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Design, Development and Cost Estimation of a Hybrid Power Generation System for a Standalone System: A Modern Approach for Powering Rural India

Kshitij Arajpure[1], Prabhu Vellaisamy[2] Dr S.S Dash[3], Dr D.P Kothari[4]
[1, 2] Student, Department of Electrical and Electronics Engineering, SRM University, Chennai (T.N) - INDIA.
[3] Professor, Department of Electrical and Electronics Engineering, SRM University, Chennai (T.N) - INDIA.
[4] Fellow-INAE, Fellow-INASc, Fellow-IEEE, Hon. Fellow, ISTE, FIE (India), Fellow- IETE, MCSI
Dean (Research and Development), J.D College of Engineering and Management, Nagpur (M.H) – INDIA.

Abstract- **As on date according to the data furnished by Rural Electrification Corporation (REC) there are about 18000 villages that still lack electrification and the ones electrified face the delinquency in the continuity of service and the power quality. This condition could be due to the features of rural populations, which are scattered and remote, have small incomes and with low power consumption. In this situation, the extension of power grids is either complex or too expensive and not encouraged by the main players involved. Moreover, Renewable energy sources are currently one of the most suitable options to supply electricity in split areas or at areas with certain distances from the grid. Also, the hybrid systems have proved to be the best option to deliver high-quality power for community energy services to rural areas at the lower economic cost with maximum social and environmental benefits. To solve this problem of rural electrification there is a very urgent need to come up with the reliable and proficient elucidation which could be done through design and development of an efficient hybrid power generation system.**

The paper investigates and focuses on building solar-wind hybrid standalone system its working, design parameters, performance, and cost involved in power generation. It also highlights the objectives, philosophy and the benefits of locally available renewable energy resources, to provide a viable solution for uninterrupted power supply as well as reduce the greenhouse effect. This initiative becomes an index in energy production sector, which helps to meet the deficiency of electric power in peak load conditions and meet the objectives of sustainable development with the confluence of traditional and modern sciences.

Keywords: Power quality, Power Generation, Renewable Energy, Hybrid systems, Standalone system, Sustainable Development

I. INTRODUCTION

The Indian subcontinent has more than 6 lakh villages in its territory as per the Census Board of India in 2001 [1]. Speaking in terms of the electrification out of these about 96% are electrified by grid connectivity however about 64% of them actually have a continuity of electrical power [2]. The main cause of this problem was identified as the feature of rural population which is dispersed, remote and with low per capita income. In this case elongation in the grid is intricate and expensive and not encouraged by main actors [3].

It is, however, important to provide cheap, clean and uninterrupted power supply to the rural population for the irrigational and domestic purpose for a country like India to boost its GDP growth and become a world power [4].

This situation creates a necessity for provision of a feasible solution to the above problems as it is eco-friendly, doesn't encourage long distributed transmission losses and simultaneously provide an uninterrupted power supply during peak load conditions for irrigational and domestic activities [5]. Solar and wind energy are two of the most viable renewable energy sources. But little research has been done on operating both energy sources alongside one another. In doing so one can ensure system stability and uninterrupted power supply [6]. The way in which this could be accomplished is illuminated in the below sections.

II. RENEWABLE HYBRID ENERGY SYSTEMS

According to the Department of Energy, U.S a hybrid energy system is demarcated as the one which combines two or more home renewable energy sources that yield non-intermittent electrical energy [7]. Another definition describes hybrid renewable energy system as the one that collaborates the wind, PV, biomass, hydro, etc. to placate the energy demand and avoid the need of long distributed transmission network [8]. Since the Indian terrain is blessed with ample amount of photo-radiation and wind flow these resources could be used directly without much energy tapping [9].

The wind and solar power generation are the two most promising renewable power generation technologies and are thus taken for study purpose.

A. Photovoltaic Energy

The photovoltaic or PV energy is considered to be the cleanest form of energy. It is effluence free, steadfast and a very less maintenance is required. According to the Solar Energy Centre Ministry of New and Renewable Energy Government of India, the Indian subcontinent receives about 200MW/Km^2 which produces an estimated value of about 655mMW when the area is considered on whole [9, 10]. Since the amount of energy produced is not sufficient for operation of medium load standalone system thus additional system modifications are required for effective and efficient operation.

B. Wind Energy

This dynamic form of energy is clean, limitless and everlasting. However, it cannot be used as the dependable source of base load and also do not generate any power when no wind is propelling the generator shaft [11]. This creates a need for supplementary system alterations for effective and efficient power generation.

From the above two segments, it is clear that there are certain precincts to both PV and wind power generating systems which exist when any one is considered implicitly for the purpose of electrification of standalone systems. However, the research methodologies suggest that on interfacing these two systems a more efficient and operative system could be designed that eliminates individual limitations of each system to get a more organized structure [12].

III. PV-WIND BASED HYBRID SYSTEM DESIGN

The below-given block diagram shows a typical system design for the basic development of a PV-Wind hybrid system design.

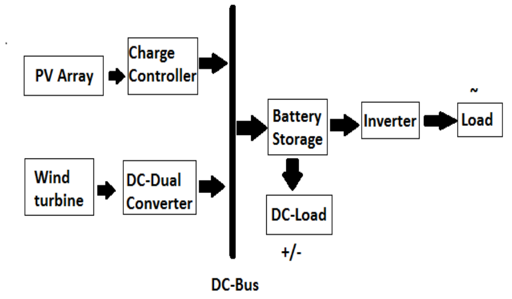

Fig.1 Block Diagram

III.I. DESIGN OF PV POWER GENERATION SYSTEM.

The design of PV system for a given load when calculated from a module study was found out to be dependent on following factors:

a. Total load connected to a system.
b. Total number of battery modules required.
c. Total number of PV plates cascaded, and
d. Budget of the system.

These four factors when studied in detail led towards the establishment of following set of equations assuming that the PV panels are radiated for 9 hours per day.

1. Total connected load to PV Panel system is calculated as-

$$P_t = \sum_{i=1}^{n} N_i * r \qquad (1)$$

2. The total watt-hour rating of a system

$$E_{sys} = P_t * T \qquad (2)$$

3. Actual power output of PV panel is

$$P_o = P_{pk} * f \qquad (3)$$

4. However, it has been observed that the power used at the end use is less due to less efficiency of PV arrays

$$P_t = P_o * \eta \qquad (4)$$

5. Energy created by one PV plate in one day is

$$E_{p/day} = P_o * 9 \qquad (5)$$

6. Number of solar panels required to satisfy given estimated daily load is

$$N_s = E_{t,day}/E_{p,day} \qquad (6)$$

Where,

E_t- Total energy, N - number of units, r- equipment rating, E_{sys}-total watt-hour rating of system, T- operating duration (in hr.), P_o – the actual power output of a PV plate, P_{pk} – Peak Power Rating, f –operation factor, P_t – power used at the end, P_o –actual power output, η- combined efficiency of the system, $E_{p,day}$- energy produced a plate in a single day, P_o- actual power output, N_s- number of solar plates, $E_{t,day}$- total watt-hour rating and $E_{p,day}$- energy produced by a panel daily.

III.II. SIMULATION FALLOUTS:

For this paper, a WAAREE made solar panel was utilized. The parameters that were used are listed in Table 1.

Parameters	Values
Maximum power [V_{max}]	100.0 W
Maximum Power Voltage [V_{mp}]	17.0 V
Maximum Power Current [I_{mp}]	5.88 A
Short circuit current [I_{sc}]	5.96 A
Open circuit voltage [V_{oc}]	21 V

Table 1. Electrical characteristics data of WAAREE solar panel STC at 25 °c, 1000w/m2, am 1.5

A 15.0 W PV panel was used for modeling purpose based on the electrical individualities of the panels. The information about the operational state of the system faults was diagnosed in MATLAB/ Simulink atmosphere as shown in the below figures.

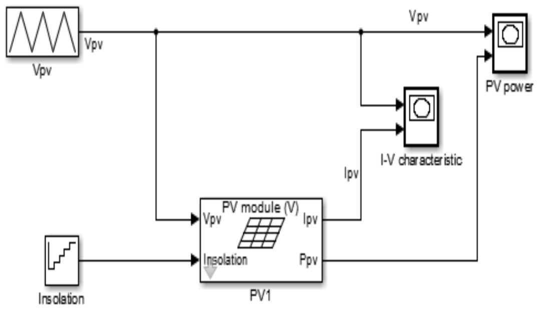

Fig.2 System implementation of PV module

A comprehensive PV module was simulated in a MATLAB/ Simulink atmosphere. The simulation outcomes illustrated the nonlinearity of the array output. The I-V characteristic expressed almost constant current up to open circuit voltage and the P-V characteristic shows the power has a maximum

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pick with respect to the voltage for the specific condition. With changes in radiation cell current changes linearly whereas cell voltage changed logarithmically as shown in below characterization graphs.

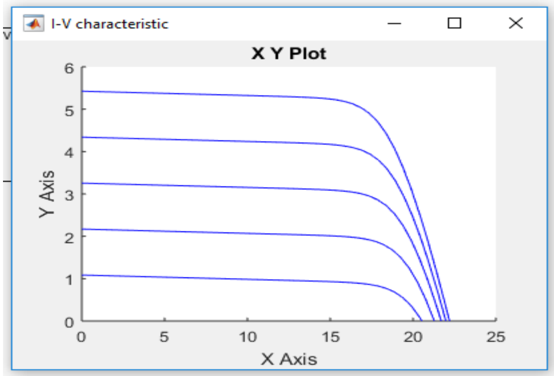

Fig.3 I-V characteristics of PV module from simulation

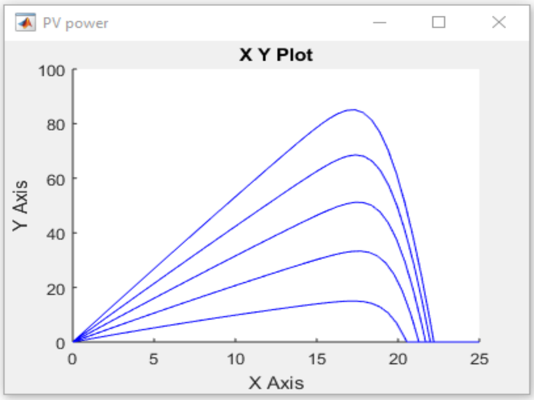

Fig.4 P-V characteristics of PV module from simulation

III. DESIGN OF WIND POWER GENERATION SYSTEM.

As per the AIMU Technical Services Committee, for any standalone hybrid system design, generally a propulsion type wind machine with DC permanent magnet generator is employed having a constant speed or directly driven gearbox [13, 18]. Also, it was observed that the capacitance factor plays a very important role as it gives us an idea about the amount of energy generated due to the variable speed of the generator prime mover which is generally considered as about 0.25-0.35 [14]. The design of wind power generation system for a given load when calculated from a module study was found out to be dependent on following factors:

a. Per unit area power of wind
b. The propulsion type wind machinery is used
c. Consideration of capacitance factor for uneven energy generation

These three factors when studied in detail led towards the establishment of following set of equations

Energy generated per unit area is

$$E_g = 0.5 * A_g * V^2 \qquad (7)$$

Actual power converted to useful energy is

$$P_{act} = C_p * T_l * G_l \qquad (8)$$

Where,

E_g-Energy Generated, A_{d}- Density of Air, V- Air Velocity, P_{act}- Actual Power Generated, C_p –Capacitance factor, T_l – Transmission loss, G_l -Generator loss.

IV. INTERFACING OF PV-WIND HYBRID SYSTEM

The root cause of the need to implement such hybrid systems is due to the irregularity and the uncertainty of wind power. Hence, the hybrid energy system needs to be designed in such a way that one power-generating element (PV in this case) must satisfy the energy demand while the other one is lacking (wind) and vice versa.

The energy storage device could be a flywheel-based energy storage (FBES), superconducting magnetic energy storage etc. However, in this case, a simple battery based energy storage is implemented.

The battery sizing is done with suitable autonomy which provides us with an idea of how long a battery module can last without recharging [15]

A basic model of a hybrid energy system consists of voltage regulator components, PV array, wind turbine and a battery bank. The voltage regulator regulates the electricity produced through the PV array and wind turbine. The excess energy is stored in the battery bank, and used when the optimum wind speed and solar radiation condition is not met.

In the battery based energy storage, when the wind speed falls below a certain threshold value, the stored energy is delivered to the plant. The storage of the energy occurs during the charging and the discharging of the battery.

There are two cases of implementation- high wind speed operation and low wind speed operation.

When the wind speed is above a threshold value that can generate 60 Hz output voltage, it is called high-speed operation [16, 19]. the required flow of energy is supplied to the primary motor, and the excess energy flow is delivered to the auxiliary motor. The auxiliary motor is coupled with a generator, and when high wind speed occurs, the excess wind speed rotates the auxiliary motor, which runs the electric generator. The mechanical energy from rotating the motor shaft is converted to electrical energy, which is stored in the battery banks.

When the speed of the wind falls below a certain threshold value, the condition calls for low wind speed operation. To compensate for the deficiency, the energy stored in the battery bank is supplied to the system, which is used to run the auxiliary motor in the system.

IV.I. DESIGN OF PV- WIND HYBRID SYSTEM

Many factors need to be taken into consideration while designing such systems. A well-designed hybrid system can provide a reliable service for an extended period of time. Some of the factors considered while designing a PV- Wind hybrid system are installation and maintenance cost, engineering cost, total PV cost etc.

For a solar-wind hybrid system with areas A_s and A_w respectively, their respective areas are calculated as

$$A_s = \eta A_{pv} \qquad (9)$$

Where,

η Is the module efficiency of PV panel, and A_{pv} is the area of PV array.

$$A_w = C_p A_r \qquad (10)$$

Where,

C_p Is the power coefficient, and A_r is the area swept by the rotor, calculated as $A_r = \pi r^2$.

The wind energy density, W is calculated as

$$W = \frac{1}{2}\rho V^3 D \qquad (11)$$

Where,

ρ Is the air density, V is the average hourly wind velocity, and D is the length of the operating period.

The supply of hourly solar and wind energies has to meet the hourly demand. This expression may be formulated as

$$SA_s + WA_w \geq d \qquad (12)$$

Where,

S Is the solar energy density on tilted surface, W is wind energy density, d and is the hourly demand.

The total cost of the hybrid energy system can be formulated as

$$C_t = C_s A_{pv} + C_w A_w + C_b B_c + \sum_{i=1}^{n} C_{sh} E_i \qquad (13)$$

Where,

C_s, C_w, C_b And C_{sh} are the unit costs of PV, wind energy generator, battery and shortage electricity respectively. E_i Denotes the total electrical energy shortage because of not meeting the demand during an hour i, while B_c is the battery capacity.

One of the main drawbacks of implementing a battery based energy storage system is the high cost of batteries.

V. CONCLUSION

The output efficiency of a hybrid system on studying various parameters was found out to be very appealing since it consists of more than one type of energy conversion system. In a country like India where coal-fired power generation systems are impotent to supply the ever increasing load demands of the urban population, rural areas face load shedding issues more frequently and for longer spells. Hybrid power generation systems when used for standalone systems such as rural ménages with limited loads performed stupendously. We then come to a conclusion that in an Indian environment where the generation of power from renewable energy sources is gaining a wider popularity. However changing weather conditions due to global warming has changed the wind behavior in tapped areas which may be solved on further research work.

VI. ACKNOWLEDGEMENT

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Kshitij Arajpure was born in Maharashtra, India on June 14, 1996. He is pursuing his degree in B.Tech. Electrical and Electronics Engineering from SRM University, Chennai. His area of interest involves in Renewable Energy Systems (RES), power generation systems and hybrid energy technologies.

Prabhu Vellaisamy was born in Maharashtra, India in 1996. He is pursuing his degree in B.Tech. Electrical and Electronics Engineering from SRM University, Chennai. His area of interest involves in VLSI, FPGA, and Renewable Energy Systems (RES).

Dr. Subhransu Sekhar Dash is presently working as a Professor in the Department of Electrical and Electronics Engineering, SRM Engineering College, SRM University, Chennai, India. He received his Ph.D. degree from College of Engineering, Guindy, Anna University. He has more than seventeen years of research and teaching experience. His research areas are Power Electronics and Drives, Modelling of FACTS Controller, Power Quality, Power System Stability and Smart Grid.

Dwarkadas Pralhaddas Kothari was born 7 October 1944 is an educationist and professor who has held leadership positions at engineering institutions in India including IIT Delhi, Visvesvaraya National Institute of Technology, Nagpur and VIT University, Vellore. Currently, he is the Dean (R&D), J.D. College of Engineering & Management, Nagpur. As a recognition of his contributions to engineering education, he was honored as an IEEE Fellow. Previously he was Vice-Chancellor at VIT University.