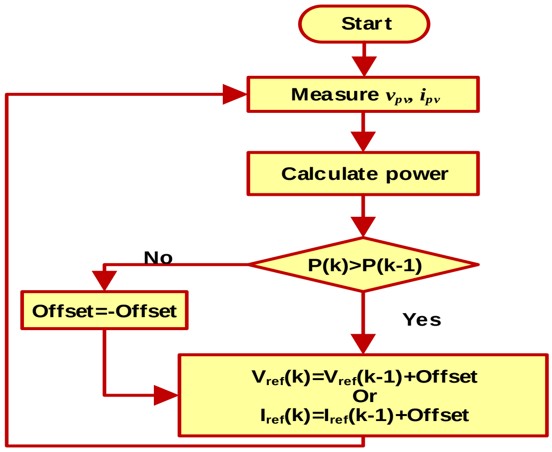

Fig. 7.P&O algorithm

To acquire the optimal point, P&O algorithms utilize a fixed perturbation step. These algorithms have few limitations such as slow convergence to the optimal point and oscillations around it. To overcome these limitations, several approaches were proposed. Huang and Ren proposed a command to manipulate the perturbation step. The variable step becomes equal to single step, if the operating point is present at the right part of the photovoltaic characteristics. The variable pitch is four times that of the right side, if the operating point is present at the left side. This method would help in minimizing the oscillations around the maximum power point.

VI. FUTURE CHALLENGES IN ENERGY MANAGEMENT SYSTEM

Under stable irradiance, few maximum power point tracking methods sustain an optimum performance. In contrast to that, under rapid variation of irradiance, the performance is dissatisfying. KF (Kalman filter) involves two steps, that is, prediction and correction. The prediction involves the predicting of the state. The correction involves rectifying of the estimation with respect to measured value. Thus, it can be utilized for estimating the maximum power point voltage, then correction of this estimate value depending upon the error generated between estimate and measured voltage of PV. The next step involves controlling of the converter to obtain the rectified value. The repetition of this process is done till the error value is close to zero. This indicates that maximum power point is reached.
Fuzzy Logic (FL) is currently treated a favourable solution to overcome complicated problems by simple approach and without the necessity of modelling the system. For the problem of non-linear systems tuning, fuzzy logic control is stated as highly effective and elegant solution. The fuzzy logic controller processing consists of three steps: fuzzification, rules inferences and defuzzification. In addition, the database is the representation of the rule table which consists of designed rules.

The fuzzy inference is a process in which fuzzy logic controller performs the computation with respect to the rule table in order to provide the output.

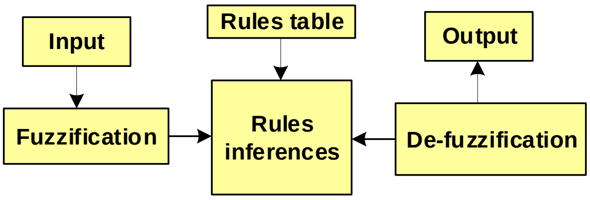

Fig. 8.Fuzzy logic controller

The maximum power point tracking controller has been proposed by using an IC-based variable step size Neuro-Fuzzy (NF). Firstly, to find the optimal neural network controller used, the proposed neuro-fuzzy controller is developed in the offline mode for testing different set of neural network parameters. Later, under different atmospheric conditions to track the output power of the PV system the online mode is used.

VII. RESULT AND DISCUSSION

The hybrid renewable energy systems corroborate to be more effective and optimistic as compared to power generation by independent energy sources. The different data illustrated in Table-I and Table-II manifest the power generation of the energy sources during the span of the day in summer and winter season.

The number of sunshine hours observed illustrate an optimistic increase in summer as compared to other seasons of the year which makes the power generation by solar PV more prominent in this season. Power generation from wind is also in a considerable amount. Substantial power generation from solar and wind energy helps the battery to get charged considerably.

Table- I: Power generation and battery charging during summer

Parameters	Power (Ah)		
	8:00-10:00 Hrs	*12:00-14:00 Hrs*	*17:00-19:00 Hrs*
Solar PV power generation	55	135	35
Wind power generation	80	145	60
Battery charged	30	100	20

In contrast to performance in Table-I, the power generated by the solar PV is substantially low due to the lack of adequate sunshine hours, which leads to less power generation by solar PV during winter. Considerable Power generation from wind aids the battery to charge in spite of lack of power generation from solar PV.

Table- II: Power generation and battery charging during winter

Parameter	Power (Ah)		
	8:00-10:00 Hrs	*12:00-14:00 Hrs*	*17:00-19:00 Hrs*
Solar PV power generation	20	35	5
Wind power generation	70	75	35
Battery charged	30	25	5

The hybrid combination of these energy sources helps to overcome the power generation constraints during the seasonal change.

VIII. CONCLUSION

This paper confers the present status of Hybrid Renewable Energy System and its role in enhancing the generation of electrical energy. This paper scrutinizes modelling of various renewable energy sources and conventional sources like diesel generator. It highlights the various energy storage devices and power flow controlling algorithms which uplifts the efficiency of the system. In order to overcome the certain instabilities in the system, various methodologies like Fuzzy controllers were introduced.

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