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A Bibliographical Survey on Integration of Hybrid Renewable Energy Sources with Diesel Generator and Storage System

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Abstract

The power consumption has increased enormously due to the intervention of high end technology and it is necessary to meet this power demand. The power pushed into any electrical system should be highly reliable, secured with sufficient quantity and quality. One such solution is to bring reliable and flexible power by introducing Hybrid energy systems into the network. The main motivation of hybrid energy systems is to improve the delivery of power at the utilities and customer end. In this paper, a complete literature review is made on the integration of solar photovoltaic, wind and diesel generator with energy storage systems like hydrogen based fuel cells and batteries. This hybrid system reduces the operating time of diesel generator, save the fuel consumption and hence accomplishes the peak demand with diesel generator.

Keywords: Solar PV, Wind, Diesel, Battery, Fuel cell.

1. Introduction

One of the major sources for a country to develop economically is energy. In any country, utilization of electrical energy increases due to technology, population growth and economic development. The increasing demand of energy consumption is becoming prominent in the agricultural, industrial and domestic sector [1] and the author has reviewed on planning and control strategies with respect to renewable and sustainable energy. The installed capacity of the electrical utility sector in India was 307.28 GW as on31stOctober 2016 and renewable power plant capacity was 28.9% of the total installed capacity [2]. The shortage of power during peak demand in India with a capacity of 2,329MW as of Jul 2017, [3] was reported by the Ministry of Power, Government of India. The shortage of power and energy demand was reduced gradually every year. The shortages of power and energy details of last three years are mentioned in Tab.1.

Table 1. The summary of shortage of power and energy demand for last three years in India [3]

SI.No.	Month and Year	Power demand of shortage (MW)	Energy demand shortage (MU)
1	Jul 2017	2,329	12
2	Jul 2016	2,549	14
3	Jul 2015	3,486	61

The authors have found that the demand for electricity can be raised around 2280BKwh by 2021-22[4] and the usage of energy from the world context could rise to 53% by 2035 [5]. Non-renewable and renewable energy sources [6] play a vital role in the energy consumption and both the energy sources are creating high impact with economic growth and emission of carbon relationship. But the coal based plant causes environmental pollution, such as Acid rains, global warming [7] [8] and the emission of greenhouse gasses which leads to changes in the climate.

In order to avoid environmental pollution, the electric capacity can be increased with the help of renewable sources like hydro, wind, solar etc. Renewable energy sources are the back bone of current green economy effort and can affect the biodiversity and ecosystems [9]. Nowadays the most prominent renewable sources are solar, wind sources and these sources are more economical in the generation of electricity. The single photovoltaic system cannot meet the peak load continuously due to the dynamic variation in climate. Energy backup is needed to meet peak power demand and provide continues supply, and this energy backup system is called *storage system*.

In solar PV system, the battery is used to improve its performance but it cannot support for a long time. The integration of the Photovoltaic system with diesel and battery hybrid standalone system is reliable compared to Photovoltaic-battery integrated system. This integration of photovoltaic systems increases the efficiency and saves the fuel consumption of diesel generator. It also improves the stability of the solar PV system and load can be met satisfactorily. The output from solar-diesel-battery is optimized with different solar irradiance varying from 0-100% and the parameter variation such as radiance, cost of the diesel, load consumption are analysed to save the intake fuel and energy cost [10].

The peak demand may not be sufficient to meet with the integration of single Diesel generator and battery simultaneously. An alternative solution is by integrating

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wind energy with photovoltaic systems which is also favourable to the environment. As the nature of solar, wind and other renewable energy sources are intermittent, the individual sources are unable to meet the peak load and to supply continuous power.

To have flexibility, the generation of electricity is enhanced with the hybrid renewable energy sources and it reduces the effect of greenhouse gasses [11]. The authors in [12] have realized the hybrid system through an experimental set up from which size optimisation and real time performance are studied. The efficiency of solar PV and the wind energy is enhanced with novelty in the integration of doubly fed induction generator based wind turbine with both rotor and grid side converter control. This system is used for injecting large power into the grid [13].

In this paper, the following section deals with brief description on solar PV system, wind energy system, Diesel generation, storage system and Fuel cell. A complete literature review is made on the integration of all sources mentioned above.

2. Photovoltaic (PV) System

Solar energy is produced from solar radiation due to which heat energy is exploited. Solar PV system [14] converts incident sunlight into electricity by the principle of photoelectric effect. This solar storage technology is developed with reduced energy payback time and the device by using conventional silicon and carbon based scalable material is achieved [15]. The Solar PV cell is a basic non-linear device of PV system and it is shown in Fig.1. [16]. These PV cells are arranged in a series-parallel configuration such that an array is formed.

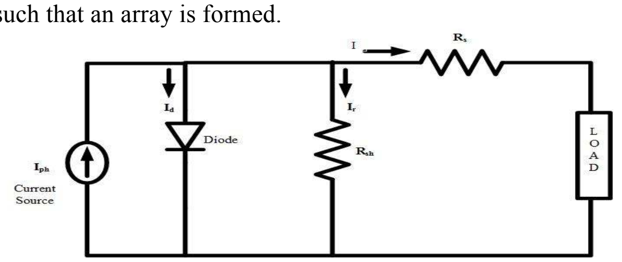

Fig. 1. Solar photo voltaic equivalent circuit [16]

The voltage-current relation of the PV array model is obtained from Eq.1 and Eq.2.

$$V_{PV} = \frac{nKT}{q}\ln\left(\frac{I_{sc}}{I_{pv}}+1\right) \quad (1)$$

$$I_{pv} = I_{sc} - I_{pvo}\left[\exp\left(\frac{q(V_{pv}+I_{pv}R_s)}{N_s KTn}\right)-1\right] - \frac{V_{pv}+R_s I_{sc}}{R_{sh}} \quad (2)$$

The various sustainable technologies were developed with the solar building system [17] and the status of utilization of solar energy in India along with its applications, battery integration with the solar photovoltaic system [18] is presented. The various photovoltaic monitoring techniques, measuring instruments and the off-grid/ on-grid PV systems is proposed to improve the performance of solar energy systems[19].The author has emphasized the significance and benefits of solar PV panels by illustrating the growth in solar PV technology since 2010 to 2014 for off-grid and on-grid system [20].

The author has reviewed 31 maximum power point trackingmethodswith13 parameters altogether and has explored a methodology to maximize the power in solar technology [21]. In [22], the author has discussed different maximum power tracking methods such as perturbation and observation, incremental conductance with intelligent techniques and a comparison is made based on the hardware design and observation of the results. A novel high performance with high gain and efficiency of stand-alone solar PV system is investigated along with an energy storage system [23] and required power tracking method is employed for DC-DC converter to achieve high efficiency.

In grid connected mode, the active power is injected into the grid without Phase locked Loop (PLL) synchronizing unit by maintaining the appropriate reactive power to the load [24].Integration of the disposable photovoltaic system [25] is explored for smart grid application with electrical power network to provide a balanced power supply, avoid voltage fluctuation and reversal power flow from the grid. Solar thermal energy is used for heap bioleaching process [26] to increase the heap temperature. Solar power is utilized for different applications such as light, heating, thermal loading etc.

3. Wind Energy System

Electrical energy is developed from the wind energy system in two steps. Firstly, the wind energy is converted into mechanical energy with the help of wind turbines and then in the second stage, the mechanical energy is converted to electrical energy with the help of a generator. The mechanical power [27] from the wind turbine is expressed as shown in Eq.3.

$$P_m = 0.5\rho A C_p \vartheta^3 \quad (3)$$

Tip speed ratio is given by the Eq.4.

$$TSR = \gamma = \frac{\omega R}{\vartheta} \quad (4)$$

Wind turbine generator starts rotating if the speed exceeds the cut-in speed and it will generate the electricity constantly if the speed reaches its rated value. The wind generator is protected if the speed of the wind exceeds its cut-out value. Power developed from individual generators at time‘t’ can be obtained by the following Eq.5 [28].

$$P_{WG}(t) = \begin{cases} P_{r-WG}\dfrac{\vartheta(t)-\vartheta_{cut-in}}{\vartheta_r(t)-\vartheta_{cut-in}} \rightarrow \vartheta < \vartheta(t) < \vartheta_r \\ P_{r-WG} \rightarrow \vartheta_r < \vartheta(t) < \vartheta_{cut-out} \\ 0 \rightarrow \vartheta(t) \le \vartheta_{cut-in} or \vartheta(t) \ge \vartheta_{cut-out} \end{cases} \quad (5)$$

The overall developed power can be estimated using Eq.6.

$$P_{WG}(T) = N_{wind} \times P_{WG}(t) \quad (6)$$

Number of wind turbines estimated according to load requirement as shown in Eq.7.

$$N_{turbine} = \frac{P_L \times SF}{P_{WG}} \tag{7}$$

Advance design and control mechanism in wind generation with variable speed leads to tap the energy with high efficiency [29]. A reliability study on peak demand power in the existing fuel based generation integrated with wind using stochastic optimization technique is carried out by the authors [30]. The author in [31] inferred that wind generation with various maximum power tracking techniques perform well for desired responses and the methods are compared

4. Diesel Generation System

The diesel generator plays a major role during peak load and other abnormal conditions. It can be used in two ways; one as energy backup and another by connecting the load directly. In [32], ON/OFF control strategy is implemented for a diesel generator to minimize the operating cost of the hybrid energy system and for optimizing the power flowing to the on-linear load. Power pinch analysis for the hybrid configuration is suggested in [33] to minimize the consumption of fuel in diesel generator by sharing the load with renewable energy sources. Back propagation feed forward algorithm and incremental conductance based wind-diesel micro grid is presented in [34] and is discussed for regulating the voltage and frequency when DG is fed to three phase load. The Diesel engine generation system mainly consists of three parts, such as Diesel Engine, Synchronous Generator and the excitation system, and the block diagram is shown in Fig.2.Excitation system provides variable DC current to maintain the desired terminal voltage.

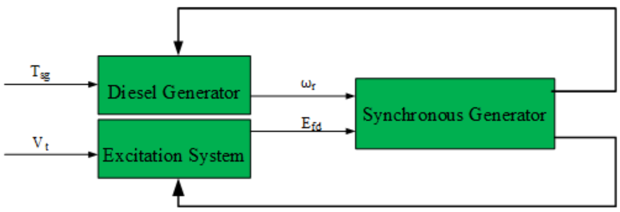

Fig. 2. Block diagram of diesel generation system [105]

Diesel engine converts the fuel flow into mechanical torque. Internal combustion engine speed is varied by regulating the fuel flow with the help of actuator and electro-mechanical devices. Speed controller is used to maintain the constant speed. Dynamic effect of engine inertia is estimated by relating the intake fuel and flywheel speed.

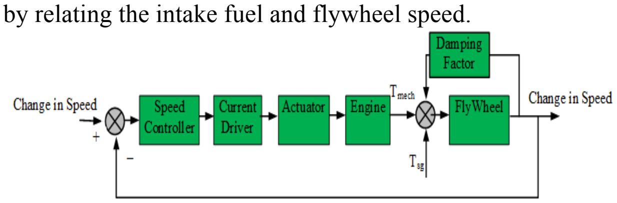

Fig. 3. Diesel engine model block diagram [105]

The transfer model of the diesel engine diagram is shown in Fig.3, and the engine mechanical motion can be represented as shown in Eq.8.

$$T_{mech}(s) = k_1 \phi(s) e^{-t_1 s} \tag{8}$$

Two axis dq-model of synchronous generator are obtained using park equation and electromagnetic torque is shown in Eq.9.

$$T_{sg} = E_d^{"} I_d + E_q^{"} I_q - (X_d^{'} - X_q^{"}) I_d I_q \tag{9}$$

Where I_d and I_q are stator and rotor current flowing through the respective winding and dynamic equations of rotor are shown in Eq.10, Eq.11 and Eq.12,

$$E_d^{"} = \frac{X_d - X_q^{'}}{1 + \tau_{qo}^{'} s} I_q \tag{10}$$

$$E_q^{"} = \frac{1}{1 + \tau_{do}^{'} s} E_q^{'} - \left(\frac{X_d^{'} - X_d^{"}}{1 + \tau_{do}^{'} s}\right) I_d \tag{11}$$

$$E_q^{'} = \frac{1}{\frac{X_d - X_d^{"}}{X_d^{'} - X_d^{"}} + \tau_{do}^{'} s} E_{fd} + \left(\frac{\frac{X_d - X_d^{"}}{X_d^{'} - X_d^{"}}}{\frac{X_d - X_d^{"}}{X_d^{'} - X_d^{"}} + \tau_{do}^{'} s}\right) E_q^{"} \tag{12}$$

Excitation system monitors the terminal voltage and provides variable DC current with the desired accuracy. The dynamic performance of the generator is carried out by the excitation system and its model is shown in Fig.4.

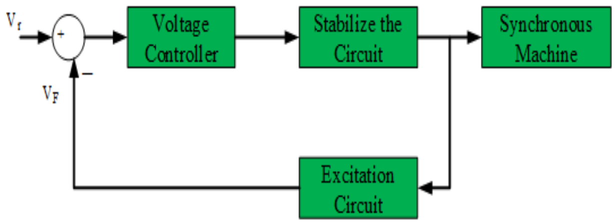

Fig. 4. Diesel Engine Excitation System models [105]

Diesel generator power is based on the fuel consumption and it is represented using Eq.13.

$$Cons_D = B_D \times P_N^D + A_D \times P_D \tag{13}$$

Consumed fuel cost is calculated using Eq.14,

$$C_f = P_{fuel} \times Cons_D \tag{14}$$

5. Electrical Storage System

Energy saving system is classified based upon the availability of energy as presented in the Fig.5 [35] [36] [37].Most of the classification of energy storage system is described in [38]. These storage systems are used in applications like medicine, transport, electric vehicles, traction, wind and solar photovoltaic industrial applications etc. The storage system is selected based on the storage duration and it can be classified into three categories as mentioned in Fig.6.

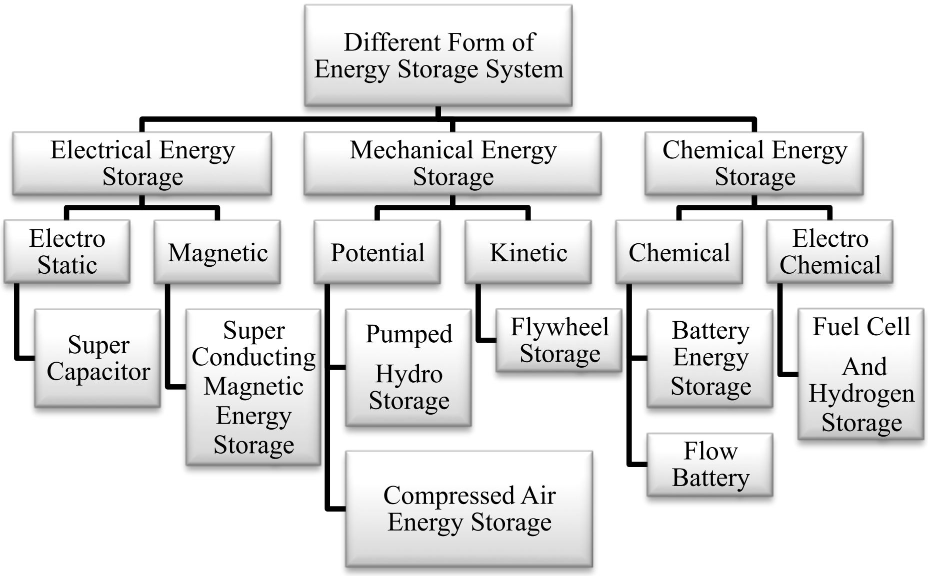

Fig. 5. Different form of energy storage system [36]

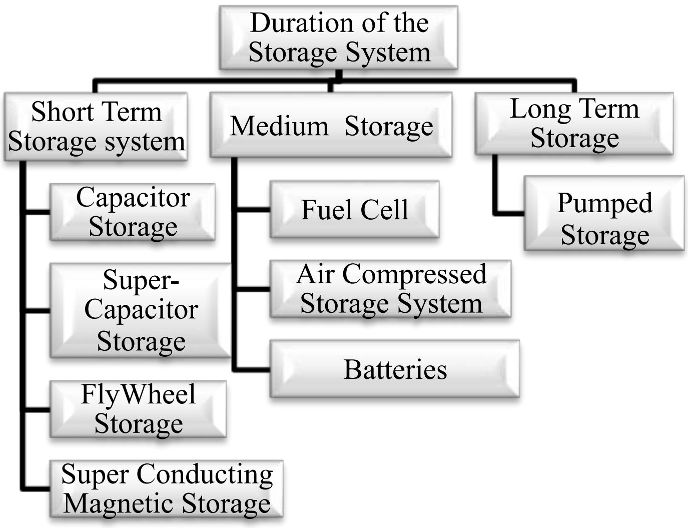

Fig. 6. Classifications of energy storage system based on Duration [35]

Renewable energy systems do not support the peak power requirement and continuous supply. In order to provide sufficient quantity of power for the customer, energy back up is needed. The choice of energy storage device is based on initial state of the charge, lifetime, cost, efficiency and reliability. The objective of the paper [39] is to maintain constant power and suppresses the power fluctuation [40] at the load end.

6. Battery storage

Battery storage integrated with hybrid system is to make energy backup and attain the peak demand. Battery stores electricity in the form of chemical energy. Valentin A. Boiceain[41] has focused on various batteries such as Lead-Acid, Nickel-metal hydride/Nickel Cadmium, Li-Ion, Sodium-Sulphur, Sodium-Nickel-Chloride ($NaNiCl_2$), Inkjet-Printed and Flow batteries. Batteries are preferred based on the state of the charge, depth of discharge, duration of support for energy backup and their capacities. The performance of the batteries and various objectives are mention in Tab.2 [42-80].

Table 2. Types of battery based on the area application and internal chemical reaction

Name of the battery/ (unit voltage)/ power density (W/Kg)	Chemical reaction	Objective
Lead Acid battery(2V)/ (150-300)	$Pb + SO_4^{-2} \leftrightarrow PbSO_4 + 2e^-$	Operating condition of the battery and Stress factor is analysed using Genetic Algorithm combined with weighted Ah model [42]. Applications: Micro grid and Hybrid energy system

	$PbO_2 + SO_4^{-2}$ $+4H^+ + 2e^-$ $\leftrightarrow PbSO_4$ $+2H_2O$	Reduce technical losses in the distribution system by long term sizing of the lead acid batter using neural network [43]. Applications: Distributed Generation(DG)
		Valve regulated lead acid battery model with predictive control is proposed to charge the battery as fast as possible without violating the constraint [44]. Applications: Automotive applications
		Characterize the morphology of Lead-Carbon with composite electrode [45]. Applications: Renewable energy sources integration applications
Lithium-ion battery(3.7V)/ (200-400)	$C + nLi^+ + ne^-$ $\leftrightarrow Li_nC$	LiFe PO_4Discharging curve is analysed by mathematical model using dual exponential function closely related to RC circuit characteristics. The state of the charge of the Lithium-ion battery is modelled [46]. Applications: Electrical vehicles and Smart grid application
		Focus on impact of negative pulses during the fast charging process and analyse the performance of battery during static and dynamic condition [47]. Applications: Smart grid.
		Economic analysis of LiFe$PO_4$is performed based on the life time of the battery with lowest quoting price. Estimates the requirement of firm frequency response of the U.K Grid [48]. Applications: National Grid Applications
		Investigation on lifetime and re-establishing the lithium ion battery state of the charge. Regulates primary frequency response [49]. Applications: Grid Applications
		Review on various aspects of Lithium ion battery and their applications [50]. Applications: Automotive Applications
Sodium and Sulphur (~2.08V)/-	$2Na \leftrightarrow$ $2Na^+ + 2e^-$	Study on the performance of sodium sulphur batteries with high doping of sodium and sulphur at room temperature [51].
		Electronically conducting cathode matrix is proposed to make excellent discharge performance of sodium-sulphur (NaS) battery [52].Applications: Grid storage application
Nickel and Cadmium (1-1.3V)/(150-200)	$Cd + 2OH^- \leftrightarrow$ $Cd(OH)_2 + 2e^-$ $2NiOOH + 2H_2O$ $+2e^- \leftrightarrow$ $2Ni(OH)_2 + 2OH^-$	Stability of the nickel cadmium battery is enhanced. Applications: Solar, wind storage applications[53]
Nickel metal hydride (1-1.3V)/(200-300)	$H_2O + e^- \leftrightarrow$ $\frac{1}{2}H_2 + OH^-$ $Ni(OH)_2 + OH^-$ $\leftrightarrow$ $NiOOH +$ $H_2O + e^-$	Stability of the nickel cadmium battery is enhanced. Applications: Industrial [54]
Sodium nickel chloride (~2.58V) /-	$2Na \leftrightarrow$ $2Na^+ + 2e^-$ $NiCl_2 + 2e^-$ $\leftrightarrow Ni + 2Cl^-$	Analyze the transient operation of Sodium Nickel chloride batteries [55]. Applications: Power fluctuation mitigation in renewable energy source applications
		Analyse the steady state behaviour and modelling of Sodium Nickel Chloride batteries [56]. Applications: High Voltage Network Applications

The batteries are used for various applications such as uninterrupted power supply (UPS), hybrid electric vehicles, and power back up in telecommunication, aerospace and medicine, Industrial solar photovoltaic system and household applications. It is also used for specific applications such as power quality improvement, power management, frequency regulation, peak saving and voltage regulation. Battery storage system is integrated with hybrid generation in both off-grids and on-grid mode to maintain the quality of power at utilities and customer end. Author in

[57] and [58] has reviewed the internal chemical reaction, capacity, and the applications of various batteries.

7. Fuel cell

The promising electrochemical device, which turns chemical energy into electrical energy by reacting positively charged hydrogen ions with the oxygen or other oxidising agents, is called Fuel cell. It consists of three major parts such as fuel, oxidant electrodes (anode/cathode) and an electrolyte squeezed between them. The electrode is covered with a catalyst layer and it is made up of porous material. Based on storage capacity and efficiency different kinds of fuel cell such as alkaline fuel cell, phosphoric acid fuel cell; solid oxide fuel cell, molten carbonate fuel cell; direct methanol fuel cell and proton exchange membrane fuel cells are developed. The authors in[59] [60][61] reviewed and made a comparative study between different kind of fuel cells with respect to their operating temperature, system output, efficiency, chemical reaction, cell voltage, advantages and applications. A comprehensive table has been made to show the complete details of various fuel cell technologies and it is shown in Tab.3. The most prominent fuel cell for hybrid and stand-alone system is PEMFC. This is due to its high efficiency, immediate response, quick start-up time, more life time and less operating temperature. The authors in [80] have demonstrated the PEMFC with precise architecture of metal free cathode which consist of nano particles of carbon and electron acceptor. This architecture controls the electrochemical reaction fuel rate.

Table 3. various types of fuel cell technology

Name of the Fuel cell	Advantages/ Disadvantages	Objectives
Alkaline fuel cell(AFC)	Advantages: Simple structure, low cost catalyst. Disadvantages: Easily contaminated by CO_2 pure oxygen is required	Finding the alkaline stability of quaternary ammonium cations for AFC [62].
		Enhancement of stability of anion exchange membrane based imidazolium salt for alkaline fuel cell [63].
		Investigation on alkaline anion exchange membrane fuel cell [64].
Phosphoric acid fuel cell(PAFC)	Advantages: Long term stability Disadvantages: initial cost is high	Maximize the power output with load matching based PAFC hybrid system [65].
		Comprehensive analysis on PAFC based refrigerator to recover the waste heat for cooling purpose [66].
		The performance of AFC hybrid system is studied based on the double function of PAFC [67].
Solid oxide fuel cell (SOFC)	Advantages: High thermal stability, High chemical stability, Noise free. Disadvantages: long start-up, cooling down time	SFOC is integrated with thermal power plant to enhance the overall efficiency [68].
		Analysis on advancement in the field of Proton – conducting electrolytes in SOFC [69].
		SOFC is integrated with Gas Turbine (GT) to enhance the efficiency of GT [70].
Molten carbonate fuel cell (MCFC)	Advantages: Do not require metal catalyst. infrastructure is not required for development Disadvantages: takes long time to operate and generate power	Performance analysis of Irreversible MCFC –Brays on heat engine is studied with respect to thermo dynamic parameter [71].
		Design and analysis of integrated MCFC system in marine applications [72]
		Review on current status of MCFC life cycle assessment [73]
Direct methanol fuel cell (DMFC)	Advantages: Can operate at low temperature, longer life, no need to charge Disadvantages: Fuel vaporization at high temperature.	Performance study of DMFC based on the fuel consumption and temperature [74].
		Performance of flowing electrodes in DMFC to reduce the methanol crossover [75]. The performance of Poly (vinyl alcohol) based composite membrane with phosphotungstic acid molecules is studied for DMFC applications [76].
Proton exchange membrane fuel cell (PEMFC)	Advantages: Fast start-up, High power density, Longer life, Low temperature. Disadvantages: Minimum maintenance is required	Author has reviewed on recent advances and challenges on PMFC [77].
		Micro structural analysis of PMFC electrodes is performed [78].
		PFMC based power conversion system is proposed with genetic algorithm for supplying power to telecommunication towers [79].

The authors have also suggested PEMFC based on precious metal free cathode which leads to the delivery of 154mW/cm^2 power at 358mA/cm^2 current. *Marcello Baricco et al*. [81] designed the fuel cell coupled with solid state hydrogen storage tank. The main intension of this project is to develop the hydrogen fuel based auxiliary power unit installed on a light duty commercial vehicle.

8. Hydrogen Storage System

The hydrogen is a clean and efficient fuel which is used in energy saving for hybrid generation to meet the necessary power. There are two possibilities for production of Hydrogen i.e. from non-renewable and renewable energy sources. In this paper, the focus is on the renewable energy based hydrogen production due to economy and less greenhouse gas emission. Primary sources for electricity generation, hydrogen production and storage system are shown in Fig.7 [82] [83]. The production of hydrogen can be taken through the electrolysis process from the renewable sources. The advance development of hydrogen storage technology is with respect to materials and methods such as chemical storage, Physisorption and compressed storage, liquid hydrogen. In Chemical storage method, hydrogen is stored through chemical reaction process using different materials such as Ammonia, metal hydrides, formic acid, carbohydrate, and liquid organic hydrogen carriers.

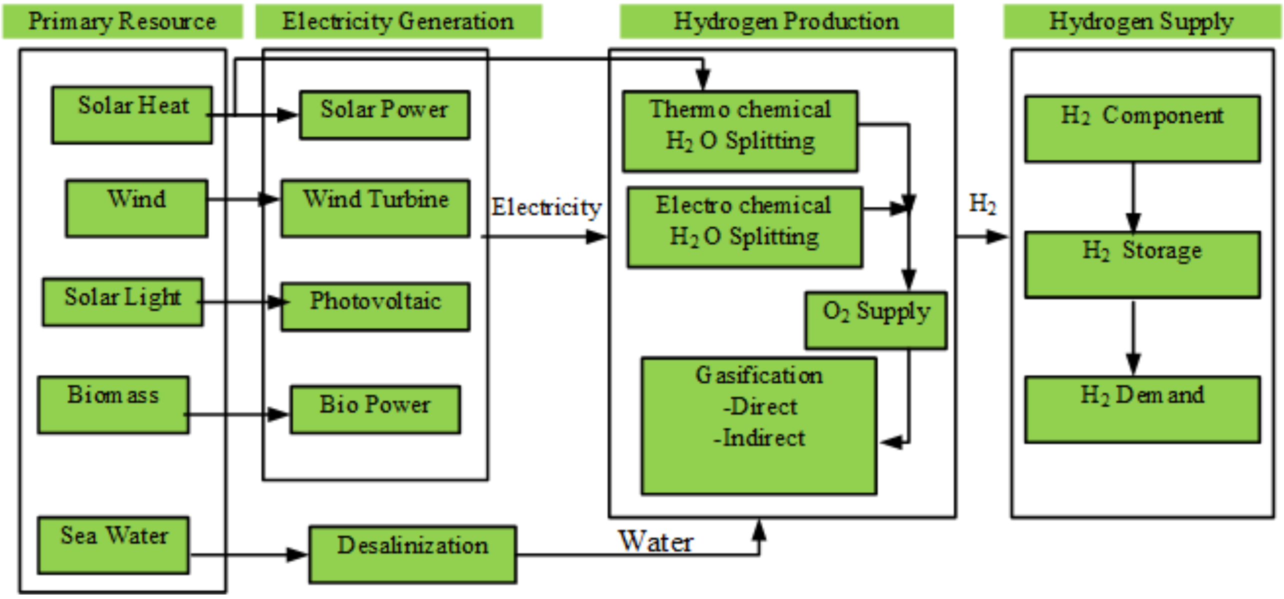

Fig. 7. Hydrogen Production systems [83]

In physisorption method, the kinetics involved in storage process of hydrogen is possible by maintaining the molecular identity of Hydrogen. In compressed storage method, hydrogen gas is stored in the high pressure tank physically. Liquid hydrogen requires cryogenic storage and it can store 0.070kg/Lof liquid hydrogen. A comparative study of Hydrogen storage methods based on various parameters like gravimetric capacity, volumetric capacity, temperature, pressure, system cost, method of storage, benefits with limitation is presented in [84].

9. Hybrid system

The integration of the multi renewable energy system is called *hybrid system*. The modelling of hybrid renewable energy sources is becoming prominent and popular in remote areas [85] and plays a major role in the distribution system. Optimal sizing [86] with artificial intelligent techniques [87] of the hybrid system can meet the load demand with less financial investment. The basic details of the hybrid system, modules of solar-wind-diesel with an energy storage system are briefly discussed in the following section. The basic diagram of hybrid system with energy storage is shown in Fig.8.The hybrid system consists of renewable/non-renewable sources, bi-directional and different type of AC/DC converters. It also consists of DC-bus and AC-bus configuration with different sources and load connection.

In a hybrid system, renewable energy sources are considered as the primary sources while the non-renewable sources are connected as a backup or directly to the load. The storage system can be used as energy back up and also to meet the peak demand. If excessive power is generated from the renewable energy sources, it can be stored in the storage system or injected into the grid with the help of grid control unit and energy management system.Fig.8 is shown with an assumption that the hybrid system is capable to supply the load without taking power from the grid. The hybrid renewable energy integration can be operated in two different modes, namely standalone and grid connected mode. According to the load demand and the geographical location, these hybrid systems are operated indifferent mode.

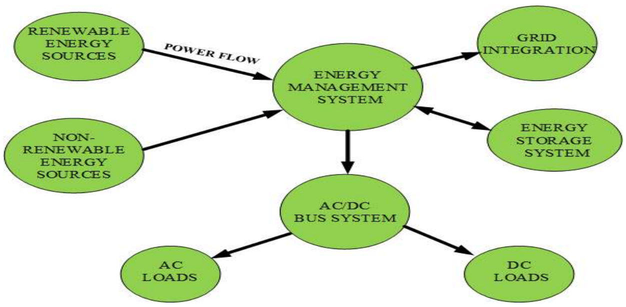

Fig. **8.** Schematic Diagram of hybrid system with Energy storage

The authors in [88] have implemented real-time integration of solar PV-wind-battery hybrid system to solve the challenges with respect to the dynamic variation of load consumption. Integration of solar photovoltaic (PV)-wind with energy storage and management system with optimizing model is discussed in [89]. The authors in [90] propose static compensator in the integration of solar PV-wind-Diesel engine hybrid system with intelligent control. In this paper, Elman neural method is applied to capture the maximum power from wind and radial basis function method is used to analyse and track the maximum power from the solar PV. This hybrid system provides reactive power with quick stabilized retorts.

Various means of cost savings, reduction in environmental pollution and comparison between different energy systems like solar PV, wind, diesel is carried out in

[91] and for the same hybrid system, *TaherMaatallahet. al.* [92] has investigated on optimizing the overall cost of the system with and without battery. In [93], the authors investigate grid connected hybrid system for household applications to track the maximum power from the hybrid sources. They have also discussed the importance of transformer-coupled boost half bridge converter and full bridge bidirectional converter for the same application. Integration of hybrid system with diesel in the AC bus system without any storage is considered [94] to regulate the dynamic variation in frequency. Adaptive–predictor-corrector-based Neuro-fuzzy controller is proposed to regulate the output of photovoltaic generator for frequency regulation. The frequency and inertia control [95] techniques are performed in the hybrid system.

The extension of grid for rural area is cost expensive and may not provide flexible power with the existing power system. The off-grid system provides flexible power for remote areas to meet the power demand. The performance of stand-alone hybrid renewable energy sources with diesel and battery storage using an optimized heuristic algorithm is suggested in [96].The optimized net present cost(NPC), reduction of CO_2 emission and greenhouse gas emission is deployed under renewable energy environment [97][98]. The authors also explain how the hybrid system is eco-friendly with the environment compared to the conventional power plant. The integration of standalone hybrid energy system is most economical and fuel-saving with maximum utilization of full load capacity of 80-100% [99]. The off-grid hybrid system with different battery technologies using genetic algorithm is discussed to achieve the system reliability [100]. *Rajanna Siddaiah and R.P.Saini* [101] reviewed the application of different optimization/intelligent techniques on modelling the hybrid system such as Genetic Algorithm, Artificial Neural Network and Particle Swarm Optimization.

The authors have compared AC and DC off-grid hybrid system, and discussed on various cost functions such as to minimize the levelized cost of energy, total life cycle cost, total net present cost models which are used in the hybrid system. The selection of various off-grids coupled configuration [102] can be estimated depends on the application. The advantage and disadvantage of off-grid AC and DC coupled configuration is shown in Tab.4. *Akbar Maliki* and *Fathollah Porfayaz* [103] has proposed the integration of solar PV-wind-Diesel with storage devices such as battery and fuel cell, and comparison is made with traditional integration of solar PV-wind-diesel hybrid system based on the modelling, sizing and cost analysis. The importance of using a small split diesel generator instead of a large diesel generator for a typical residential building is discussed lucidly in [104].*Sana Charfi et al.* [105] have taken the power generation from three different countries, namely the Kingdom of Saudi Arabia, Tunisia and Jordan on which a complete investigation on its total investment is carried out. Diesel, PV-battery storage bank and hybrid PV-Diesel engine-battery bank modelling and cost analysis are done. It is identified that the Kingdom of Saudi Arabia maintains the efficient hybrid system compared to the other two countries in terms of cost and pollution.

From the comparison made in Tab.4, it is found that DC bus configuration is highly reliable and simple in terms of design and cost. And hence DC configuration is taken for further discussion in the remaining part of the paper. DC configured hybrid system consists of solar PV, Wind generation, Diesel generator, Battery, Fuel cell, Hydrogen storage tank, Electrolyzer, control units and converters which are illustrated in Fig.9. The solar PV and wind sources are the primary input for supplying required power and peak load. Excessive power is drawn from the storage devices, such as battery and hydrogen storage system.

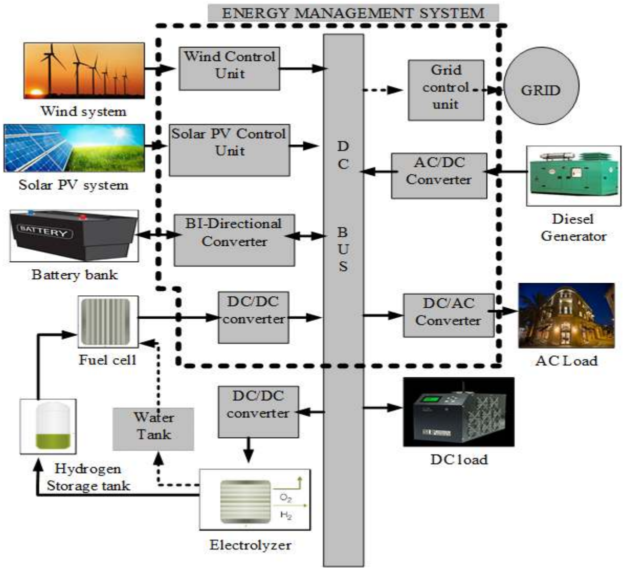

Fig. 9. Hybrid energy systems with Hybrid storage units

Table 4. Comparison of different off-grid AC and DC bus system

Type of coupled Configuration	Advantage/ Disadvantage
DC-bus system	Advantage: No complexity in configuration synchronization-Not required. Disadvantage: Unable to supply AC loads when DC/AC converter fails.
Power Frequency AC- bus system	Advantage: Good for remote area applications. Disadvantage: Necessity of synchronizing unit for AC bus system to extract power from renewable energy sources
Hybrid configuration	Advantage: High efficiency with less cost. Disadvantage: Complexity in control and management in both AC&DC bus system
Combining of Diesel, Hybrid configuration	Advantage: Favourable for rural area with enhanced capacity and fuel saving. Disadvantage: Causes environment pollution and complex in control.

It is found that the following strategies can be adapted under different combination of available energy sources.

- In the absence of sunlight and during the transient period, the load demand can be met by the supply of wind-diesel generator and storage system.
- If the wind fails to supply, then the power can be supplied from solar PV-diesel with an energy storage system and vice versa.
- If wind and solar PV fails, then diesel generator and storage system can supply the power with the help of energy management control scheme.
- The excessive power from the prime input can be stored and injected into the grid with the help of grid

synchronizing unit and energy management control scheme.

10. Sizing Methodology of Hybrid System:

Sizing methodology of hybrid system are classified into different types based on the design and level of complexity such as probabilistic, analytical, iterative and hybrid methods. Probabilistic method is used for finding one or two system based performance indices like Loss of Power Supply Probability (LPSP), Levelized Cost of Energy (LCE), Level of Autonomy (LA), Net Present Value, Annualized Cost of System (ACS), Expected Energy Not Supplied (EENS) and Battery State of the Charge (SOC). Analytical method is used to examine the single or multiple performances of the indices on hybrid system. In this method, results are obtained by computational method using simulation tool like HOMER.

Table 5. Objective, constraints and techniques used in Hybrid system

Constraints	Tool/Technique	Objectives
Minimize the levelized cost of energy and LPSP	Hybrid Optimization Of Multiple Energy Sources(HOMER)	To achieve minimum cost of energy with require load demand using hybrid system [107].
Cost of Energy (COE), Net Present Cost (NPC)	HOMER	Optimize the result with minimum COE, NPC and renewable fraction of 41.6% [108].
Total net present cost	HOMER	To design a hybrid system at Ouled Fares, and Mouafkia in Chief at Algeria [109].
COE, NPC	HOMER	Hybrid system simulation with three different diesel prices per litre [110].
loss of power supply probability (LPSP)	Genetic Algorithm(GA)	To attain minimum desired loss of power supply probability with battery saving space capacity [111].
Cost of energy and State of charge	Guaranteed convergence PSO with Gaussian mutation	To optimize the cost invested in the form of fuel and initial investment on a hybrid system [112].
Cost /kWh, level of autonomy	Particle Swarm Optimization (PSO)	To improve the performance in terms of overall cost [113].
Total operating cost	Optimization using Genetic Algorithm	The hybrid PV-wind-Diesel-Battery operation is optimized using model predictive control [114].
Net present cost (NPC)	Stochastic method	To optimize the size of the battery for commercial building [115].
Minimize the Total Cost	Fuzzy under GAMES environment	To minimize total cost and CO_2emissionofhybrid system [116].
COE, Operating Life Cycle(OLC), LPSP	Total performance index	Study on hybrid power system performance related to economic and environmental impact [117].
LPSP and cost analysis	Multi object particle swarm optimization	The best configuration and sizing of hybrid system are analysed [118].
Cost of Electricity(COE),Total Net Present Cost (TNPC)	HOMER	Optimum design of Hybrid System with reduced COE and NTPC [119].
COE, NPC	HOMER	To study the cost of hybrid system powering the telecom tower is located at remote area [120].
Net present cost (NPC), COE	HOMER	To improve the performance of Hybrid system, and optimize the net result in NPC, COE compared to diesel generator alone [121].

In Iterative method, optimized results are obtained by recursive process. This method is applied for optimization of reliability and total cost involved in integrated renewable energy system. The authors in [106] have made review on sizing methodology of hybrid energy system. Tab.5 shows the objectives framed by different authors with different constraints [107 – 121].

11. Power Management in Hybrid system

Providing necessary power to the load continuously by managing the multiple source and state of the energy storage system is termed as power management system. The author in [122] has presented power management in standalone wind-photovoltaic-fuel cell Hybrid system. The overall power management and control strategy for a hybrid system block diagram is shown in Fig.10. Net power is calculated based on the power difference between total power generation by the multiple sources and load.

$$P_{Net} = P_{pv} + P_{wind} - P_{load} - P_{SC} - P_{comp} \quad (15)$$

At any time if solar PV, wind is generated excessive power ($P_{Net.}$>0) then the excessive power is transfer to the electrolyzer and it can be further stored in hydrogen storage tank through the gas compressor. Gas compressor also consumes the power (P_{comp}).The power balance equation can be represented in Eq.16.

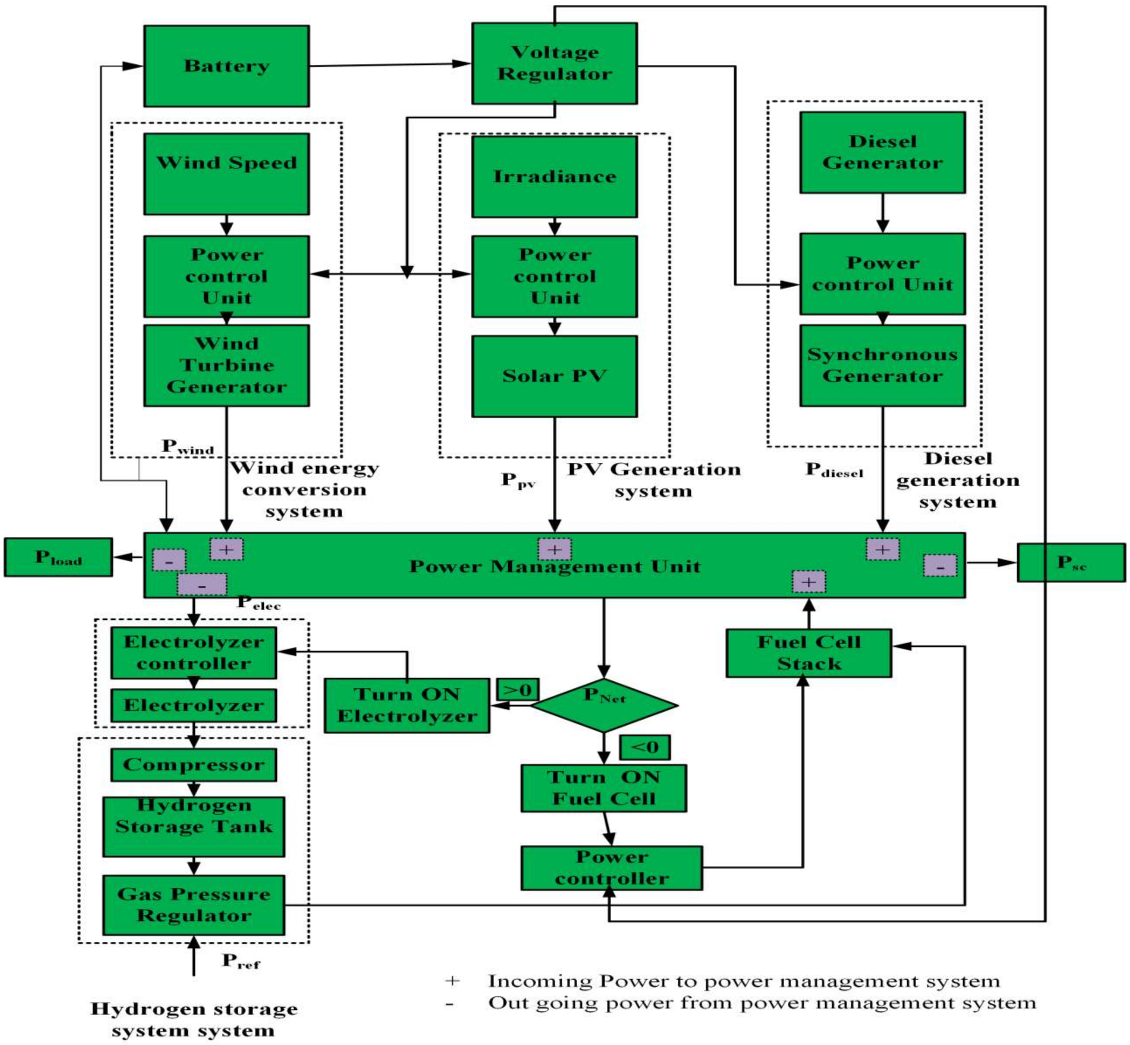

Fig. 10. Power Management in Hybrid system

$$P_{pv} + P_{wind} = P_{load} + P_{SC} + P_{comp} \tag{16}$$

The power supply from the wind-PV is less than the load demand then the power can be supplied from the Fuel cell and diesel generator. The power is shortages exist at any time then the power balance is obtained from Eq.17.

$$P_{load} = P_{wind} + P_{pv} + P_{diesel} + P_{FC} \tag{17}$$

The power management is quit complex in hybrid system. *Erkan Dursun and Osman Kilic* [123] has explained and simulated hybrid system with power management scheme. The power management in hybrid system can be categorized into three different cases. In the first case, if P_{excess}> 0 and state of the charge (SOC_{max})>SOC>SOC_{min} then the battery will be discharge and electrolyzer will contributes the power. In second case, If P_{excess}≤0, SOC_{max}>SOC>SOC_{min}, then the power battery bank will discharge and fuel cell will not run. Battery bank is charged when SOC≤ SOC_{min}andP_{excess}≤0.in this case the fuel cell will run. In the third case, P_{excess}>0, SOC_{max}>SOC>SOC_{min} the battery will be charge and electrolyzer also work for providing continuous supply. At P_{excess}<0, the battery and fuel cell are not run to meet the peak demand then the diesel generator will work for continuity supply. The mathematical power balance equation can be calculated using the following Eq.18.

$$P_{load} + P_{comp} + P_{load} = P_{wind} + P_{pv} + P_{diesel} \tag{18}$$

The smart energy management algorithm are balance the electrical demand with source, Improve the grid reliability, Schedule the dispatch of hybrid sources. The combination of solar PV, wind, diesel, Fuel cell, and Battery storage based hybrid system are becoming popular .the author in [124] has studied for different plant with different cities in India such as Amritsar, Ludhiana, Patiala, and Chandigarh in Punjab. The authors has found best solution for the cost of energy for respective cities with load of 1.3kW peak is PV-Wind-Diesel-Battery storage system are useful. The challenging research is going on the hybrid system to meet the load demand continuously with less investment and more reliable. The ministry of new renewable energy (MNRE) government is planned for hybrid system with the capacity of 10GW by 2022[125].

12. Conclusions

In this paper, a review on optimal sizing, modelling, control and management of solar-wind-diesel with the energy storage system are presented. The various issues on solar, wind and control technique are also compared. The selection of various configurations in hybrid and storage system improves the performance of the system. Integration of hybrid systems with an energy storage system makes the power balance and can avoid power fluctuation during the dynamic variations in the environment. The importance of solar-wind with diesel, energy storage integration creates benefit in solving the power crisis issues in remote locations.

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Nomenclature:

I_{pv}	photovoltaic current (A)	□	density of air (kg/m^3),
V_{pv}	Photovoltaic voltage (V)	A	area cut by the turbine blades (m^2)
K	Boltzmann constant(J/K)	C_p	Coefficient of the power
T	Cell reference temperature(℃)	Ω	specific turbine rotor speed (rad/s)
I_{sc}	Short circuit current (A)	ϑ	wind velocity (m/s)
I_{pvo}	diode saturation current (A)	R	turbine blade radius (m)
q	Electronic charge (coulombs)	$P_{r\text{-}WG}$	Rated power (kW)
N_s	number of cells in series	$\vartheta_{cut\text{-}in}$	cut in value of the speed(m/s)
R_s, R_{sh}	series and shunt resistance (Ω)	$\vartheta_{cut\text{-}out}$	cut out value of the speed(m/s)
n	diode ideality factor	ϑ_r	wind generator rated speed (m/s)
i(t)	radiation of the solar (kw/m^2)	$P_{WG}(T)$	overall developed power (kW)
A	area of the photovoltaic system (m^2)	$P_{WG}(t)$	power developed from individual generator (kW)
η_{pv}	overall efficiency of the PV system	N_{Wind}	Number of wind turbine generators
N_{pv}	Number of PV modules.	SF	Safety factor (commonly 120%)
E_L	Daily estimated energy demand (kWh)	P_{WG}	output power of the wind turbine (kW)
η_{batt}	Efficiency of the battery	P_L	Required load power (kW)
η_{inv}	efficiency of the inverter	□(s)	Fuel flow(kg/s)
A_{Tcf}	correction factor of the temperature	T_{mech}	mechanical torque after the delay time t_1(N-m)
$H_{t(av)}$	average global irradiation of the solar plant(kWh/m^2)	k_1	Engine torque constant(pu)
X_d, X'_d, X''_d	synchronous, transient and sub transient reactance of d-axis (Ω)	X_q, X'_q, X''_q	synchronous, transient and sub transient reactance of q-axis (Ω)
E_{fd}	Excitation field voltage(V)	τ'_{do}, τ''_{do} and τ''_{qo}	time constant of the open circuit, sub-transient time constants
P_N^D	Rated power(kW)	P_D	diesel generator output power(kW)
B_D, A_D	Consumption curve coefficient with (L/kwh) as unit	P_{fuel}	Fuel price($/L)
T_{sg}	Electromagnetic torque(N-m),	P_{pv}	Power generated from Solar Photovoltaic system(kW)
P_{Net}	Total net power(kW)	E''_d, E''_q	sub transient voltages with reference d-axis and q-axis (V)
P_{wind}	Power generation from wind energy conversion system(kW)	P_{diesel}	Power generation from Diesel generation system(kW)
P_{load}	Power supply to the load(kW)	P_{FC}	Power from Fuel cell(kW)
P_{sc}	Self-consumed power(Watt)	$P_{electrical}$	Power supply to electrolyzer (kW)
P_{comp}	Consume the power(Watt)	Pb	Platinum
SO_4^{-2}	Sulphur oxide	$PbSO_4$	Platinum sulphur oxide
e^-	Electrons	H_2O	Hydrogen dioxide

H^+	Hydrogen-ion	Li^+	Lithium-ion
C	Carbon	Li_nC	Lithium carbonate
Na^+	Sodium-ion	$Cd(OH)_2$	Cadmium hydroxide
Cd	Cadmium	OH^-	hydroxide
$LiXXO_2$	Lithium xenon oxidised	$Ni(OH)_2$	Nickel hydroxide
$NiOOH$	Nickel oxy hydroxide	$NiCl_2$	Nickel Chloride