DESIGN AND SIMULATION OF STAND ALONE INTEGRATED RENEWABLE ENERGY SYSTEM FOR REMOTE AREAS

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Abstract

The availability of energy plays an important role in the development of a country. Electricity availability is essential for economical growth and improvementin quality of life of rural and semi-urban population. In order to achieve this, rural electrification should gain importance. Rural electrification requiresgrid extensionof the existing power system o remote areas which is difficult and costly. Impact of burning fossil fuels on environment and rapid depletion increases the supply demand gap. Development of Integrated Renewable Energy System for isolated load is a promisingway outfor rural electrification. Integrated renewable energy systems generate power making use of renewable energy sources that are available regionally which can electrify rural households. In this paper, an attempt has been made to develop an Integrated renewable energy system for power generation using solar and wind resources. Integration of solar and wind systems has been done for supplying isolated load and the model has been implemented in MATLAB/SIMULINK and the results are summarized.

Keywords- Renewable Sources, Solar System, Wind System, Integrated Renewable Energy System, Power.

1. INTRODUCTION

For the development of a country, electrification of rural areas also plays a key role as it improves living standards, education, better transportation system, communication system, health care and provides economic stability. In order to accomplish this we need to extend the grids of the existing power system to remote areas which is difficult and costly. The dearth of conventional energy resources, increase in fuel prices and concern on the environment from the impacts of burning fossil fuels has made power generation from conventional energy sources unsustainable. The demand and supply gap continues to increase exponentially if not met by other resources of power generation. Integrated renewable energy system (IRES) provides the most promising solution for rural electrification of isolated areas devoid of power grid access [1]. The current international development in rural electrification is to exploit renewable energy resources to the maximum extent.

Renewable Energy (RE) is in-exhaustive while other sources of energy are limited and are prone to depletion. The environmental impact of power generation from renewable energy technologies is less as compared to conventional energy technologies as these are clean sources of energy [2]. The only drawback of opting for power generation from a renewable energy source is its availability. Due to the heavy dependence of these sources on climatic conditions and natural uncontrollability, electrical power can be generated only when they are accessible. In this regard, taking into

account a particular renewable energy source for power generation is associated with the problem of reliability of supply [3]. Integrating two or more renewable energy sources is an impressive solution to provide uninterrupted power supply and accomplish the demand of electricity. The rapid advancement in photovoltaic and wind turbine generator technologies provide vast opportunities for utilizing solar and wind resources for electrical power generation.

In this paper, a stand-alone IRES model employing solar and wind power generation systems is presented. The solar cell designed is using the static equations of a PV cell. The solar system consisting of three panels connected in series is designed [4]. The Variable Speed Wind Energy Conversion System consisting of Horizontal Axis Wind Turbine connected to Permanent Magnet Synchronous Generator (PMSM) is designed [5]. The wind system presented is direct driven system. Both the sources are connected to a common DC bus, thus integrating both the sources. This implemented system is Integrated Renewable Energy System. This system is a two stage conversion system. Initial stage consisting of generation and boosting the voltage levels to the required level and the second stage is the conversion of DC voltage to the AC, to interface the load to the system [3]. The Boosting of the DC voltage can be obtained using DC-DC converter i.e. Boost or Step-up converter and the inversion of DC to AC can be achieved using an inverter. To reduced the EMI and the harmonics in the system, Pulse Width Modulation (PWM) technique and LC filter are employed.

2. MODELLING OF SOLAR SYSTEM

In this system, power generation is done by converting the available solar radiation into electrical energy using a photovoltaic (PV) cell. The solar radiation is electromagnetic and it can be directly converted into electricity through photo voltaic effect. A single photovoltaic cell can produce a very small amount of electrical energy. In order to rise the power level to that which is convenient for use, these cells must be connected in series and parallel. The series and parallel connection of the PV cell is known as a module and modules connected in series and parallel is called array as shown in Fig. 1. These series and parallel connections of PV cells aid in obtaining increased voltage and increased current [4].



Fig-1: Solar PV Panel

The solar PV system is implemented in MATLAB/SIMULINK by using the V-I characteristic equations of PV cell. The corresponding circuit of the generic PV model consists of a photo current, diode, a resistor in parallel corresponding to leakage current and a resistor in series corresponding to internal resistance to current flow as shown in Fig.2[6, 7].



Fig-2: Generic model of PV cell

Current equation is given as

$$I = I_{pv} - I_0 \left[e^{\left(\frac{V + IR_s}{aV_T}\right)} - 1 \right] - \frac{V + IR_s}{R_{sh}}$$

Where,

$$V_T = \frac{N_s K_T}{q}$$

 I_{pv} = Light generated current or photo current and is given as

$$I_{pv} = \frac{a}{a_n} \Big[I_{pvn} + K_1 \big(T - T_n \big) \Big]$$

 I_o = Diode current $q = 1.6*10^{-19}c$ = charge of electron

$$K = 1.38 \times 10^{-23} J / K$$
 =Boltzmann's constant

 R_{s} =series resistance

a = diode ideality constant

 R_{sh} = shunt resistance

T = operating temperature

 I_{pvn} represents the short circuit current of the cell at 25°C and 1Kw/m², K₁ represents the cell's short circuit current temperature coefficient, T_n is considered as reference temperature, G_n represents the nominal irradiance and G/G_n is solar insolation in Kw/m² radiation [8]. I_o the saturation current of the cell is given by the Eq. (2),

$$I_{0} = I_{on} \left[\frac{T}{T_{n}} \right]^{3} e^{\left(\frac{qE_{g} \left(\frac{1}{T_{n}} - \frac{1}{T} \right)}{aK} \right)}$$
⁽²⁾

 I_{on} represents the reverse saturation current of the cell at a particular reference temperature and solar radiation. E_g is energy band gap of semiconductor used in the PV cell. Band gap of silicon at $25^{\circ}C$ is 1.12.

$$I_{0n} = \frac{I_{scn}}{e^{\left(\frac{V_{0cn}}{aV_{Tn}}\right)} - 1}$$

$$I = N_p I_{pv} - N_p I_0 \left[e^{\left(\frac{\left(\frac{V_s + IR_s}{N_s}\right)}{aV_T}\right)} - 1 \right] - \frac{\left(\frac{N_p V}{N_s} + IR_s\right)}{R_{sh}}$$

$$(3)$$

$$(4)$$

The equivalent circuit of general PV array is as shown in Fig. 3.

(1)



Fig-3: Equivalent circuit of a general PV array.

Modelling of PV array based solar power generation was implemented in MATLAB/Simulink and the proposed model is simulated. A low magnitude DC power is generated which is incompatible for supplying loads. In order to step up the output voltage obtained by the PV array, a boost converter is used. The MATLAB/Simulink model of solar power generating system employing PV modules along with boost converter is as shown in Fig. 4.



Fig-4: MATLAB/Simulink model of Solar power generation.

3. MODELLING OF WIND SYSTEM

Wind energy is the one of the finest technologies existing now a days to provide a sustainable energy supply. Wind energy system is one of the emergent source of renewable power generation with negligible adverse environmental impacts and is considered as one of the impending sources of alternative energy for the future. As compared to large scale, small scale wind energy conversion systems are more efficient and cost effective. Standalone wind energy conversion systems offer a feasible solution to generate power at isolated localities where utility grid extension is not feasible. The surface of earth heats and cools disproportionately, creating atmospheric stress zones that result in flow of air from high pressure areas to low pressure areas which causes wind. Wind is also created by rotary motion of earth. This wind is able to exert a force and creates movement which is utilized in the wind energy conversion systems. The power present in the wind in the form of kinetic energy is converted into electrical power. This conversion is known as wind energy conversion system(WECS). The kinetic energy is captured by the turbine blades of wind turbine and it is converted into load torque. This shaft is directly connected to the generator rotor shaft. This connection is known as direct driven system. The power available in the wind is given by the Eq. (5).

$$P_{air} = \frac{1}{2}\rho A v^3 \tag{5}$$

Where,

 ρ is the air density(approximately 1.225kgm⁻³), A is the swept area rotor (m²), V is the wind speed (ms⁻¹).Power transferred to the wind turbine rotor is given by the Eq. (6).

$$C_P = \frac{P_{windturbine}}{P_{air}}$$

Where,

C_p is the power coefficient,

$$P_{windturbine} = C_p P_{air} = C_P \frac{1}{2} \rho A v^3 \tag{7}$$

The C_p value is defined by Betz limit, C_p is the ratio of mechanical power at shaft to the power available in the wind and given as the function of tip-speed-ratio λ .

$$l = \frac{\omega R}{v} \tag{8}$$

Where w is the rotational speed, R is radius of tip rotor and v is wind speed (ms⁻¹). Power coefficient C_p and tipspeed ratio λ are used to describe the performance of wind turbine rotor. The present work represents a system in which a PMSG feeds an isolated load through boost converter in a closed loop configuration. Fig. 5 shows a wind turbine connected to PMSG to generate electrical energy [9]. The conversion is in the form of KE-ME-EE. Due to deviations in wind, the corresponding electrical energy output is also fluctuating. The AC output voltage of PMSG is converted into DC voltage by using diode rectifier and rectifier filters are used in order to filter the DC voltage [10, 11].



Fig-5: Variable-speed wind turbine with PMSG.

3.1 Modelling of PMSG

The permanent magnet synchronous generator is used to generate the electricity from the mechanical energy. The dynamic model of the PMSG is derived from two-phase synchronous reference frame in which the q axis is 90^{0} ahead q the d axis with respect to direction q rotation as shown in Fig. 6. [12].



Fig–6: d-q and α - β axis of a typical salient-pole synchronous machine.

The mechanical angle is the angle between the d-axis of the rotor and d-axis of the stator. The assumptions made for mathematical modelling of PMSG are: (a) the mechanical sitting of the stator winding is 120° apart in the air. The magnetic, hysteresis and saturation effects are negligible. The rotor inductance has negligible effect on it

due to the presence of stator slots, when damping windings are not taken into considerations. Hence, the Stator construction is in symmetrical manner. (b) The other assumption made is the neglecting the winding capacitances with constant resistances, which makes power losses constant [13].

The mathematical model of PMSG in synchronous reference frame is given by

$$\frac{di_a}{dt} = \frac{1}{L_{ds}} v_d - \frac{r_s}{L_{ds}} i_d + \frac{L_{qs}}{L_{ds}} \omega_e i_q \tag{9}$$

$$\frac{di_q}{dt} = \frac{1}{L_{qs}} v_q - \frac{r_s}{L_{qs}} i_q - \frac{L_{ds}}{L_{qs}} \omega_e i_d - \frac{\psi_f \,\omega_e}{L_{qs}} \tag{10}$$

Where,

- $\frac{v_d}{i_d} \text{ d-axis voltage (V)/current(A)}$ $\frac{v_q}{i_q} \text{ q-axis voltage(V)/current(A)}$ $r_s \text{ stator resistance (}\Omega\text{)}$ $L_{ds} \text{ stator d-axis inductance (H)}$ $L_{as} \text{ stator q-axis inductance (H)}$
- *qs* 1
- ψ_f permanent magnetic flux(W_b)
- ω_e electrical speed (rad/s)
- $\omega_e = p\omega_m$

Where,

p pole pairs

 ω_m mechanical speed(rad/s)

$$T_e = 1.5 p(L_{ds} - L_{qs}) \mathbf{i}_d \, \mathbf{i}_q + \mathbf{i}_q \psi_f$$

$$\frac{d\omega_m}{dt} = \frac{1}{J} (T_e - F\omega_m - T_m)$$
(11)

Where,

J combined inertia of load and rotor(kg-m²)

F combined viscous friction of load and rotor(Nm-s)

 T_m shaft mechanical torque (N-m)

The equivalent circuit of PMSG in d-q synchronous rotating reference frame as shown in Fig. 7 and Fig. 8.



Fig-7: d-axis equivalent circuit



Fig-8:q-axis equivalent circuit

A wind power generating system along with boost converter is designed in matlab and it is as shown in Fig. 9 its simulation results are as shown in Fig. 14 and Fig. 15.



Fig-9: wind power generating system

4. INTEGRATED RENEWABLE ENERGY

SYSTEM

Integrated renewable energy system utilizes two or more locally available renewable energy resources like hydro, solar, wind, biomass, geothermal etc., to supply the electricity in local villages [14]. By integrating renewable energy sources which are available in that area we can generate and distribute power at low cost and fulfil the demand of electricity in remote and rural households. The solar and wind power generating systems are integrated. The block diagram of this system is as shown in Fig. 10.



This is a simple block diagram representation of IRES with two renewable energy systems. Here solar system (RES1) is connected to DC bus as the output of the solar power system is DC power. If the power output is AC as wind system then it is given to DC bus through converter. By using the inverter we convert the DC power to AC and then it is supplied to load [15]. If the supply is more than load then the excess power then it is supplied to dump loads [16]. The renewable energy sources are of low cost and by using them we can overcome the scarcity of conventional fuels. Rural energy needs can be satisfied [17]. They are inexhaustible and environment friendly. We can have a improved public health and environmental quality. The IRES is one of the best solution to electrify the un-electrified areas. solar system and wind system are integrated to supply a load of 3000 watts is designed in matlab and it is as shown in Fig. 11 and its output voltage, line voltage, current and power are shown in Fig. 16, Fig. 17 and Fig. 18 respectively.



Fig-11: solar and wind integrated system with non-linear load.

5. SIMULATION RESULTS AND VALIDATION

The solar panel is designed for an open circuit voltage (v_{oc}) of 36.88v and short circuit current (I_{sc}) of 8.72A. The complete system consisting of three solar panels gives the open circuit voltage (v) and short circuit current (I) are 200v and 8.251A. The three phase, when connected to power system, the load requirements are nominal voltage of 440V with 50Hz frequency. The requirements of the load, in this case, can be met by either converting the DC to AC supply and stepping up the voltage using a step-up transformer or by using boost converter. Using a transformer requires special equipment and space for maintenance and operation. A boost converter is used with a gain value of 3.5 and the voltage (v) increased to 700 volts thereby the current (I) value is 2.2 amps.

The boost converter is a step-up DC/DC converter. The converter uses a transistor switch, typically a MOSFET or IGBT. Depending on the switching pulses and formula, the

boosted voltage (V_a) can be seen as v

$$v_i\left(\frac{1}{1-D}\right)$$
 which

gives the relation between V_i and V_o . The gain value of the boost converter is the inverse of the duty cycle i.e., G=1/D. And duty cycle is defined as the ratio of switch on time period of switch to total time period of switch. Hence the output voltage and current of boost converter obtained for a duty cycle of 0.75 is 700V and 2.2A for an input of 200V and 8.251A. Hence the efficiency of this boost converter is 98%.



Fig-12: Solar system output voltage and current.

The solar system is simulated and the required voltage of 700V and current of 2.2A are obtained as shown in Fig. 12.



The required output power of 1500W from the solar system is obtained and the simulation result is as shown in Fig. 13.

A variable speed wind energy conversion system consists of a PMSM with wind turbine. The output obtained from wind turbine connected to PMSM is variable with respect to its magnitude and frequency. So as to attain constant output, the AC output of wind energy is converted into DC. This DC is maintained at a required DC level using boost. The output of boost is interconnected to the solar DC system. The solar DC system is maintained at 700V constant DC. Hence, the boost converter of wind has to maintain a DC link voltage of 700V. This interlink of DC voltages from both the renewable sources forms the integrated renewable energy source. Hence the efficiency of this boost converter is 97%.



Fig-14: Wind system output voltage and current.



The wind system is simulated and the required voltage of 700V and current of 2.2A are obtained as shown in Fig. 14.

Fig-15: Wind system power output

The required output power of 1500W from the wind system is obtained and the simulation result is as shown in Fig. 15. The solar system and wind system having parametric values of 1500W, 700V and 2.2A are integrated to get the desired output power of 3000W. The designed load is an AC three phase load with requirements of 440V and 50Hz system. To integrate the load with the system, an inverter is used as interface between the load and the system. It also converts DC source to AC. Thereby the obtained output voltage (v) and current (I) from inverter are 440V and 6.9A respectively.



Fig-16: Integrated solar and wind system output voltage and current.

The Integrated solar and wind system is simulated and the required voltage of 440V and current of 6.9A are obtained as shown in Fig. 16.



Fig-17: Integrated solar and wind system line voltage



Fig-18: Integrated solar and wind system power output.

Hence the required output power of 3000W from the integrated solar and wind system is obtained and the simulation result is as shown in Fig. 18.

6. CONCLUSION

Uneconomical extension of the grid has led to the generation of electric power at the user end. Integrated renewable energy systems have been recognized as a feasible option for energy supply in stand-alone applications and it is also cost effective. With developed technologies the use of renewable energy sources such as micro-hydro, wind, solar, biomass and biogas is being explored. IRES electrifies the remote areas using renewable energy sources available in that area. In this paper solar and wind energies are considered and integrated. This paper provides design of solar and wind system and integrated solar and wind system for an isolated load of 3000watts. The simulation results of solar system and wind system with parametric values of 1500W, 700V and 2.2A and integrated solar and wind system for isolated load of 3000W with three phase AC voltage and current of 440V and 6.9A respectively are shown. By using IRES for isolated loads the social and economic status of people will be improved.

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