Hybrid Distributed Power Generation System using PV and Wind Energy

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ABSTRACT
This project deals with a grid connected wind-PV hybrid distributed generation system employing permanent magnet synchronous generator(PMSG) driven by a variable speed wind turbine and PV array connected to a load and the grid. PMSG wind turbine connected to a dc-dc converter via three phase diode rectifier and PV array along with a dc-dc converter connected to the DC link which operates under a centralized three phase inverter. The optimum torque tracking scheme is employed to achieve maximum power extraction in wind power generation system. The incremental conductance algorithm is used to achieve MPPT in PV system. In the proposed system, the wind and PV system alone cannot meet the load demand due to the uncertainty in weather conditions causing a high degree of mismatch between the power generation and consumption. To avoid this problem, wind energy conversion system and PV system are made to operate alternatively to meet the load demand based on its availability.

General Terms
Wind energy conversion system, solar energy Conversion system

Keywords
Distributed generation, Hybrid system Wind - PV system

1. INTRODUCTION
In the last few decades, renewable energy sources has been getting more importance due to the increase in the cost of petroleum products and the pollution caused by the use of fossil fuels. The ever increasing population leads to increase in energy demand. To meet this demand distributed power generation systems are penetrated into the power system to form a new type of power system, the micro grid. It can be connected to the main power grid or can operate autonomously. Distributed power generation system has the advantage of reducing blackouts, which affects the power grids. It could also reduce the adverse effects of terrorism, if electric supply is attacked. The deregulated power market is also an important reason for developing the distributed power generation. [1]

There are different wind turbine configurations: with or without gearbox, the generator can be synchronous or asynchronous and finally the connection with the grid can be through a power converter or directly connected. Different modes of operation can be used depending on the wind turbine configuration. They are classified in variable-speed and fixed-speed. For fixed-speed operation, the system is very simple and thus the cost is usually. Normally they are connected to the grid by means of a power converter. It increases the cost of the whole system but allows full controllability of the system. Among all these configurations, the trend is to use variable-speed wind turbines because they offer more efficiency and Control flexibility which is becoming very important to comply with the grid requirements.

Permanent Magnet Synchronous Generator (PMSG) is an interesting solution which is based on variable-speed operation. The variable speed wind turbine with full scale frequency converter is an attractive solution for research on distributed power generation systems. The advantages of PMSG over induction machines are the high efficiency and reliability, since there is no need for external excitation, smaller in size and easy to control. The generator is directly connected to the grid through a full scale back-to-back power converter. The power converter couples the generator to the grid. Generator converter is used to control the torque and speed and the grid side converter is used to control the power flow in order to keep the DC-link voltage constant. The two converters are connected by a DC link capacitor in order to have a separate control for each converter. [4]

At present photovoltaic (PV) generation is also getting more importance in the renewable energy sources application. It has the advantages of simplicity in allocation, high dependability, and absence of moving parts. The solar cell conversion ranges from 12% of efficiency up to a maximum of 29%. So the PV generation gives a confidence to select hybrid distributed generation system.

Hybrid power systems usually integrate renewable energy sources with fossil fuel based generators to provide electrical power. They are generally independent of large electric grids and are used to feed loads in remote areas. Hybrid systems offer better performance, flexibility of planning and environmental benefits compared to the diesel generator based stand-alone system. Hybrid systems also give the opportunity for expanding the generating capacity in order to cope with the increasing demand in the future. Remote areas provide a big challenge to electric power utilities. Hybrid power systems provide an excellent solution to this problem as one can use the natural sources available in the area e.g. the wind and/or solar energy and thereby combine multiple sources of energy to generate electricity. In this project we are discussing about the grid integrated wind-PV hybrid system with maximum power extraction. [2]

In this work, the research will be focused to develop the grid connected hybrid wind-PV system to meet the load demand alternatively based on its availability. This system employing permanent magnet synchronous generator driven by a variable speed wind turbine and PV array connected to the load and grid. The optimum torque tracking scheme is employed to achieve maximum power extraction using incremental conductance algorithm in PV system. Finally, the whole system is analyzed using MATLAB.

2. PROPOSED SYSTEM

The fig.1 shows the control structure of grid connected hybrid distributed generation system. The proposed system includes wind energy conversion system, solar energy conversion system and a current controlled grid side inverter. The output of the wind energy conversion system is not constant due to the varying wind and other reasons. Similarly the output of the solar energy conversion system is also not constant due to solar irradiation. But the efficiency of PV cell has been increased and Maximum Power Point Tracking is also blooming in the recent years. Hence the necessity of any other battery or conventional sources (i.e. diesel generator) can be avoided. If one of the energy conversion systems (wind or PV) fails, the other energy conversion system will operate alternatively to meet the load demands. The whole system operates only on clean sources of energy.

3. WIND ENERGY CONVERSION SYSTEM

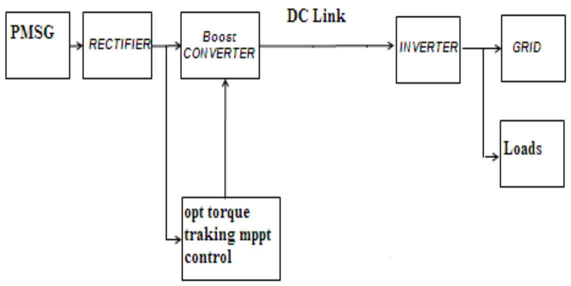

Fig 2: Block diagram of wind energy conversion system

The block diagram of the wind energy conversion system is shown in fig 2. It includes PMSG, three phase rectifier, optimum torque tracking MPPT controlled boost converter connected to the DC-Link which is in turn connected with the grid side inverter

3.1 Wind Turbine Characteristics

The output power of the wind turbine by the wind turbine (power delivered by the by the rotor) is given by:

$P_t = 0.5\ p\ AC_p\ (\lambda, \beta)\ x\ (v_w)^3$

$P_m = 0.5\ p\ AC_p\ x\ (\omega_m R/\lambda)^3$ (1)

Where ρ is the air density (kilograms per cubic meter),

v_w is the wind speed in meters per second,

A is the blades' swept area, and

C_p is the turbine-rotor-power coefficient, which is a function of the tip-speed ratio

(λ) and pitch angle (β).

ω_m = rotational speed of turbine rotor in mechanical radians per second, and

R = radius of the turbine

The coefficient of performance of a wind turbine is influenced by the tip-speed to wind-speed ratio, which is given by

$TSR=\lambda=(w_m R/v_w)$ (2)

The wind turbine can produce maximum power when the turbine operates at maximum *Cp* (i.e., at *Cp*_max). Therefore, it is necessary to keep the rotor speed at an optimum value of the tip-speed ratio λ_{opt}. If the wind speed varies, the rotor speed should be adjusted to follow the change.

3.2 Optimum Torque Tracking Control

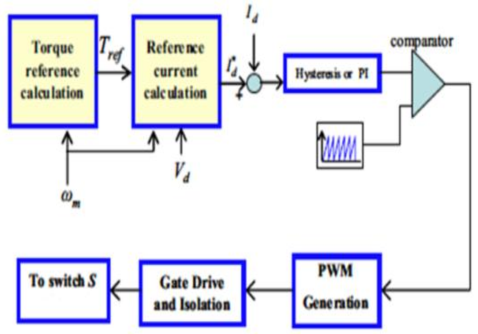

Fig 3: Shows Block Diagram of Optimum Torque Tracking Control

The main objective is to control the duty cycle of the IGBT used in boost converter in WECS, to extract maximum power from the variable speed wind turbine.
The steps to be followed for maximum power extraction:-

i) Measure the generator speed
ii) Find the reference torque using equation

$T_{ref}^* = X_{opt}\ (\omega)^2$ meas (3)

This calculated reference torque is used to find the reference DC current by using the rectifier output voltage v_d

$ID_{ref}^* = (Tref^*\omega_{meas})\ /v_d$ (4)

iii) Then compare the reference DC current and actual measured DC current to produce the error value. This error is fed to the current regulator (PI controller) for generating the pulses to regulate the output of the diode rectifier and the generator torque by varying the duty cycle of the boost converter.

The measured torque will be compared with the calculated optimum torque. If the reference torque is less than the measured torque, then the generator speed will be increased. If the reference torque is more than measured torque then the generator speed will be decreased Therefore the measured torque and reference torque settles down to the (same point) optimum torque point at any speed for maximum power extraction. [9]

4. SOLAR ENERGY CONVERSION SYSTEM

The block diagram of solar energy conversion system is shown in fig. 4 .It includes a modeled PV array, boost converter controlled by incremental MPPT algorithm. Then it is connected to the Dc link. This DC link connected to the grid side inverter.

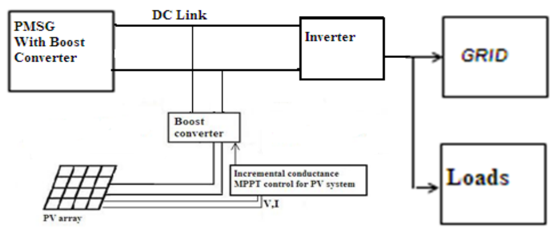

Fig 4: Block Diagram of Solar Energy Conversion System

4.1 Modeling of PV Model

The photovoltaic system can generate direct current electricity without environmental impact when is exposed to sunlight. The basic building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity. The output characteristic of PV module depends on the cell temperature, solar irradiation, and output voltage of the module. The fig 5 shows the equivalent circuit of a PV array with a load

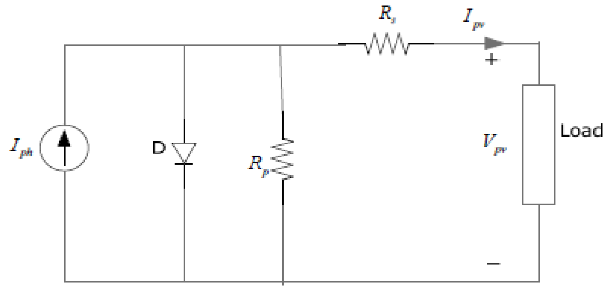

Fig. 5 Equivalent circuit of a solar cell

Usually the equivalent circuit of a general PV model consists of a photocurrent, a diode, a parallel resistor which expresses a leakage current, and a series resistor which describes an internal resistance to the current flow. The voltage current characteristic equation of a solar cell is given as

$I_{pv} = I_{pH} - I_s[\exp(q\ (V_{pv} + I_{pv} + I_{pv}\ R_s\ )/k\ T_c\ A\ )-1] - (V_{pv} + I_{pv}\ R_s)/R_p$ (5)

The photocurrent mainly depends on the cell's working temperature and solar irradiation, which is explained as

$I_{PH}=[I_{sc}+K_i(T_c-T_{ref})]\lambda/1000$ (6)

The saturation current of the cell varies with the cell temperature, which is represented as

$I_s=I_{RS}(T_c/T_{Ref})^3\exp[qE_G(1/T_{Ref}-1/T_c)/kA]$ (7)

The shunt resistance Rsh of the cell is inversely related with shunt leakage current to the ground. Usually efficiency of PV array is insensitive to variation in R and the shunt-leakage resistance can be assumed to approach infinity without leakage current to ground. Alternatively a small variation in series resistance Rs will significantly affect output power of the PV cell. The appropriate model of PV solar cell with suitable complexity is shown in Fig. 5, Equation (3) can be modified to be

$I_{pv}=I_{PH}-I_s[\exp(q(V_{pv}+I_{pv}R_s)/kT_cA)-1]$ (8)

There is no series loss and no leakage to ground for an ideal PV cell, i.e., Rs = 0 and Rsh = ∞.So equation (3) can be rewritten as

$I_{pv}=I_{PH}-I_s[\exp(qV_{pv}/kT_cA)-1]$ (9)

A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. So the current and voltage equation of the array with Np parallel and Ns series cells can be represented as

$I_{pv}=N_pI_{PH}-N_pI_s[\exp(q(V_{pv}/N_s+IR_S/N_p)/kT_cA)-1]-(N_pV_{pv}/N_s+I_{RS})$ (10)

The efficiency of a PV cell is sensitive to small change in series resistance but insensitive to variation in shunt resistance. The role of series resistance is very important for a PV module and the shunt resistance is approached to be infinity which can also be assumed as open. The mathematical equation of the model can be described by considering series and parallel resistance as

$I_{pv} = N_p\, I_{PH} - N_pI_s\,[\exp\,(q\,(V_{pv}/N_s + I\,R_S/\,N_p\,)\,/k\,T_c\,A)-1]$ (11)

The equation (3.7) can be simplified as

$I_{pv}=N_pI_{PH}-N_pI_s[\exp(qV_{pv}/N_skT_cA)-1]$ (12)

The open-circuit voltage V_{oc} and short-circuit current I_{sh} are the two most important parameters used which describes the cell electrical performance. The above mentioned equations are implicit and nonlinear; hence, it is not easy to arrive at an analytical solution for the specific temperature and irradiance. Normally $I_{PH}>>I_s$, so by neglecting the small diode and ground-leakage currents under zero-terminal voltage, the short-circuit current is approximately equal to the photocurrent, i.e.

$I_{PH} = I_{sc}$ (13)

The open-circuit voltage parameter is obtained by assuming the zero output current. With the given open-circuit voltage at reference temperature and ignoring the shunt-leakage current, the reverse saturation current can be acquired as

$I_{RS}=I_{sc}[\exp(qV_{oc}/N_skT]$ (14)

Additionally, the maximum power can be stated as

$P_{max} = V_{max}\ I_{max} = ý\ V_{oc}\ I_{sc}$ (15)

4.2 Incremental Conductance MPPT

In incremental conductance method the array terminal voltage is always adjusted according to the MPP voltage it is based on the incremental and instantaneous conductance of the PV module

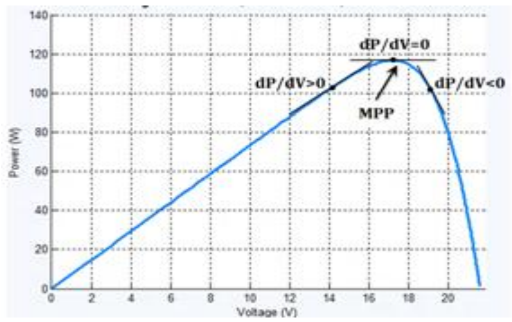

Fig 6: Incremental conductance MPPT PV curve

Fig. 6 shows that the slope of the P-V array power curve is zero at The MPP, increasing on the left of the MPP and decreasing on the Right hand side of the MPP. The basic equations of this method are as follows.

$dp/dV=-I/V$ At MPP (14)

$dp/dV>-I/V$ Left of MPP (15)

$dp/dV<-I/V$ Right of MPP (16)

The left hand side of equations represents incremental conductance of P-V module and the right hand side represents the instantaneous conductance. When the ratio of change in output conductance is equal to the negative output conductance, the solar array will operate at the maximum power point.

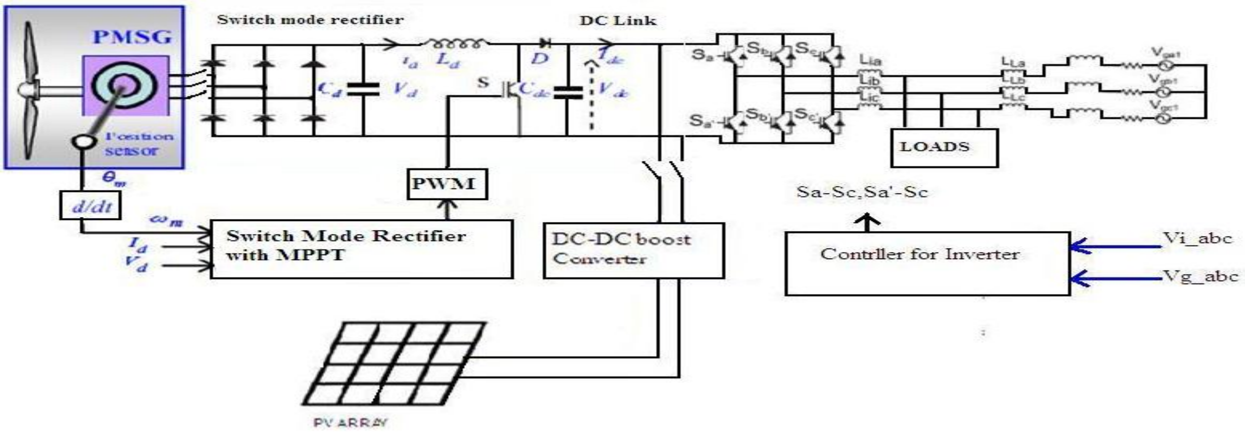

Fig 1: Control Structure of Proposed System

5. GRID SIDE CONVERTER

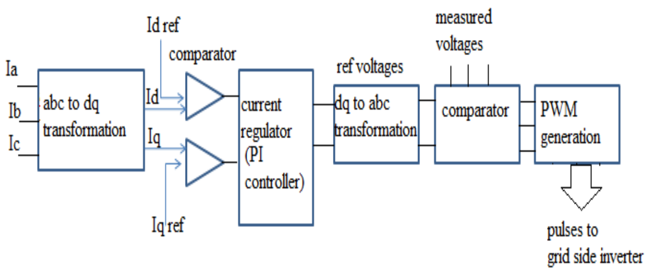

Fig 7: Block Diagram of Grid Side Converter

The grid side inverter is connected to the dc link of proposed hybrid system. The conversion unit which performs the interface functions between the dc bus and three phase ac grid followed by the L filter that transports and distributes the energy to the end user and the load. The controller provides a constant output and maintains the voltage at the point of common coupling. The inverter works in a constant current control mode to provide a constant power to the main grid. This controller provides a constant current output. In this current control, inverted output current from filter is measured and transformed into a synchronous rotating reference frame .i.e. abc transformed into dq frame. In other words, it is easier to regulate and solve the two phase variables as dc quantities [6].

Then it is compared with the reference currents. This comparison gives an error value that is fed to the current regulator to generate the reference voltage for inverter. Again dq is transformed into abc frame to produce the voltage references, then it is compared with the measured grid voltages to produce error. These voltage errors are amplified with a gain and the amplified signals are compared with the fixed frequency triangular carrier wave of unity amplitude to generate gating signals or IGBT's of the grid side inverter. [3], [7].

6. RESULTS AND DISCUSSIONS

The proposed system is simulated in MATLAB/ SIMULINK using Sim power systems tool boxes. The MPPT Control Scheme was modeled for Wind-PV and controller for grid connected inverter also developed. In order to provide Uninterrupted Power Supply (UPS) to the load .controller also enhance stability of the system. The designed controller has to efficiently operate in the hybrid system. The performance of the proposed system is depicted in the specific results shown below:

For 55kw, 4 pole PMSG based variable speed wind turbine is simulated. The output voltage is shown in fig. 8

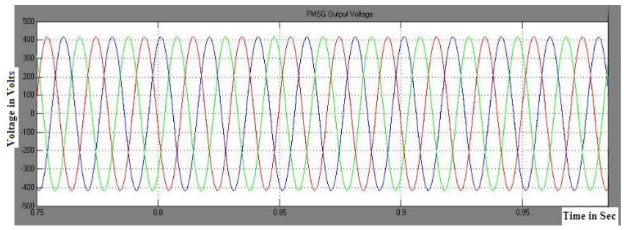

Fig 8: PMSG output voltage

The MPPT technique used for the wind turbine is based on the optimum torque tracking control which uses boost converter to maintain constant dc link voltage which is depicted in fig. 9.

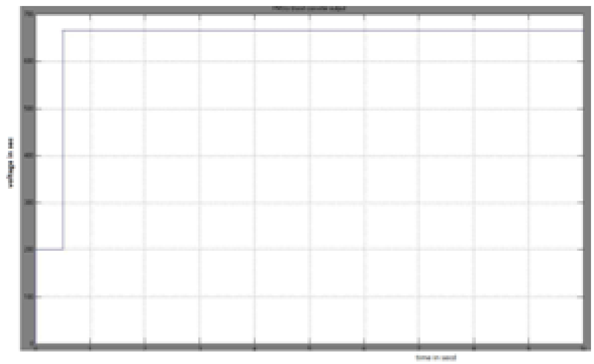

Fig 9: boost converter output voltage

Similarly boost converter is used in the PV system with incremental conductance algorithm as shown in fig. 10.

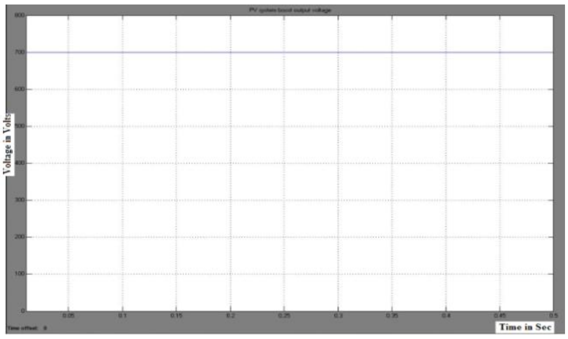

Fig 10: PV-Boost converter output voltage

A hybrid system operates either with wind or PV system alternatively. The constant DC link voltage converts to AC through current controlled grid side inverter whose voltage is shown in fig. 11.

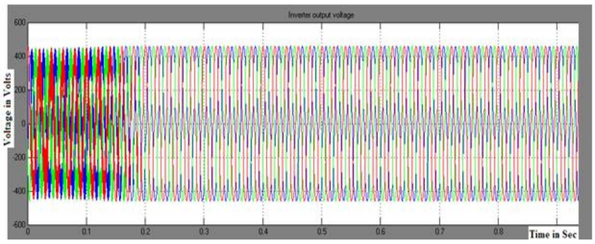

Fig 11: Grid side inverter output voltage

The load voltage for the constant load used in simulation is also shown in fig. 12.

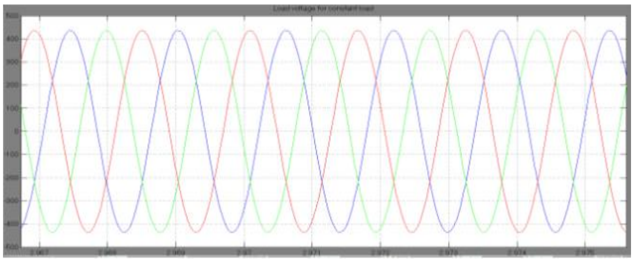

Fig 12: Load voltage at constant load

In order to analyze the performance of grid side inverter based on controlled strategy the load is reduced to 50% which is explained through load voltage in fig. 13.

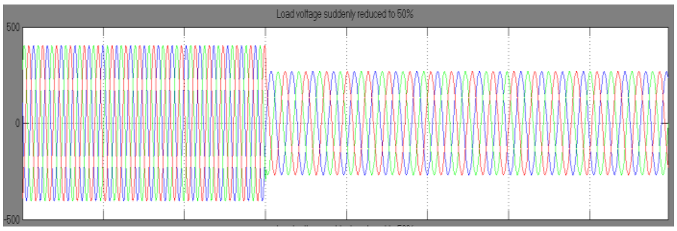

Fig 13: Load voltage is suddenly reduced to 50%

7. CONCLUSION

In this research work, the modeled hybrid distributed generation system is devised to accomplish the task of supplying uninterrupted power to meet the load demands. Most of the hybrid systems are modeled with the battery backup or diesel generator unit for reliable supply. Here we have modeled the wind and PV system because the increased efficiency due to the effective MPPT control gives assurance in reliability. In addition to the benefits mentioned, control strategy addresses the immense bottlenecks (arising due to meteorological uncertainty) in reliably coordinating different sources with the utility. In future the multi agent applications maybe developed that provides intelligence to this developed model. The multi agent systems are used to control distributed generation system in a simulated environment during various fault conditions

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