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A Comprehensive Review: Energy Storage System for Hybrid System Including Wind Energy Generation System and Solar Energy Generation System for Utility Grid

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Authors' contributions

This work was carried out in collaboration between both authors. Author VS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author LG managed the analyses of the study. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Small grid industry has tremendous growth in the present market. This paper presents a comprehensive review of hybrid energy generation system with energy storage system. The hybrid system is the combination of wind energy conversion system and photo voltaic energy generation system with energy storage system. This system is grid connected so as to feed the energy in the grid and take the energy from the grid. Since this power is very highly variable when it is generated by the wind, solar etc. Consequently, Renewable energy has limited contribution in the power generation and this type of energy generation is difficult to control. So this problem is solved by integration of this hybrid energy system with Energy Storage System.

This paper presents the up to date Technical review for Energy generation System with the integration of energy storage system. The aim of this paper is to provide a broad prospective on the status of hybrid energy generation with Energy Storage System and grid interfacing technology to

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researcher & application engineers dealing with advantages, disadvantage and main application when it is connected to the power system. A more than hundred research articles on this subject is allow appended for a quick overview & reference.

Keywords: Hybrid Energy Generation System (HEGS); Wind Energy Generation System (WEGS); Solar Energy Generation System (SEGS); Energy Storage System (ESS); control technique.

1. INTRODUCTION

Mostly Energy demand of the consumer presently full fill by the conventional energy sources like coal, natural gas & oil etc. but they have very limited resources on the earth like fossil fuel, natural gas etc. They have also a major drawback, because of the generation of hazardous wastage which leads the environment for the global warming, increase the CO_2 in the atmosphere etc. The disadvantage of the conventional energy sources will lead to researcher for the development of Green Energy produced by the non- conventional energy sources [1].

In the present day, Installation of Wind Energy Generation System (WEGS) and Solar Energy Generation System (SEGS) are very common at small scale. The Wind Energy (WE) and Photovoltaic Energy (PVE) are now well developed cost effective and are being used widely [2,3]. The hybrid energy system is the combination of two or more non-conventional energy sources for the generation of power. It is an excellent approach for the distribution of power. The main advantages of Hybrid Energy Generation System over conventional energy generation system are, this technology is installed near to the load or connected to the utility grid. In this review the hybrid energy generation system consist of the wind and solar energy [4]. A wind turbine converts the mechanical Power of wind into electrical power and this is converted into dc by use of rectifier and it's synchronization with Solar Energy Generation System (SEGS) [5]. A solar PV array produced DC voltage, before connecting this HEGS to grid, we have to convert DC into AC and by using DC-link capacitor maintains a constant DC voltage at the input side of voltage source inverter. VSI is used to convert the output of hybrid system into AC and interfacing with grid. The grid connected system is more reliable and deliver continuous power to the utility grid but the generation of power from wind and solar is highly variable and sometimes it is not controlled. To overcome this problem, Energy Storage System might be used as a solution. Energy Storage System plays an important role in power system Operation, Control and Management [6]. The Efficient Energy Storage System gives the following advantage in power system.

- More efficient use of renewable energy generation.
- Maximization of renewable generation contribution to the utility grid.
- Better supply to the consumer
- Reduction of green house gases emission.
- Reduction the cost of Transmission system of power.
- Improving the reliability of the power system.
- Use of power system is more efficient way.

This paper is presented in to seven parts. Starting with the introduction, the subsequent sections cover the state of art, different energy conversion system descriptions and modelling including Wind Energy Generation System (WEGS), Solar Energy Generation System (SEGS), Energy Storage System (ESS) and Hybrid System (Combination of all), the economic and technical considerations and their selection according to the load and grid requirement and concluding the remarks [7-9].

2. STATE OF ART

The hybrid technology consist of the combination of Wind Energy Generation System (WEGS), Solar Energy Generation System (SEGS) and Energy Storage System (ESS) which provide smooth and reliable power supply to the loads and as well as utility grid. A DC-DC boost converter is used for getting higher and maintained voltage at DC-Link. WEGS, SEGS and ESS are connected in parallel with DC-Link. The DC-Link (DC-Capacitor) is providing the constant voltage to the Voltage Source Inverter (VSI) as input. A passive filter is used between VSI and electric grid to get ripple free voltage. A d-q based current control method is used to generate the pulse for Voltage Source Inverter [10]. The Voltage Source Inverter gives the required AC output with the help of control circuit, which is fed to the consumer load and utility electric grid [11].

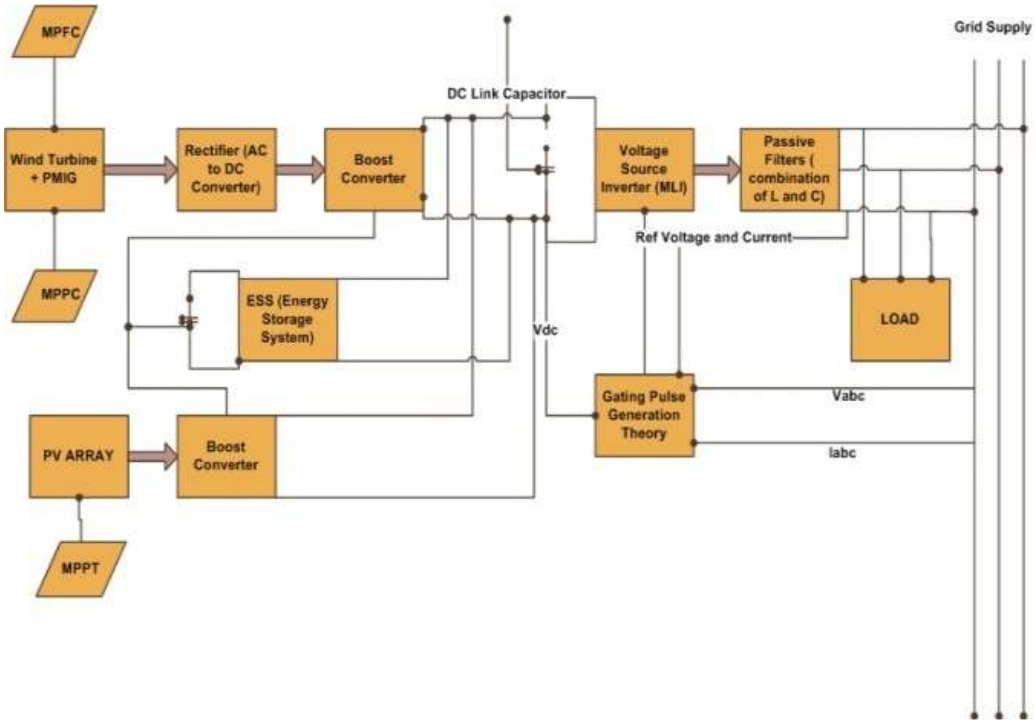

Fig. 1. Basic building block of hybrid energy generation system connected to the grid

3. WIND ENERGY GENERATION SYSTEM (WEGS)

The wind is free, clean and in exhaustible form of renewable energy, because of the uneven heating in the environment, the irregularities of earth surface and earth movement on his magnetic axis, wind is originated. The wind energy is converted into electrical energy through wind machine. Some of the following characteristics are as below:

1. Rated power of WT machine. It is the maximum power developed by the rotor and is also the generator rating.
2. A minimum speed at which wind machine starts rotating called cut in speed (V_C).
3. The minimum speeds of wind at which machine generate rated power is called rated speed (V_R), at this speed blades of WT machine become active position.
4. Maximum speed at which machine develops power is called furling speed (V_F), Beyond this speed machine will stop.

3.1 Components of WEGS

Wind Energy Generation System has the various components which are as follows.

3.1.1 Wind turbine

The working principle of WT is to transform kinetic energy of wind into rotating mechanical power of the turbine rotor blades.

The basic expression for the generated power by wind is

$$P_{WT} = \frac{1}{2} \rho A C_P (\lambda_i, \beta) V^3 \quad (1)$$

Where,

P_{WT} = Power of WT
ρ = Air density in Kg/m^3
A = Swift area of the WT = πR^2
R = WT blade length
λ = Tip speed ratio = $\frac{\omega_t R}{V}$
β = Blade pitch angle
ω_t = WT rotational speed
V = Wind speed
C_P = Power coefficient

The power coefficient is the fraction of wind captured by wind turbine. According to Betz Rule power coefficient will be about 60%.

$$C_P(\lambda_i, \beta) = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{-21/\lambda_i} + 0.0068\lambda_i \quad (2)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (3)$$

The Torque on WT is calculated by the following formula:

$$T_{WT} = \frac{P_{WT}}{\omega_{WT}} = \frac{\rho\pi R^5}{2\lambda^3} C_P(\lambda_i, \beta)\,\omega_{WT}^2 \quad (4)$$

This is the block diagram of the WECS.

Two types of the turbine are used in present scenario

- Horizontal axis wind turbine
- Vertical axis wind turbine

Many large models of WEGS are based on horizontal axis wind turbine, because they have high efficiency, ability to turn the blades as per requirements and lower cost-to-power ratio. Horizontal wind turbine has the following parts which are as follows.

- **Wind turbine blade:** Basically rotor or blades converts the wind power into rotational shaft power. Wind turbine blade is the area of the wind machine which accumulates the power on the air is known as the blades. Generally rotor blade is made of two or even more wooden, fiberglass or iron blades. They rotate an axis of vertical and horizontal at a rate which is determined by the wind velocity. The blades are attached to the center of the main base.
- **Drag design:** Wind machine uses the knife designs of blades which are run by using either drag or lift. Use of drag design and style promote the blades out of the way.
- **Lift design:** The lift edge design of blades engages the same principle as Kite, Airplanes and Birds to fly. While blades attached to main axis like rotor of wind turbine. Lift-power wind machine have much higher rotation power transfer speeds than move type of Lift.
- **Tip speed ratio:** The tip speed would be the ratio in rotational pace of the blade towards the wind velocity. If the TSR is high, more quickly turning of the actual wind at the given wind speed. Lift type of wind machine has maximal tip-swiftness ratios around 10, while drag type wind machine has less than ten. That's why high rotational velocity demands of electrical generator so it is clear that lift type of wind turbine is practical due to its application [12].

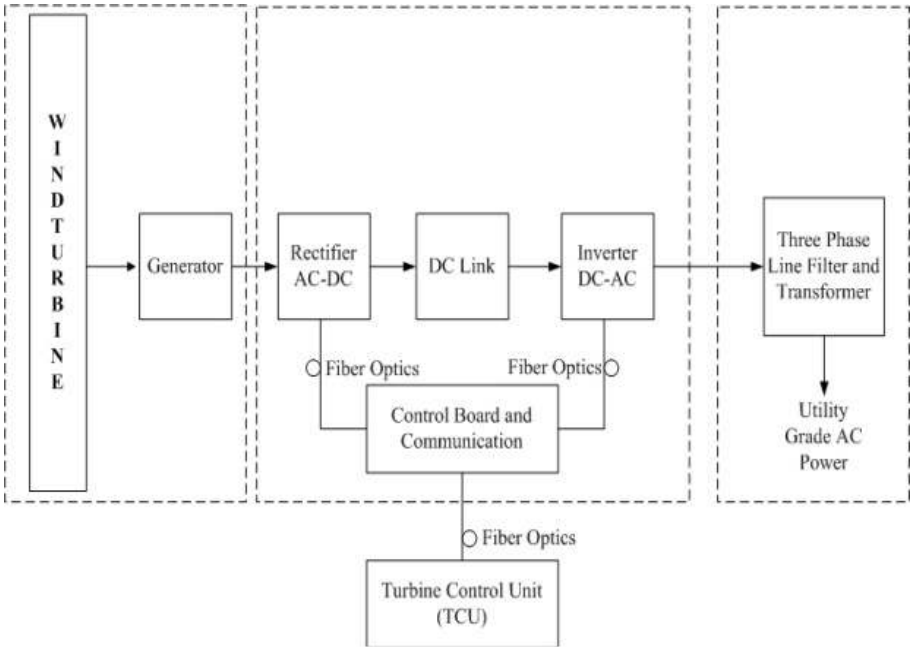

Fig. 2. WT power generation block diagram

3.1.2 Generator

The main function of generator is converting the particular rotation of wind machine blades directly into electricity in wind energy conversion system. Generator models produce alternating current and they are available in a large range of output electrical power ratings. The generator's standing or size of it, is influenced by the length of the wind generator blades. Generators that generate AC usually are equipped along with features to generate the accurate voltage as well as constant consistency of power, even if the wind velocity is varying. Variable velocity wind turbine is popular due to their unique capability to capture maximum power from the wind air. But it is possible due to maximum power point tracking (MPPT) algorithm, we can improve the efficiency of generator. Following generators are mainly used for power conversion in wind turbine machine [13].

- Doubly Fed Induction Generator (DFIG).
- Permanent Magnet Synchronous Generator (PMSG).
- Induction Generator (IG).
- Synchronous Generator (SG).

Now a day the doubly fed induction generator (DFIG) is popular for variable velocity of wind turbine. The need of gear box in doubly fed induction generator to synchronize wind turbine speed and rotor speed of generator, but gear box require frequent maintenance and most of time Doubly Fed Induction Generator (DFIG) suffer from faults due to presence of gear box, so system become a unreliable that's why Researcher like the work with Permanent Magnet Synchronous Generator (PMSG), Because it is a self- excited machine and it work as a leading, lagging power factor and also it has high efficiency [14]. For maintaining output ac Voltage at a constant amplitude and frequency, an AC to DC converter and DC to AC inverter are used. The common DC link voltage is directly affected if there is any change in environmental condition or wind velocity or connected electrical load. For getting constant output voltage at the terminal across load, DC link is used. The relation between DC voltage and AC voltage is given by following equation.

$$V_{LL1}=\frac{\sqrt{3}}{2\sqrt{2}} K V_{DC} \quad (5)$$

Where,

K = Modulation Index of Pulse Width Modulation Inverter (= 1)
V_{LL1}=Fundamental phase to phase RMS voltage on AC side.
V_{DC} = DC link voltage.

The group of most popular Wind Turbine Generators is in below Fig. 3.

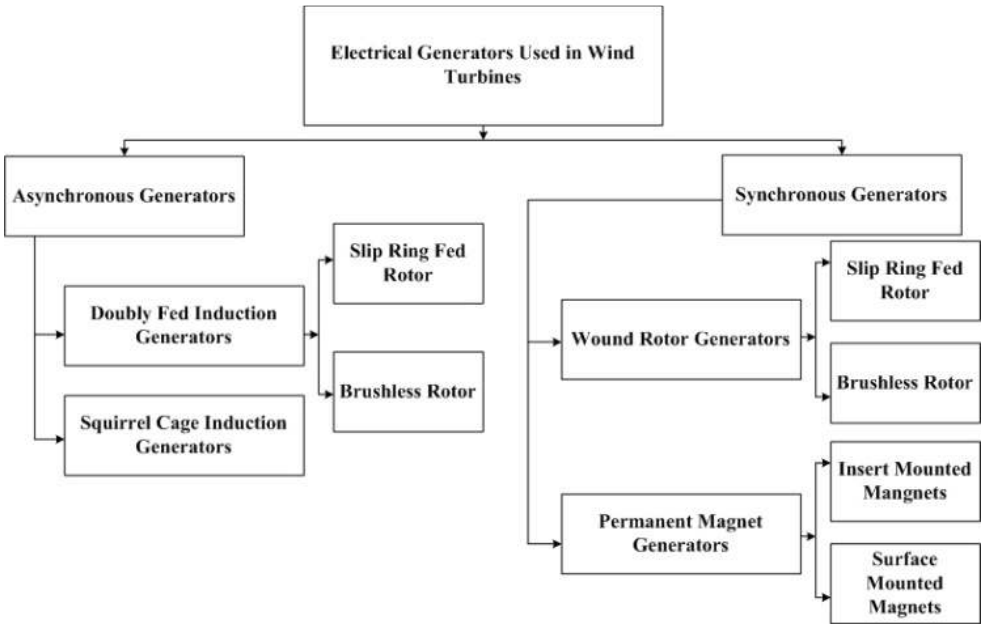

Fig. 3. Types of generators in WECS

Now a day the direct current generators are usually found in low-voltage and much low – power stand alone system with small size wind strength application.

3.1.3 Rectifier

The main function of Rectifier in our proposed system is to convert the AC output voltage which received from wind machine to DC voltage. The three- phase bridge rectifier is commonly used in hybrid Wind-Solar Energy Generation System with Energy Storage System. It is full-wave rectifier and gives six-pulse ripples on the output voltage. Each one of six diodes conducts for 120^0. The pair of diodes which are connected between that pair of line supply lines having the highest amount of instantaneous line to line voltage will conduct.

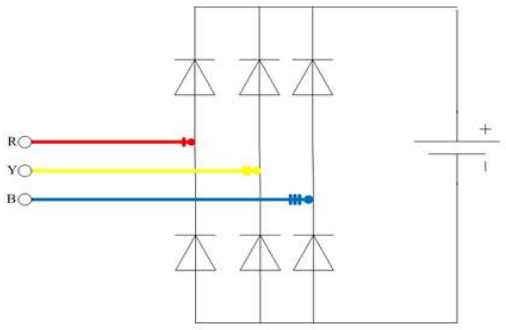

Fig. 4. 3- Phase bridge rectifiers

Table 1. Comprehensive report of wind generator converter topologies on control schemes

Generator	Converter options	Control schemes
PMSG (kW)	Diode Bridge /SCR/Inverter/ Compensator	Simple firing angle control of one converter
	SCR Rectifier/ SCR Inverter	Simple firing angle control of both converter
	Diode Bridge /Hard switching inverter	Power Mapping Techniques including stator frequency deviator control MPPT, Wind Prediction Control
	Diode bridge/DC boost/hard switching inverter	Vector control of supply side inverter DC Voltage control via Chopper duty Ratio
	Back-Back hard switching inverters	Generator controlled through MPPT Inverter Current control through PI Controllers
DFIG (kW-MW)	Diode Bridge /SCR Inverter	Sliding Mode Control
	SCR Rectifier/ SCR Inverter	Dual Thyristor Firing angle control
	Back-Back hard switching inverters	Vector control of rotor and supply side space vector modulation or PWM MPPT, space vector control
	Matrix Converter	Vector control of rotor and supply side double space vector PWM switching
IG (kW-MW)	Back- Back Hard switching Inverters	Vector control, use fuzzy logic controllers, use rotor slot harmonics and model reference adaptive system
SG (kW-MW)	Diode bridge/DC boost/hard switching inverter	Phase angle displacement control supply voltage control
	Back- Back Hard switching Inverters	Supply real and reactive power control generator electromagnetic Torque Control

If V_m is the maximum value of phase voltage.

The average and RMS output voltage is calculated by the following equation.

$$V_{DC} = \frac{2}{2\pi/6}\int_0^{\pi/6}\sqrt{3}\,V_m\,(\cos\omega t)\,d(\omega t) = \frac{3\sqrt{3}}{\pi} \quad (6)$$

$$V_m = 1.654\,V_m \quad (7)$$

$$V_{rms} = \left[\frac{2}{2\pi/6}\int_0^{\pi/6} 3\,Vm^2\,cos\omega t\,d(\omega t)\right]^{1/2} = \left[\left[\frac{3}{2} + \frac{9\sqrt{3}}{4\pi}\right]\right]^{1/2} V_m = 1.654\,V_m \quad (8)$$

3.1.4 DC-DC boost converter

The DC-DC boost converter is commonly used for obtaining regulated DC power supply, but in our proposed system the DC-DC boost converter is used to regulate DC output voltage which collect from the renewable Energy Sources at DC link, but we know that the wind turbine generator produces AC output That is converted to DC by application of rectifier The circuit diagram of DC-DC boost converter is shown in below:

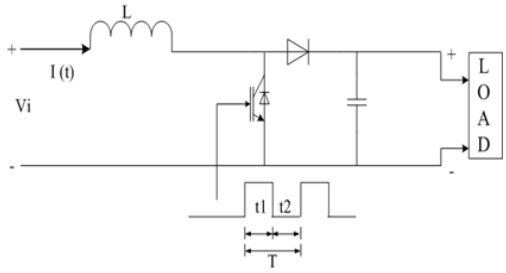

Fig. 5. Circuit of DC-DC boost converter

Basically the DC-DC boost converter contains four components, Electronic Switch, Diode, Inductor and Capacitor. The DC-DC boost converter works in two modes of operation first is continuous conduction mode (CCM) for efficient power conversion and second is discontinuous conduction mode (DCM). It is used for low power or stand by operation [15].

3.1.5 Inverter

In Wind Energy Conversion System, The main function of this power electronics device is convert a DC input voltage into symmetric AC output voltage required in magnitude and frequency. The output AC voltage could be fixed or variable at a fixed or variable frequency. A desirable AC output voltage can be obtained by varying the input DC voltage which is collected from rectifier and maintained the gain of inverter constant. For ideal inverter it should be sinusoidal. However, the wave forms of practical inverters are non-sinusoidal and contain some harmonics. In Hybrid power generation system, three phase Voltage Source Inverter (VSI) is used to interface between DC and AC component. But requirement of fixed DC link voltage along with control of reactive and active power, Researcher is apply various control techniques to three phase grid connected Voltage Source Inverter [16]. The circuit diagram as shown in below:

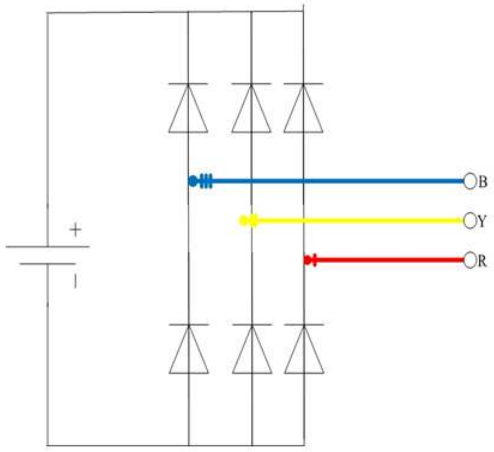

Fig. 6. Circuit connection of inverter

3.1.6 Grid connection

The interfacing of wind mill to the grid depends on the generator as well as power conversion devices which are used. Actually, Wind Energy Generation system is based about the application of power electronics. Therefore the wind turbine configuration can be divided into some techniques.

- Directly connected to the grid without power electronic converter.
- Directly connected to the grid with power converter.
- Connected with partially-rated power converter.

In our proposed system Wind Turbine Generator (WTG) is connected with power electronic converter.

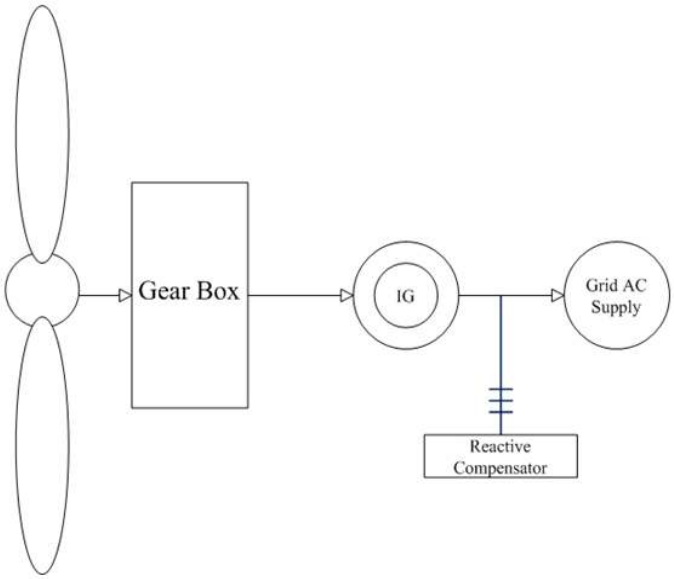

Fig. 7. Grid connection of wind turbine with generator

4. SOLAR ENERGY GENERATION SYSTEM (SEGS)

Solar Energy Generation System (SEGS) is made up of several photovoltaic solar cells array, inverter, battery, charge controller etc. Small PV Cell is capable of the generation of 1 or 2 Watt power which depends on the material used. For higher power generation, PV Cells are parallel connected together to form higher power modules. Peak watt rating is the key performance of PV Modules.

Solar Energy Conversion System (SECS) is based on photoelectric phenomena. PV cell converts the electromagnetic radiation of sun or intensity of solar radiations into electrical energy. The physics behind the Solar Cell or PV cell is semiconductor material. PV Cell is similar like PN Junction diode [17-20]. The PV Cell single diode model is as shown in the Fig. 8.

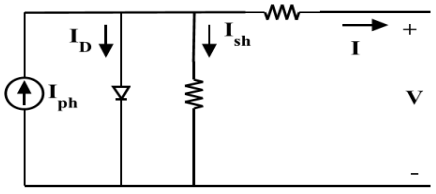

Fig. 8. PV Cell in a single diode model

In this Fig. 8 the current output of the PV cell (I) is equal to the current generated by the illumination current (I_{ph}), less the diode current (I_D) and the shunt leakage current (I_{sh}). Series resistance (R_S) show the internal resistance to the current flow and depends on the depth of the P-N junction, the doping of the P-N junction and contact resistance. Conversion efficiency of the solar radiation to the electricity is sensitive to the small variation in series resistance (R_S) but is insensitive to the variation in shunt resistance (R_{sh}). A small variation in the in series resistance (R_S) can decrease the PV cell output significantly. For describing the PV cell electrical characteristics and performance, two most important parameters are considered, they are open-circuit voltage (V_{OC}) and the short-circuit current (I_{SC}). The open-circuit voltage (V_{OC}) can be calculated by applying KVL in the above circuit:

$$V_{OC} = V + I R_{sh} \quad (9)$$

$$I_d = I_D \left[e^{\frac{Q V_{oc}}{A K T}} - 1 \right] \quad (10)$$

Where,

I_d = Diode Current
I_D = Saturation Current of the Diode
Q = Electron Charge = 1.6 x 10^{-19} Coulombs
A = Diode Ideality Constant
K = Boltzmann constant = 1.38 x 10^{-23} joule/ ^oK
T = Temperature on absolute scale ^oK

The Load current is given by:

$$I = I_{ph} - \left[e^{\frac{Q V_{oc}}{A K T}} - 1 \right] - \frac{V_{oc}}{R_{sh}}$$

The maximum photo voltage is generated under the open circuit voltage condition when ignoring the ground leakage current with zero as following:

$$V_{OC} = \frac{AKT}{Q} \log_n \left(\frac{I_{ph}}{I_D} + 1 \right) \quad (11)$$

The efficiency of the PV cell is as defined as following:

$$\eta = \left[\frac{\text{Electrical Power Output}}{\text{Solar Power Raiation Intensity to the Cell}} \right]$$

4.1 Types of PV System

Solar PV system are generally classified based on where functional and operational requirement and their component configurations. It can be configured into grid connected and standalone system as follows:

4.1.1 Grid- connected solar PV system

When solar energy conversion system is directly connected to utility grid and load, it is called Grid-Connected Solar PV System. It is the bidirectional interface between solar energy conversion system (SECS) and utility grid for consumer load [21-24]. Fig. 9 shows the function of Grid connected Solar PV System.

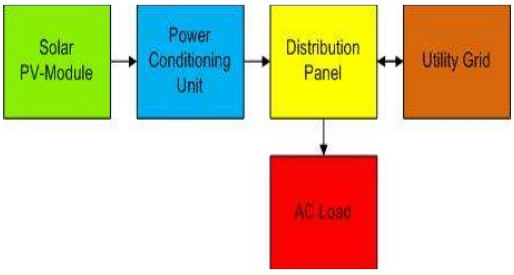

Fig. 9. Grid connected solar PV system

4.1.2 Standalone solar PV system

When Solar PV system is directly connected to the utility load (AC or DC) and no interaction with the utility grid, this type of the system is called Standalone Solar PV System / Direct Coupled PV System. The Fig. 10 shows the Stand alone PV System with Battery Storage System.

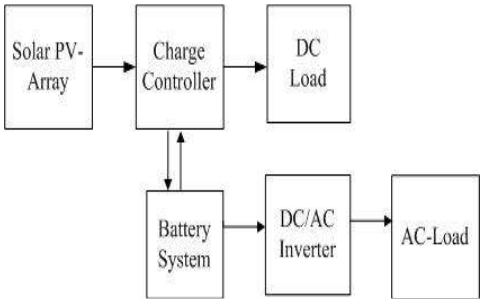

Fig. 10. Stand alone PV system with BSS

5. ENERGY STORAGE SYSTEM

As the contribution of intermittent energy storage is increased in the total power generation energy storage system becomes more famous in the present market scenario. The work philosophy of ESS is to store energy from intermittent energy sources at the time of low load demand and retrieve this stored energy back to the load at the time of high load demand. As power generation companies moving towards having more generation contribution from renewable energy sources, the power output is highly variable i.e. Most of the times they produces high energy output when it is not needed means low load demand and low energy generation at the time of high load demand. Because of only this problem renewable energy generation system has less contribution alone in the power generation. To overcome this problem combination of Renewable Energy Generation System is used with Energy Storage System (ESS) as a solution.

There are many different technologies used in power utilities as an ESS. These technologies are as following [25-27].

- Superconducting Magnetic Energy Storage
- Super- capacitor Storage
- Hydrogen Storage
- Different Type of Batteries
- Flywheel Storage
- Pumped Hydro Storage
- Compressed Air Energy Storage (CAES)

These technologies are suitable for certain applications based on different characteristics. For the use of these technologies main important factors are initial capital cost, yearly maintenance and aging cost, running cost, round trip efficiency (RTE), Storage Capacity, charging cycle, discharging cycle and lifetime.

The main advantages after using ESS are maximize the contribution of renewable energy, efficient and continues use of renewable energy sources, better generation and demand matching, lower environment pollution, reduce grid installation cost and improvement in the operation and control of power system [28-30].

6. HYBRID ENERGY GENERATION SYSTEM (HEGS)

Day by day, the demand of electricity is rapidly increasing, but the available conventional and individual nonconventional sources are not able to supply electricity as per required of consumer [31,32]. This type of hybrid power generation system will work as bridge between supply and demand during peak demand and can also be used remote/ hilly areas where conventional power generation is accessible.

In this paper, a wind-photovoltaic power generation and energy storage system is review by study of several research articles.

Hybrid energy generation system is unique method of power generation with use of SEGS and WEGS. It includes ESS, DC-Link, Converter and Inverter etc. It is also more advantageous when individual power generation system is not completely reliable, when any one of the power supply system is shut down, the other can supply the power to consumer load and utility grid [33-35].

This complete hybrid system contains various components like PV-Wind Generation System, ESS, DC to DC Converter, Inverter and their control techniques with Grid. The basic block diagram is shown in Fig. 11.

EESS is one of the key technology which plays an important role in present era, because the power generation from Wind and PV System is intermittent variable according atmospheric condition that's by Energy Storage System has play major role in different- different aspect.

- ESS reduced electricity costs by storing electricity obtained at off-peak times when its price is lower.
- In order to improve the reliability of power supply, ESS support users when power network failure occurs due to natural disasters'.
- The main role is to maintain and improve power quality, frequency and voltage.
- Enhance the frequency regulation of electric grid.
- Also improve power system operation, Control and management

Actually emerging market required in on grid areas, ESS is solve the problem such as excessive power fluctuation and undependable power supply which are associated with the use of large amounts of Renewable Energy Sources. Energy Storage technology is one of the important part of this Hybrid Energy Generation System that can be considered to support to Wind/PV Energy Generation System integration and provide grid operators with additional means for frequency control. Also provide the means for wide spectrum of power system application which can benefit to generation utilities, Transmission & distribution.

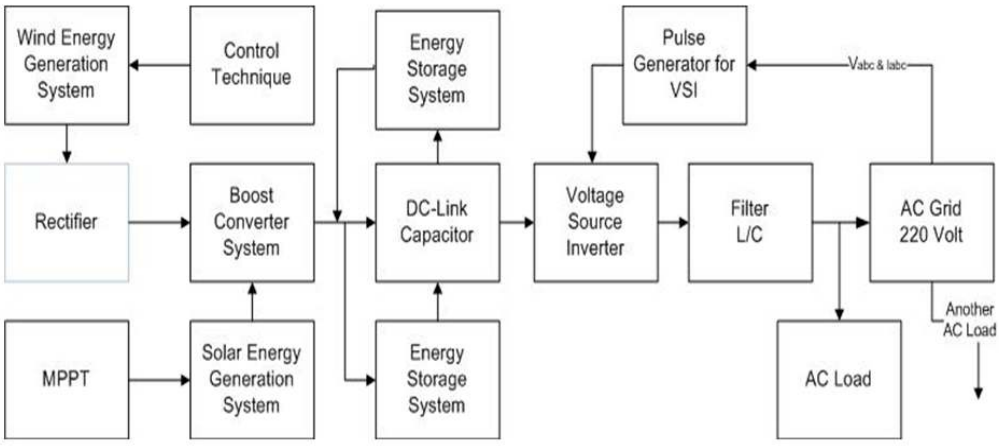

Fig. 11. Proposed hybrid energy generation systems with energy storage system

The basic technical characteristics of HESS are [21]:-

- Storage capacity
- Energy Density
- Charging and Discharging rate
- Storage duration
- Storage Efficiency
- Economics
- Initial cost
- Round Trip Efficiency
- Life Span and Payback period etc.

7. ADVANTAGE AND DISADVANTAGES OF HYBRID ENERGY GENERATION SYSTEM [36]

7.1 Advantages

- Reduced fossil fuel cost, by using REGS and efficient operation of Generation.
- Lower life-cycle cost compared to stand alone system i.e. SEGS or WEGS.
- Improve Reliability of power system.
- Reduced Green house effect.

7.2 Disadvantages

- Increase the Additional cost of REGS by requirement of Batteries and custom device i.e. Power electronic components like Converter, Inverter, DC-Link and utility grid.
- Less experience of customers and supply utilities with Renewable Energy Hybrid Power System Technology.
- Hybrid Energy Generation System is more complicated.

8. CONCLUSION AND FUTURE SCOPE

In the current scenario of wind-solar Hybrid Energy Generation System with Energy Storage System was implemented. But synchronization between wind-solar and energy storage system with electric grid are the main challenges. Renewable Energy Generation sources such as solar and wind are highly variable output which depends on environment condition, Due to this reason , most of time these Renewable Energy sources are not giving a power. This means that renewable energy sources produce high power when it is not needed and low level power produce when it is needed, Because of this RES has limited contribution in power generation and it is also difficult to be controlled. To overcome this problem of REGS by use of Energy Storage System (ESS) like Battery and solid oxide fuel cell (SOFC). By this review study we can achieved many benefits when using efficient energy storage system in power utilities. Some of important benefits such as maximize the contribution of RES at large scale, Better generation and demand matching, Lower green house gases emission, reduced grid connection cost also transmission losses and enhance the operation and control of power system. This study gave an up-to-date technical review of Hybrid Energy Generation System that is combination of WEGS, SEGS and Energy Storage Technologies, Stating its working principal, Simulink modeling, Advantages, Disadvantages and important application into power system.

The future scope of hybrid power generation system is to develop huge model by produce the power in MW or GW to fulfill the electricity requirement of a urban and rural areas for a day. We can generate the large amount of power from the Renewable Energy Sources into future by using the proper location. Many locations or sites are available in India where large potential of wind and solar energy. From this study we can design the hybrid power system which fulfill the load requirement of the consumer in rural areas where electricity not in approach i.e. hilly area of world. Also we can reduce the pollution and fulfill the power demand into the future.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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