Mathematical Modelling of a Hybrid Solar-Wind Power Generator

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Abstract – *Energy today, is the need of 21st century. The renewable energy resources therefore are used in great amount as they are effortlessly available and charge free. But these energies in standalone forms have drawbacks such as irregularity, obtainability in all time etc. which can be overcome by hybrid energy systems. Though solar and wind energy are two of the most feasible renewable energy sources, slight research has been done on operating both energy sources together with one another in order to take advantage of their corresponding characters. In this paper, we develop an optimal design for a hybrid solar-wind energy plant, where the variables that are optimized over include the number of photovoltaic modules, the wind turbine height, the number of wind turbines, and the turbine rotor diameter, and the goal is to minimize costs. Hybrid power system provide reduction in complexity, maintain lowest unit cost, energy fluctuations due to DPSP (deficiency of power supply probability), with the help of proper design, advanced fast response, good optimization and control feasibility. This paper provides review of hybrid solar and wind power system.*

Key Words: **Renewable Energy, Hybrid, Wind Turbines, Economical, Efficient**

1. INTRODUCTION

Since 17th century there is escalation in energy requirement due to rise in population day by day. Environmental concern and cost are the problems are taken under consideration while discussing numerous methods and procedures of generation of power via hybrid renewable energy resources. Among the extensive range of problems facing our world today, there is global consent that greenhouse gas (GHGs) emissions have the prime negative impact on our environment. GHGs contain carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydro fluorocarbons and per fluorocarbons. The scarceness of fossil fuels and their speedy depletion worldwide has made it essential to search for substitute energy sources that would meet the existing levels of demand. In addition, much of the world's population lives in remote or rural areas, which are sporadically populated and geographically isolated. Due to the low demand, such regions are not connected to the grid. To develop such areas, a well-organized as well as financially feasible method needs to be found to make available these areas with electricity.

It has been recommended that renewable energy sources may be well-suited to this task. Besides being pollution free, they are free recurring costs. They also offer power supply solutions for remote areas not accessible by the grid supply. There are various such places in India which represents systems with hybrid energy providing increase economy and environmental conditions. The technical feasibility of PV wind hybrid system in given span of load demand was evaluated and economical evaluation of standalone PV, standalone wind and PV wind hybrid system have been established using the model. It offers generation of power in rural areas. Hybrid model with proper assembly is keen interest for recent years. India among fifteen states Rajasthan and Gujarat are one of the most potential states of renewable energy resources.

Renewable energy sources such as solar energy and wind energy have been clean, inexhaustible, limitless, and environmental friendly [1]. Such properties have fascinated the energy sector to use renewable energy sources on a higher scale [2]. However, all renewable energy sources have disadvantages. The one that is common to wind and solar sources is their dependency on unpredictable factors such as weather and climatic conditions. Fortunately, due to complementary nature of both sources, some of these complications can be addressed by overcoming the weaknesses of one with the strengths of the other [2]. This brings us to the hybrid solar-wind power plant concept. A system that gets together two sources of energy is called a hybrid system. The concept of having hybrid power stations is not new, but has gained fame in recent years [1]. Hybrid energy stations have proven to be profitable for reducing the depletion rate of fossil fuels, as well as supplying energy to remote rural areas [3], without harming the environment.

1.1 Solar Power

The process of transforming sun energy into electricity which can be done by following two methods

1) By using photovoltaic (PV)

2) By using concentrated solar power i.e. concentrating at intensity of sun thereby using lenses, mirrors and tracking systems. Solar power systems primarily contain of solar panel made up of PV cells (semiconductors) which discharges electrons on absorption of heat and transforms solar energy to electrical energy, batteries which store the power generated. The movement of electron produces the electric current.

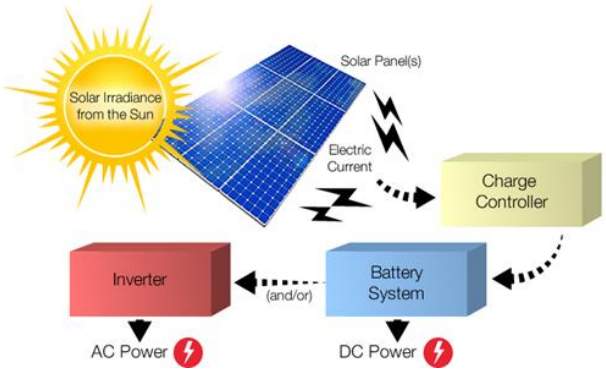

Fig -1: Generation of Solar Power

1.2 Wind Power

Sample Wind power is the usage of air flow through wind turbines to mechanically power generators for electricity where speed and direction of wind is main factor. Wind power provides variable power which is very consistent from year to year but which has significant variation over shorter time scales.

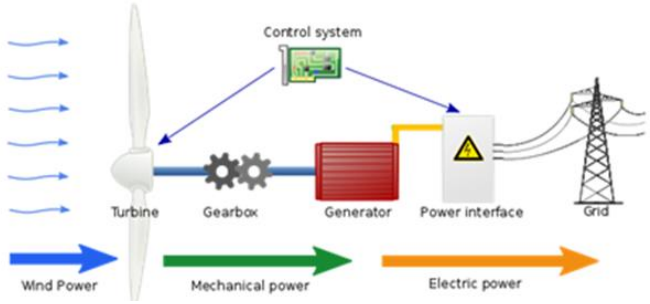

Fig -2: Generation of Wind Power

It is therefore used in combination with other electric power sources to give a consistent supply. Wind farms contains individual turbines connected to electric power transmission grid which produces plentiful, renewable, widely distributed, clean, and inexpensive electrical energy.

1.3 Hybrid Energy System

Hybrid energy system is a combination of two or more energy resources such as sources at a time like wind, solar, biomass, etc. Wind and solar hybrid combination is concerned to be best module because it is plentiful and environmental friendly. Also the stand alone system of this combination has drawbacks that wind cannot flow continuously and solar radiation is present approx. 8 to10 hours a day. Thus this combination is hybridized with energy storing batteries. Wind speeds are at minimum in the summer when the sun shines brightest and longest. The wind is at maximum in the winter when less sunlight is available. Because the peak operating time for wind and solar system take place at different times of the day and year, hybrid system are more likely to generate power when you need it.

They also proposed power supply solutions for remote areas, not accessible by the grid supply. Today, around 30,000 wind turbines and more than 1, 00,000 off-grid Solar PV systems are mounted all over the world. Hybrid systems can address restrictions in terms of –

1. Fuel Flexibility
2. Efficiency
3. Reliability
4. Emissions
5. Economical

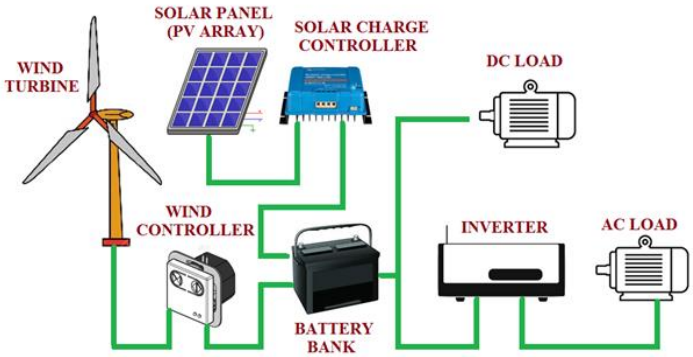

Fig -3: Proposed Schematic of Hybrid Solar-Wind Power Generator

2. WORKING PRINCIPLE

2.1 PV Solar Array

Whenever the light falls on the LDR sensor, its resistance reduces and thus the huge amount of current flows through the diodes .Which results into rotation of the motor and thus permits the tracking of the panel. Thus it adjusts itself to the direction of the intensity of the sun. They are controlled and successfully operated by the controllers.

2.2 Wind Turbines

Wind turbines produce kinetic energy through the rotations of turbines which are mounted the on the top of the tower and transforms it to the electrical energy .Wind turbines are manufactured on the basis of its wide span of vertical and horizontal axis types. They are becoming a gradually important source of intermittent renewable energy.

2.3 Working of Hybrid Solar Wind Power System

Hybrid Solar and wind hybrid power systems are designed using PV panels and small wind turbine generators for generating electricity. Generally, solar wind hybrid systems have small capacity. Typical power generation cannot go beyond more than 1kW to 10kW. Solar power system contains solar panels, solar photovoltaic cells, and batteries for storing the transformed energy. The electrical energy

generated by solar panel is in AC form which can be transformed to DC using invertors. The solar panel outcome is electric power which can be given in Watts or Kilo watts. These solar panels are available at the output ratings like 5 watts, 10 watts, 20 watts, 100 watts etc. Hence we can select the solar panel as per our requirement. But, the solar panels cannot resist factors like climate, panel alignment to the sun, sun light intensity, the presence of sunlight duration, etc. During normal sunlight a panel which has 12 volt 15 watt can produce 1 Ampere current. The large wind turbines are rotated and thus kinetic energy is produced by these rotations which can be transformed to electrical energy. Least wind speed required for connection of the generator to the power grid is known as cut in speed while, extreme wind speed required for the generator for disconnecting the generator from the power grid known as cut off speed. Generally, wind turbines are accessible to the span of speed between cut in and cut off speeds. Wind turbine is a device contain three blades which on rotation produces the electricity in such a way that that the axis of rotation must be aligned with the direction of blowing wind. A gear box is termed as a high-precision mechanical system because it transforms energy from one device to another device. Horizontal axis turbines and vertical axis turbines are the most often used turbines. An electrical generator is followed wind turbine; hence it is known as wind turbine generator. It generates electricity into battery bank with the help of solar charge controller and wind controller. The DC load which is stored into battery is transformed into AC load with the help of inverter.

3. OBJECTIVE

We have to develop a system to overcome the "inconsistent" nature of renewable energy resources. By mixing wind and solar technologies in a single unit a user can for the first time reliably depend on a renewable energy generation system. Not only does, the system overcome the variations of resources in a 24-hour period, but, over the course of a year as well. A hybrid energy solution smoothes out the highs and lows of energy generation times due to seasonality as solar irradiation and wind speeds change throughout the course of the year. A truly hybrid solution will compensate for seasonal losses of power generation not especially depending on one type of renewable energy system. It is easy to see that the mixture of wind and solar is a natural one, and one which is complementary on a seasonal basis. Our main objective is to minimize the cost and maximize the power output.

Overall Project Cost = Cost of Solar Plant +
Cost of Wind Plant +
Maintenance Cost (solar/wind) (1)

4. CONSTRAINTS

4.1 Demand Constraint

Hybrid Equation (2) make sure that our model meets the power demand of the load, using the power generated from the hybrid system – from both wind turbines and solar modules. The power produced by both sources is considered over a 12 month period under different weather conditions (e.g. greater solar radiation in summer, high wind in the winter).

$$Po\ (Wind) + Po\ (Solar) \geq P\ demand \quad (2)$$

4.2 Height and Radius Constraints

Equation (3) limits the height of the wind turbine to 130 meters, while Equation (4) limits the rotor radius to 30 percent of the tower height.

$$h \leq 100 \quad (3)$$

$$r \leq 0.3*h \quad (4)$$

5. METHODOLOGY

5.1 Proposed Calculation

The total power produced by this system may be given as the addition of the power produced by the solar PV panel and power produced by the wind turbine. Mathematically it can be represented as,

$$P_T = N_W * P_W + N_S * P_S \quad (5)$$

Where,
P_T is the total power generated
P_W is the power generated by wind turbines
P_S is the power generated by solar panels
N_W is the no of wind turbine
Ns is the no of solar panels used

5.2 Calculations for wind energy

The power generated by wind energy is given by,

Power = (density of air * swept area * velocity cubed)/2 (6)

$$PW = \tfrac{1}{2}.\ \rho\ (AW)\ (V)^3 \quad (7)$$

Where,
P is power in watts (W)

ρ is the air density in kilograms per cubic meter (kg/m^3)
AW is the swept area by air in square meters (m^2)
V is the wind speed in meters per second (m/s).

5.3 Calculations for solar energy

To determine the size of PV modules, the required energy consumption must be estimated. Therefore, the power is calculated as

PS = Ins (t) * AS*Eff(pv) (8)

Where,
Ins (t) = isolation at time t (kw/ m2)
AS = area of single PV panel (m2)
Eff(pv) = overall efficiency of the PV panels and dc/dc converters.

The overall efficiency is given by,
Eff(pv)= H * PR (9)
Where,
H = Annual average solar radiation on tilted panels.
PR =Performance ratio, coefficient for losses.

5.4 Overall Cost

The total cost of the solar-wind hybrid energy system is depend upon:
1. The total no of wind turbines used
2. Total no of solar panels used

Therefore the total cost is given as follows

Total cost= (No. of Wind Turbine * Cost of single Wind Turbine) + (No. of Solar Panels * Cost of single Solar Panel) + (No. of Batteries used in Battery Bank * Cost of single Battery)

CT = (NW * CWT) + (NS * CSP) + (NB * CB)

Where,
CT is the total cost in Rs.
CWT is the cost of single wind turbine in Rs.
CSP is the cost of single solar panel in Rs.
CB is the Cost of single Battery in Rs.
NW is the number of wind turbine used
NS is the number of solar panels used
NB is the number of Batteries used in Battery Bank.

Solar-wind hybrid energy systems requires only initial investment. It will efficiently work with the non- renewable energy sources. When accounted for a lifetime of reduced or avoided utility costs. The cost of the system is based on the factors such as system chosen, wind resource on the site, electricity costs in the area, and the battery bank required. Cost of the Wind-Solar Hybrid system is minimized using renewable energy sources.

6. OPTIMIZATION

As stated earlier, a mixture of solar PV and wind sources increases overall energy output. However, energy storage system is required to have a continuous power supply and cover any shortage in power generation from the renewable energy sources. The storage system can be battery banks, fuel cells, etc. with a more concern here on battery banks. Many optimization techniques have been described which could be applied to reach a techno-economically optimal hybrid renewable energy system [3-6], [7-8]. A comparison was made for various optimization techniques of hybrid systems in [9]. For distant areas which represent most of the stand-alone application for hybrid solar PV and wind systems, it is not always easy to find long-term weather data, such as solar radiation and wind speed that are used for sizing purposes. Hence, some artificial intelligence techniques such as fuzzy logic, genetic algorithms and artificial neural network are used for sizing stand-alone systems in comparison with traditional sizing method based on long-term weather data.

7. CHALLENGES AND SOLUTIONS

Main challenges and possible solutions for hybrid solar-wind stand-alone system are given in Table 1.

Table -1: Possible challenges and Solutions

No.	Challenges	Solutions	References
1	Higher storage cost	Combining both PV solar and wind powers will reduce the storage requirements and eventually the overall cost of the system.	10 & 15
2	Less usable energy during the year.	Integration of non-conventional energy generation with battery storage and diesel generator back-up systems.	11 & 16-18
3	Intermittent (Irregular) energy / power quality	Integration of non-conventional energy generation with battery storage or fuel cell and in some cases with diesel generator back-up systems.	11,12-14, 16-22 & 24
4	Protection	Appropriate protection devices essential to be installed for safety reasons including up gradation of existing protection schemes in particular when distributed generators are introduced.	22
5	Storage runs out	Integrate PV and wind energy sources with fuel cells.	20 & 21
6	Environmental and safety concerns of batteries and hydrogen tanks.	Integrating PV and wind energy sources with fuel cells instead of large lead-acid batteries or super storage capacitors, leads to a non-polluting reliable energy source and decreases the total maintenance costs.	20,21 & 23

8. CONCLUSIONS AND SCOPE FOR FUTURE WORK

This paper has provided a mathematical modelling of a solar-wind hybrid system, also the challenges and opportunities on integrating solar PV and wind energy sources for electricity generation. The hybrid system diminishes the dependence on one single source and has improved the reliability. The major challenge for grid-connected system as well as the stand-alone system is the intermittent (irregular) nature of solar PV and wind sources. By combining the two resources into an optimal combination, the impact of the adjustable nature of solar and wind resources can be partially resolved and the overall system becomes more reliable and economical to run. This absolutely has greater impact on the stand-alone generation. Energy management schemes should ensure high system efficiency along with high reliability and minimum cost. Better planning with precise forecasting of weather pattern, solar radiation and wind speed can help in decreasing the impact of intermittent energy. Voltage and frequency oscillation, and harmonics are main power quality issues for both grid-connected and stand-alone systems with greater impact in case of weak grid. Hence we could increase the efficiency of the system as compared with their individual mode of generation.

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