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A Review on Mathematical Modeling of Solar, Wind and Hydro Pumped Energy Storage System

Neeraj Kumar Singh[1], M. R. Bachawad[2]

PG Student [EPS], Dept. of EE, Government College of Engg, Aurangabad, Maharashtra, India[1]

Assistant Professor, Dept. of EE, Government College of Engg, Aurangabad, Maharashtra, India [2]

ABSTRACT: Sustainable low-carbon energy is much in demand which emphasize the untapped potential of Renewable Energy sources. Still most of the developing countries have Energy crises which block the nation development. These crises can be overcome by using Hybrid renewable energy sources. The Power output of these Renewable Energy Resources fluctuates widely as weather pattern changes. This variable output can lead to voltage and frequency fluctuations, which adversely affect grid reliability and stability. Bulk Storage can support the development and optimal integration of Renewable Energy Resources. This paper deals with the Hydro pumped energy system using Doubly Fed Induction Generator (DFIG) that can be Efficient and Effective Energy Storage System for Renewable Sources for those rural areas which are away from the Grid system

KEYWORDS: Hybrid system, HPES (Hydro pumped energy system), PV system, DFIG (Doubly Fed Induction Generator), Hydro Energy Storage System (HESS), Doubly Fed Induction Machines (DFIM)

I. INTRODUCTION

The use of energy plays important roles in one's life. The availability and accessibility of sufficient amount of energy accelerate individual's and nation's development. Since the use of electrical energy has become an important and integral part of our life, its supply should be sustainable and secure. But that energy should be environmental friendly, economical and it should be easily acceptable by our society. Still now major part of electricity generation is done by Fossil Fuels like oil, coal and gas which are limited in stock in nature at the same time it create lots of pollution which are harmful to humankind. To overcome the problems of conventional Fossil Fuels Non-conventional sources should be implemented.

Non-conventional sources are non predictable in nature so Effective and Efficient Energy storage system is required .As penetration levels of Renewable energy is increasing day by day which affect the Grid stability led to the application of Bulk Energy Storage for Renewables. **Hybrid system** consists of more than one resource which is integrated so that demand and supply flow of electric power is balanced. Hybrid energy resources can be used in **two different modes** the First mode is **Island mode** in which generated electricity is consumed by the locally connected loads, Second mode is **Grid connected mode** in which total power generated is transmitted to the grid. The most important parameter for the Hybrid system with Energy storage is to balance between consumption and generation of active and reactive power. Fig.1 shows HPES which consist of machine which can act as motor as well as generator according to requirement of the Hybrid system.

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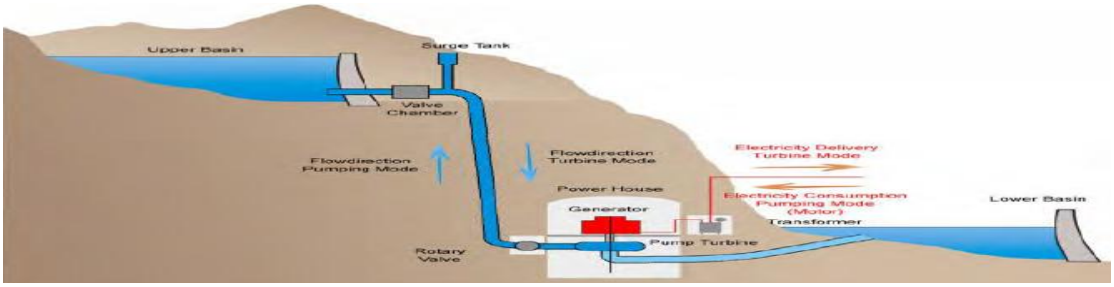

Fig.1 Hydro Pumped Energy System

II. LITERATURE SURVEY

Dr. Mohan K Khedkar[1] proposed a hybrid system which consists of Wind-PV system connected to batteries. In his proposed system excess of energy generated by the wind-pv system was given to batteries. But this system was failed during low wind and low solar intensity so to overcome these defect large battery systems was required which increased the overall cost of the system.

Shujun Liu, Zaijun Wu[2] performed the feasibility study of solar, wind and battery system. Excess energy was stored in battery system but the system was failed to full fill the load requirement at low wind and low solar intensity.

Stefanos V. Papaefthymiou, Eleni G. Karamanou[3] suggest a wind and pumped hydro system. By using pumped hydro system the penetration of the renewable energy increased by 50% which was approximately 28% with wind or wind and Pv system.

Sercan Teleke, Mesut E. Baran[4] study PV –Wind and Battery system with control strategy such that maximum utilization of battery system can be done. By using the new strategy the Battery system was utilized to maximum of 70% which was quite good result. But to have a long life of battery system it required large size battery system which is approximately 15%-25% of the solar/wind power system.

R. W. Wies, R. A. Johnson, John Aspnes[5] carried a study on hybrid system consist of wind, solar and diesel engine for Alaska region. For optimum and economical use of the hybrid system calculation is carried out for the different configuration. It's found that the system was efficient for required load but the cost of the system was increased.

Junhui Zhao, Korey Graves, Caisheng Wang[6] discussed and perform a practical on solar, pumped hydro and battery system to have more efficient hybrid system. A control strategy was suggested such that when battery was failed to supply power to load then hydro system comes in to existence to stable the whole system and maintains demand and supply chain..

Agustín A. Sánchez de la Nieta, Javier Contreras[7] shows coordinated strategy between wind and reversible hydro units for the midterm planning that reduces the imbalance of wind power and improves system efficiency. A stochastic mixed integer linear model is used, which maximizes the joint profit of wind and hydro units.

III. MATHEMATICAL MODELING

As stated above the Hybrid system consist of different technologies which can convert renewable energy to use full electrical energy like wind generators, solar PV system, hydro power system, biogas conversion systems etc. Mathematical modeling of hybrid system means to know different parameters which will affect the performance of Hybrid system. Modeling of different renewable resources is described below.

1. SOLAR PV SYSTEM

Electromagnetic waves emitted by the sun referred as Solar Radiation. The range of wavelength varies from 300nm to 400nm.

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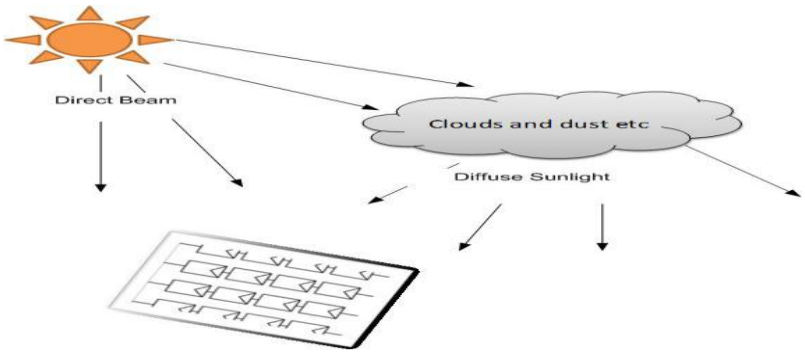

Fig. 2 Type of radiation from the sun

As in above figure (Fig.2) two type of radiation that is direct beam radiation and diffused beam radiation. Standard test condition (STC) is referred to distinguish between two different PV systems.

1. The reference vertical irradiance E with a typical value of 1000W/m2
2. Reference cell temperature for performance rating, to with a typical value of 25℃ with tolerance of $\pm 5\%$.
3. A specified light spectral distribution with an air mass, AM =1.5.

Similarly Nominal operating cell temperature defines as temperature reached by open circuited cell in following condition.

1. Irradiance on cell surface is 800W/m2.
2. The ambient temperature is 20℃.

To account of other ambient test condition the approximate expression is as follow:

$$T_{cell} = T_{amb} + \frac{NOCT - 20}{0.8} S$$

Where T_{cell} is cell temperature(℃), T_{amb} is the ambient temperature(℃), S is the solar insolation $(kw/m2)$. Solar cell are characterized and compared with each other with four parameters: short circuit current I_{SC}, open circuit voltage V_{OC}, fill factor FF and efficiency η. PV characteristic of solar cell is shown in Fig.3.

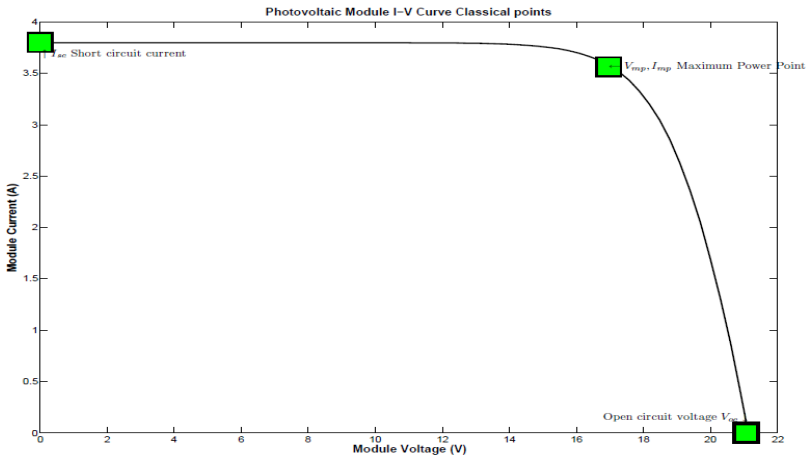

Fig.3 PV characteristics

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Vol. 4, Issue 12, December 2015

Small solar cell is the basic building blocks of PV array system. The solar PV module is obtained by interconnecting smaller solar cells. An ideal solar cell can be considered as a current source wherein the current produce is proportional to the solar irradiation intensity. The two models that are used to model solar cell are described below.

1. **Single exponential model:** In this model solar cell is consist of only one diode which represent the recombination losses in the cell itself. Fig.4 shows single exponential model consists of single diode.

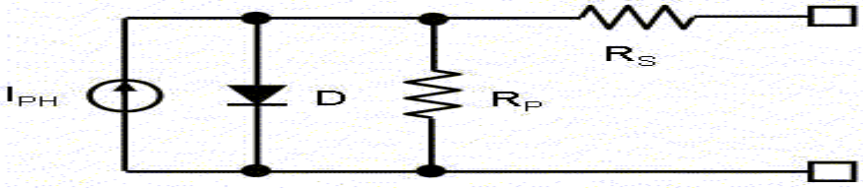

Fig.4 Single exponential model of solar cell

By using the single exponential model the I-V equation can be obtained as follow

$$I = I_{ph} - I_O\left\{\exp\left[\frac{q(V + IR_S)}{AkT}\right] - 1\right\} - \frac{V + IR_s}{R_p}$$

Where A is a diode constant, K is boltzmann's constant, T is the cell temperature, R_S is series resistance (ohms), R_P is parallel resistance (ohms)

2. **Double exponential model:** In this model it consists of two diodes which represent two different recombination losses which are recombination losses in space charge region and the other is losses in emitter region (as shown in Fig.5).

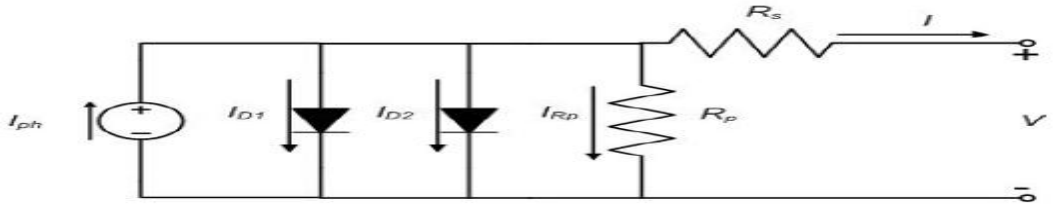

Fig. 5 Double exponential model of solar cell

The expression of current in double exponential model of solar cell is given as follow

$$I_{total} = I_{ph} - I_{D1} - I_{D2} - \frac{V - IR_S}{R_P}$$

$$I_{Diode1} = I_{01}\left[\exp\left(\frac{V + IR_S}{AkT}\right) - 1\right]$$

$$I_{Diode2} = I_{02}\left[\exp\left(\frac{V + IR_S}{AkT}\right) - 1\right]$$

Where I_{01} and I_{02} are reverse saturation current of diode 1 and diode 2, I_{ph} is the current from the solar cell, I_{D1} and I_{D2} are the respective diode current.

2. DFIM FOR WIND TURBINE AND HPES SYSTEM

Power in the wind can be converted to useful electrical energy by using Wind Energy Converters which are wind turbines. The fundamental equation governing the mechanical power of the wind turbine is given by

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$$P_W = \frac{1}{2} C_P \rho A v^3$$

Where C_P is power coefficient, A is area of rotor blades(m^3), p is air density(kg/m^3),v is the velocity of wind.
Wind turbine consist of shaft gear box, generator which may be induction or synchronous and control strategy to get maximum output in all the condition of wind variation.
The general scheme of electrical energy's generation from the wind power on the basis of using doubly-fed induction generator (DFIG) is shown in Fig.6.

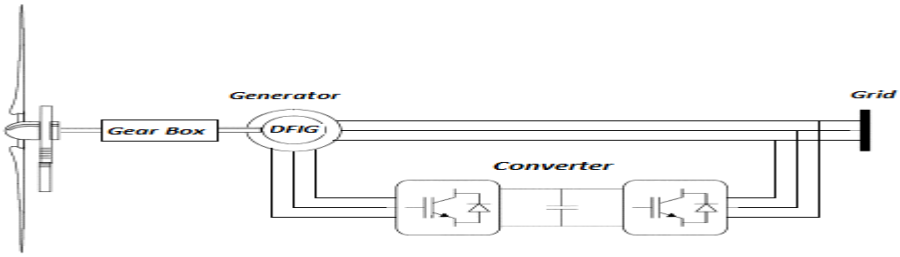

Fig. 6 DFIG wind turbine

The stator is considered to be connected to the grid directly whereas the rotor is connected to it via back-to-back converter. The main part is **Grid Side Converter** and **Rotor Side Converter,** Grid Side converter is used to regulate the DC bus capacitor and Rotor side converter is used to control the power and also for voltage measurement.

In HPES the same system work as motor to pumped water to the reservoirs and at the same time it can work as generator depending on the energy generated by the other systems. Suppose if energy generated by other system connected with HPES is more than it work as motor to pump water and if energy generated is low then to supply the load demand it will work as generator.
Mainly DFIG system is used for the HPES so that it can work efficiently. The general formula to determine the hydraulic power is given as below.

$$P_H = \rho g Q H$$

Where P_H is mechanical power produced by turbine shaft (watts), ρ is the density of water (1000 kg/m3),g is the acceleration due to gravity (9.81m/s2).
The dynamic model of Doubly Fed Induction Machines can be developed by using d-q reference frame. The concern equation is as follow:

$$v_{abcs} = r_s i_{abcs} + \rho \lambda_{abcs}$$
$$v_{abcr} = r_r i_{abcr} + \rho \lambda_{abcr}$$

Where v_{abc} denote voltage and subscript s and r denotes the parameter associated with stator side and rotor side.

$$v_{dq0} = k v_{abc}$$

Where k is $k = \frac{2}{3}\begin{bmatrix} \cos\emptyset & \cos\emptyset - \theta & \cos\emptyset + \theta \\ \sin\emptyset & \sin\emptyset - \theta & \sin\emptyset + \theta \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$

IV. WORKING METHEDOLOGY

This Hybrid System consists of solar PV system, DFIG wind system and a Hydro pumped system which consist of Doubly Fed Induction Machine. Two Case are taken in to account for the Hybrid system

Case I- When the solar PV system and Wind system is generating more than requirement:
Under this condition the HPES will work as motor to pumped water from low reservoir to upper reservoir or we can say as hydro energy storage system (HESS).

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Case II- When the energy generated from solar PV system and Wind system is less:
In this condition the HPES will work as generator. The water stored in upper reservoir will be move to lower reservoir making the HPES system to work in generating mode.

So from above discussion we can conclude that the HPES system will consist a machine which can be operate both as motor as well as generator. So for the HPES system another DFIG system will be used for proper operation of the purposed system. Fig.7 represented the flow chart and the steps involve for the Hybrid system consist of Wind, Solar and HPES.

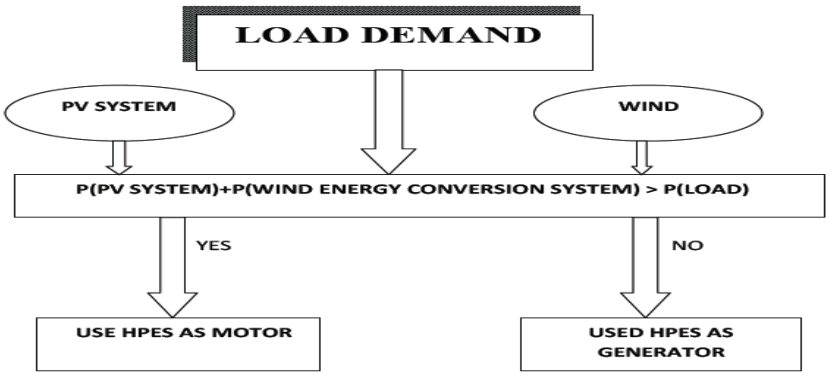

Fig.7 Flow Chat of purposed system

V. CONCLUSION

Renewable Energy system with Effective and Efficient storage system is capable of handling large energy demands. Hydro Pumped Energy System is most promising upcoming technology to increase the renewable energy penetration level. Globally there are 270 HPES working and under construction with combine generating capacity of 127,000 MW.DFIG systems is suitable for HPES technology for better operation and performance. Variable speed system is preferable for HPES because the parameters like power is varies due to which it must run at optimal speed for maximum output, so Doubly Fed Induction Machines precede among other available system.

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