MODELING AND CONTROL OF A GRID CONNECTED WIND-PV HYBRID GENERATION SYSTEM

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MODELING AND CONTROL OF A GRID CONNECTED WIND-PV HYBRID GENERATION SYSTEM

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By

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Dedicated to my Family & Friends

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CERTIFICATE

This is to certify that the thesis report entitled "MODELING AND CONTROL OF A GRID CONNECTED WIND-PV HYBRID GENERATION SYSTEM", submitted by Ms. SANJUKTA PATEL bearing roll no. 212EE4251 in partial fulfillment of the requirements for the award of Master of Technology in Electrical Engineering with specialization in "Power Electronics and Drives" during session 2012-2014 at National Institute of Technology, Rourkela is an authentic work carried out by her under our supervision and guidance.

To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

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ABSTRACT

In electric distribution system Power control of a hybrid generation system that is wind and solar system for interconnection operation is presented in this paper. Renewable resources such as the solar wind etc offers clean, abundant energy .As the power demand increases power failure also increases so the renewable energy can be used to provide constant loads. To converting the basic circuit equation of solar cell into simplified form a model developed including the effects of changing solar irradiation and temperature. This paper consists of PMSG as a wind generator, solar array, dc-dc converter and grid interface inverter. Power control strategy is used to extract the maximum power. Maximum power point tracker (MPPT) control is essential to ensure the output of photovoltaic power generation system at the maximum power output as possible. There are many MPPT technique. In this paper perturbation & observation (P&O) method and incremental conductance (IncCond) method are used and simulated in Mat lab/Simulink. P&O method is simple in operation and hard ware requirement is less, but it has some power loss. IncCond method has more precise control and faster response, but it has higher hardware requirement. in order to achieve maximum efficiency of photovoltaic power generation, an efficient control methods that is (P&O) should be chosen. The voltage source inverter interface with grid transfers the energy drawn from the wind turbine and PV array to the grid by keeping common dc voltage constant. The simulation results show the control performance and dynamic behavior of the hybrid wind-PV system.

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ACRONYMS

V_{pv} :	Output voltage of the PV module
I_{pv} :	Output current of the PV module
T_r :	Reference temperature
T :	The module operating temperature
I_{ph} :	Photo current of the PV module
I_o :	Saturation current of the PV module
A,B :	Ideality factor
k :	Boltzman constant
q :	Electron charge
R_s :	Series resistance of the PV module
I_{SCr} :	Short-circuit current of the PV module
K_i :	Short-circuit current temperature co-efficient
λ :	Illumination of the PV module
E_{go} :	Band gap energy of silicon
N_s :	Number of series cells
N_p :	Number of parallel cells
P_m :	Mechanical power of the wind turbine
T_m :	Mechanical torque of the wind turbine
R :	Radius of the blades
w_m:	Shaft Angular velocity
λ :	Tip speed ratio of the Wind Turbine
V_s :	Input dc voltage for the boost converter
V_0 :	Output dc voltage for the boost converter
C :	Capacitance of the boost converter
V_{LL}:	Line to line voltage of the Wind Generator
k :	Duty ratio of boost converter
t_{on} :	ON periods of the boost converter
t_{off} :	OFF periods of the boost converter

ΔV_d :	Peak to peak output dc voltage of boost converter
I_d :	Output dc current from boost converter
f_s :	Switching frequency of the boost converter
T_s:	switch period of the boost converter.
V_{LL1} :	Fundamental phase to phase rms voltage on ac side
K :	Modulation index of PWM inverter
V_{dc} :	Dc supply voltage
S1,S2,S3,S4,S5,S6 :	Switches
L :	Filter inductance
C :	Filter capacitance
R :	Load resistance
i_L:	Inductor current
i_c:	Capacitor current
I_0 :	Load current
V_c:	Voltage across capacitor
V_0 :	Output voltage
T_s:	Switching period
K :	Duty cycle
Is :	Source current
V_d :	D-axis voltage
V_q :	Q-axis voltage
i_d :	D-axis current
i_q:	Q-axis current
K_i :	Gain of integral controller
w_c :	Cut-off frequency
w_o :	Resonant frequency
ρ :	Air density in kg per m^3
A :	Swept area of turbine
V_w :	Wind speed in metre per sec
C_p :	Power coefficient

CHAPTER 1

1.1 Introduction

Combined win-PV hybrid generation system utilizes the solar and wind resources for electric power generation. Individual wind and solar renewable sources have unpredictable random behavior. As throughout the day solar energy is present but due to the sun intensity and unpredictable shadows by the clouds, birds, trees etc the solar irradiation levels varies. Due to this cause solar energy is unreliable and less used.

Wind is a form of solar energy. Due to the uneven heating of the atmosphere by the sun wind flow. Due to the earth terrains, bodies of water and vegetation the wind flow patterns are modified. Wind turbine converts the kinetic energy in the wind in to mechanical then to electrical by rotating the generator which are connected internally. Wind is highly unpredictable in nature as it can be here one moment and gone in another moment but it is capable of supplying large amount of power. Due to this concept of wind energy it is an unreliable one and less used.

So it is better to use hybrid generation system which is better than individual wind or individual PV generation system. So it is overcome the demerits of individual system. Grid interface of hybrid generation system improves the system reliability.

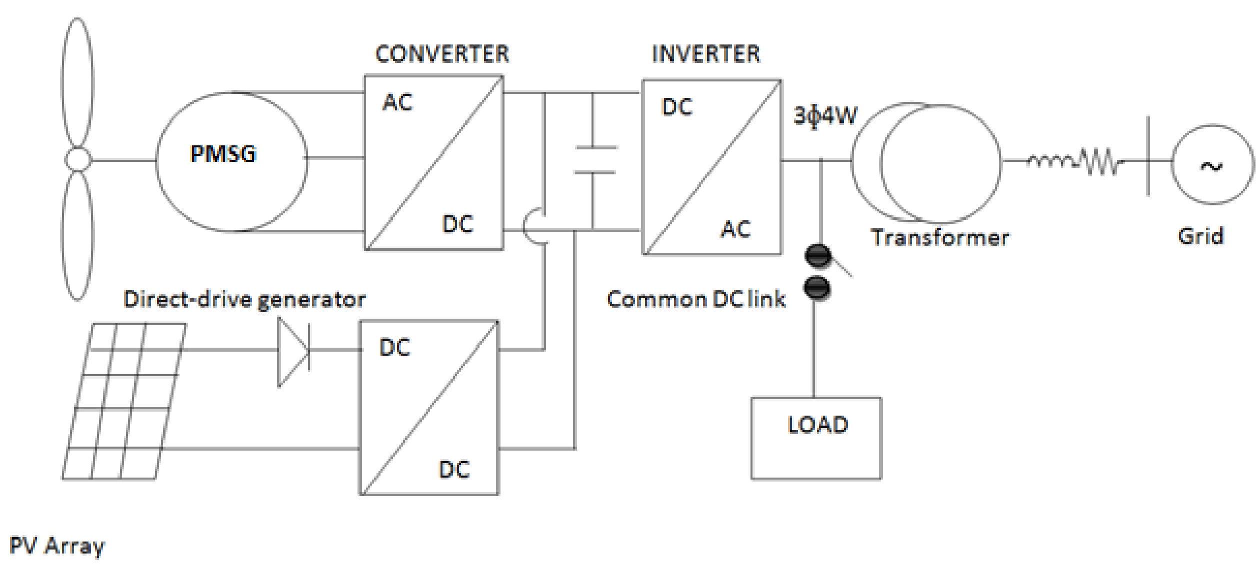


Fig. 1.1system representing Grid-connected hybrid wind/PV

In this system there is a wind turbine, the output of the wind turbine goes to permanent magnet synchronous generator. The output of the wind system is in ac so we need ac to dc converter to convert the ac output in to dc .Similarly in the PV side the output of the PV array is connected with a dc-dc boost converter to rise the output voltage up to a desire level. And the output of PV and wind are connected with a common DC link voltage. The common DC link voltage will be connected with the DC to AC converter and the output of the inverter is synchronizing with grid. This inverter changes DC power from PV array and the wind turbine into AC power and it maintain the voltage and frequency is equal to the grid voltage and frequency.

1.2 Literature Review

N. Pandiarajan and RanganathMuthu presented a paper in which the mathematical equation of the PV sell is presented in a sequential manner. A single diode model is taken in to account and all the mathematical equation are presented step by step using the matlab/simulink software. A single module having 36 numbers of series cell and single parallel cell with a capacity of 36 watt power is chosen and by using the software the I-V and P-V curve with different irradiation and temperature will be plotted.

Swul-KI Kim, Eung-Sang Kim, Jong-Bo Ahn In this paper a hybrid generation system is representated. That is wind and solar system are connected together to form a hybrid system .after that this system is synchronize with grid for distribution purpose. In this system there is a wind turbine, the output of the wind turbine goes to permanent magnet synchronous generator. The output of the wind system is in ac so we need ac to dc converter to convert the ac output in to dc .Similarly in the PV side the output of the PV array is connected with a dc-dc boost converter to rise the output voltage up to a desire level. And the output of PV and wind are connected with a common DC link voltage .The common DC link voltage will be connected with the DC to AC converter and the output of the inverter is synchronize with grid. This inverter changes DC power from PV array and the wind turbine into AC power and it maintain the voltage and frequency is equal to the grid voltage and frequency.

Ling Lu, Ping Liu presented a paper in which Photovoltaic model is simulated, and the different output characteristics with different MPPT technique are describe.. Two different algorithms that is P&O MPPT algorithms and incremental conductance method is describes very clearly and simulated using mat lab/Simulink. After that it compare the result of both the method and conclude that both methods are used for the maximum PowerPoint tracking. The P&O method is easier then Inc Cond method ,also the hardware requirement is less in P&O method but there is some loss whereas Inc Cond method gives better result than P&O but hardware requirement is more. So according to the requirement proper MPPT technique will be chosen.

Sibasish Panda, Anup Kumar Panda and H.N Pratihar presented a paper in which A 3.5 kW output power from the PV array is synchronize with the grid. MPPT algorithm used in this paper perturb and observe (P&O)because of its simplicity. The software used here is Matlab/Simulink. From the simulation result it is observed that with MPPT the power fed to the inverter from PV array has increased by 14%. Phase locked loop is used for grid synchronization which effectively synchronizes the inverter voltage and frequency with the grid voltage and frequency. In case of fault it is observed that to become stable at nominal frequency it takes only 0.2 sec for the system. Various fault analysis that is LL, LG, LLL, LLG on grid side has been performed.

Teenajacob and Arun S presented a paper in which combined solar and wind energy system with a convertor technology is presented which used CUK and SEPIC converter in the design. This new topology overcomes the drawback of other normal converter. According to the topology more than one source is supply to the load. Depending on the availability of the energy sources the sources are separately or simultaneously supplied. From The hybrid generation system a output voltage is obtained which is the sum of the CUK and SEPIC converter to model the PV panel, DC-DC converter, wind turbine matlab/simulink software is used. This system has lower operating cost.

Munish Kumar and Mukhtiar implemented the model of a grid connected photovoltaic system. The system consists of a simple model of photovoltaic array, grid connected inverter and MPPT with boost converter. In this paper P&O method of MPPT control and DC voltage control loop with current control loop method is used.

Kun Ding, XinGaoBian, HaiHao Liu and Tao Peng presented a paper in which Metlab/Simulink software is used for PV model which control includes a control S-function builder and the current source. For every PV module the parameter of irradiance and temperature are set independently. With different irradiance and with varying temperature it is observed that the MPPT will be working properly. Under various conditions by using the software it will be possible to plot the I-V and P-V curve.

Dezso Sera, Laszlo Mathe and TamasKerekes presented that the P&O and INC are largely identical under both static and dynamic conditions. Both the MPPT are based on the same mathematical relation of the derivative of power with voltage and found that the INC neglects the second order term in the discrete differentiation of the power. Under both static and dynamic conditions, the differences between the two MPPT trackers are within the statistical variations among successive tests of the same method. Finally it is concluded that the INC is not treated as a separate MPPT but as a specific implementation of the P&O algorithm.

C.N.Bhende,S.Mishara and S.G.Malla presented a paper in which a stand-alone system with variable speed wind speed having PMSG as a wind turbine is described. The wind generator used here is a Permanent Magnet Synchronous Generator. The output voltage of the inverter has maintained constant at rated value by maintaining the voltage across the capacitor to be constant. Controlling the modulation index the common DC link voltage is maintained to be constant. The software used here for the simulation model of the PMSG is Matlab/Simulink.

1.3 Research Motivation

- Grid connected hybrid wind-solar generation system is one of the burning research field now a days.
- Wind energy is the cheapest form of renewable energy and PV offers added advantage over other renewable source because they produces no noise and require least maintenance.
- Combination of solar and wind power source provide prudent form of power generation.
- The challenge to implement the project and the new research area of study were the motivations of the project.

1.4 Thesis Objectives

- The basic objective of this paper is to extract maximum power and to maintain power quality to a satisfactory level from the varying condition of the wind as well as from the Photovoltaic array with different solar irradiation.
- To capture the maximum power from the PV system, maximum power point tracking is applied& for wind turbine to capture maximum power variable speed control technique is used.

1.5 Thesis Organization

CHAPTER-1

This chapter deliberates about outlines about solar and wind system, literature review, motivation and objective organization of the thesis.

CHAPTER-2

This chapter deliberates about Solar cell, modeling of a solar cell, effect of output with the Variation of Solar Irradiation and temperature.

CHAPTER-3

This chapter deliberates about Boost converter and different modes of operation that is charging and discharging mode of operation of boost converter.

CHAPTER-4

This chapter deliberates about different Maximum power point tracking algorithms, comparison between Perturbation observation (P&O) method and Incremental conductance method, Flow Chart of (P&O) Algorithms, flow Chart of Incremental Conductance Algorithms.

CHAPTER-5

This chapter deliberates about the details of wind turbine and permanent magnet synchronous generator.

CHAPTER-6

This chapter deliberates about the Control Strategy, Modeling of 3-Φ Voltage source inverter and a details of Phase locked loop, abc to dq transformation, LC Filter, pulse width modulation.

CHAPTER-7

This chapter deliberates about the simulation result and discussion.

CHAPTER-8

This chapter deliberates about the Conclusion and suggestion for future work and References.

CHAPTER 2

2.1 Solar Cell

In PV panels solar cells are the basic components and it is made of silicon. A solar cell is generally a p-n junction which is made of silicon. It is made up of two different layers when a smaller quantity of impurity atoms added to it. A PV system convert's sunlight in to electricity and the PV cell is basic device of the photovoltaic system. No of Cells are combined and grouped to form PV panels or modules. No of PV Panels can be grouped to form large photovoltaic arrays. The solar arrays are the combination of number of cells connected in series or in parallel or the combination of a group of panels.

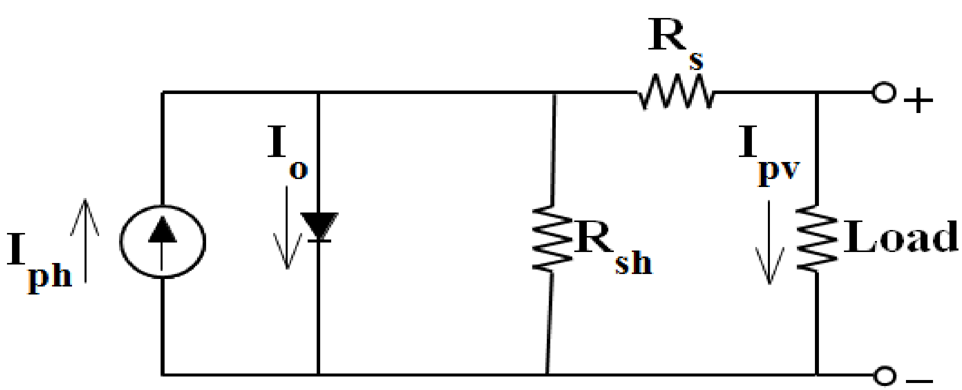
Day by day conventional source of energy are diminishing fast, with rise in cost. Again the large use of conventional fissile fuels which are the primary source of energy causes the savior environmental pollution. Due to the possible solution to the environmental problem renewable energy offers a promising alternative source. Also renewable energy supply power to the remote communities where main electrical grid is absent .Photovoltaic generation system has many merits such as less maintenance, noise free and pollution free so it's becoming increasingly important as a renewable source. Solar panel is used in PV system to convert sunlight into electricity and provide energy to the consumer or feed power to the grid.

There are many stages are used in grid connected PV system like PV array, DC to DC converter, DC to AC converter. In this paper a model is developed through converting common circuit equation of solar cell in to simplified form including the effects of changing solar irradiation and changing temperature. In this paper a control approach for interfacing the PV array with DC-DC converter.

The power injected into the grid from the PV panel through two stages. In first stage in order to enhance the DC voltage level of PV panel the PV array is connected to the DC-DC converter. And MPPT is used to track the maximum power point in order to achieve the maximum power point. In second stage through grid connected inverter control dc power is converted into ac power. Also this control control the current and power injected from the grid.

2.2 Modeling of a Solar Cell

PV array are formed by combine no of solar cell in series and in parallel. A simple solar cell equivalent circuit model is shown in figure. To enhance the performance or rating no of cell are combine. Solar cell are connected in series to provide greater output voltage and combined in parallel to increase the current. Hence a particular PV array is the combination of several PV module connected in series and parallel. A module is the combination of no of solar cells connected in series and parallel.



Fg.2.1 Circuit diagram of a single PV cell

Photo-current of the module:

$$I_{ph} = [I_{scr} + k_i(T - 298)] * \lambda/1000$$

Reverses saturation current of the module:

$$I_{rs} = I_{scr}/[\exp{(qV_{oc}/N_s kAT)} - 1$$

Saturation current of the moduleI_0:

$$I_o = I_{rs}[\frac{T}{T_r}]^3 \exp{[\frac{qE_{go}}{BK}\left\{\frac{1}{T_r} - \frac{1}{T}\right\}]}$$

The current output of PV module:

$$I_{pv} = N_p \times I_{ph} - N_p * I_o[\exp\left\{\frac{q * V_{pv} + I_{pv}R_s}{N_s AKT}\right\} - 1]$$

This equation is used to simulate in mat lab/Simulink and the result shows the nonlinear characteristics of photovoltaic array at different irradiations and temperature.

Table 1 : Solar Module (36 W) Specification	
Rating	37.08 W
Current at Peak	2.25 A
Voltage at Peak	16.56 V
Short circuit current	2.55 A
Open circuit voltage	21.24 V
Total number of cells in parallel	1
Total number of cells in series	36

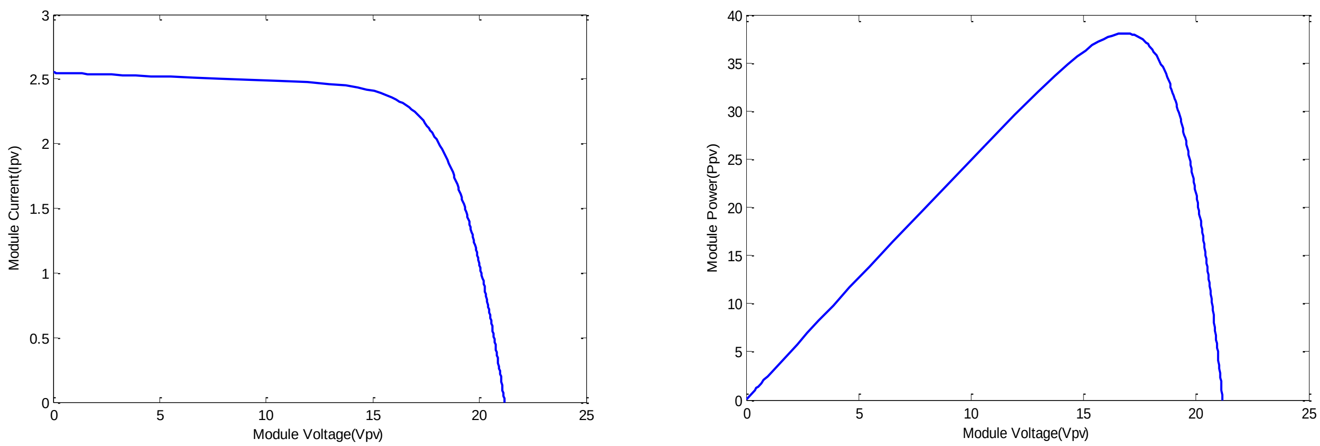


Fig.2.2V-I & P-V Characteristics of a 36w PV module

2.3 The Effect of Different Solar Irradiation.

The Voltage vs Power characteristics and Voltage vs Current characteristics of a solar cell are mainly dependents upon the solar irradiation. If there is change in the environmental condition then the solar irradiation level change which results different maximum power. So maximum power point tracking algorithm are used to maintain the maximum power constant if there is any change in the solar irradiation level. If the solar irradiation level is higher, then the input to the solar sell is more which results more magnitude of the power with the same voltage value. Also when there is increase in the solar irradiation the open circuit voltage increases. Because, when there is more solar light fall on the solar cell, with higher excitation energy the electrons are supplied, they increase the mobility level of electron and more power is generated.

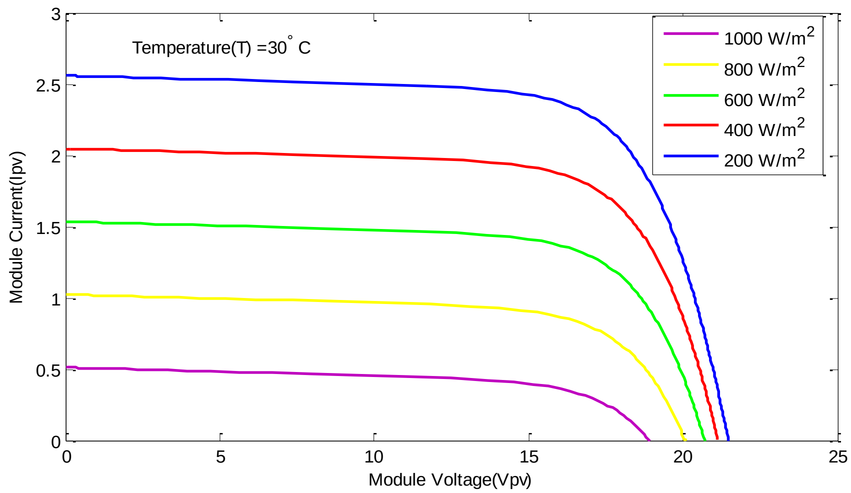


Fig.2.3 V-I characteristics with different irradiance

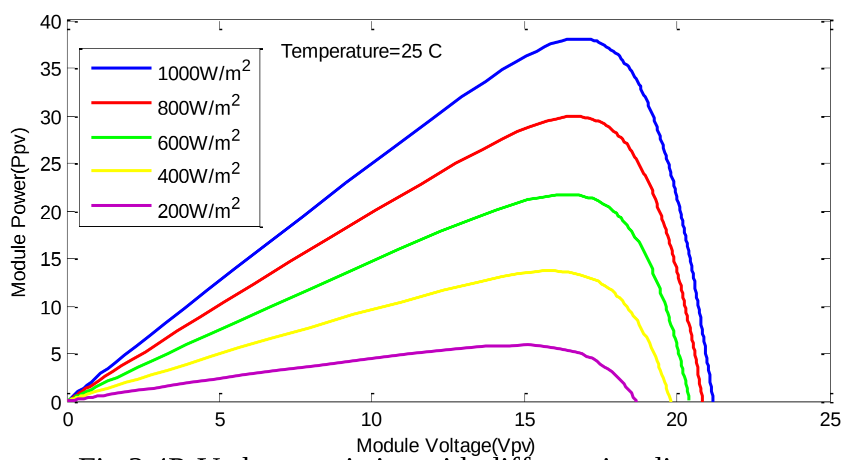


Fig.2.4P-V characteristics with different irradiance

2.4 Temperature variation effect of the PV module.

According to the variation of temperature also the output of the PV cell very. When the temperature of the solar cell increases the power generation capability also change which is an undesirable feature. With the increase in temperature the open circuit voltage decreases which results increase in the band gap so more energy is required to cross the barrier. As a result the solar cell decreases its efficiency.

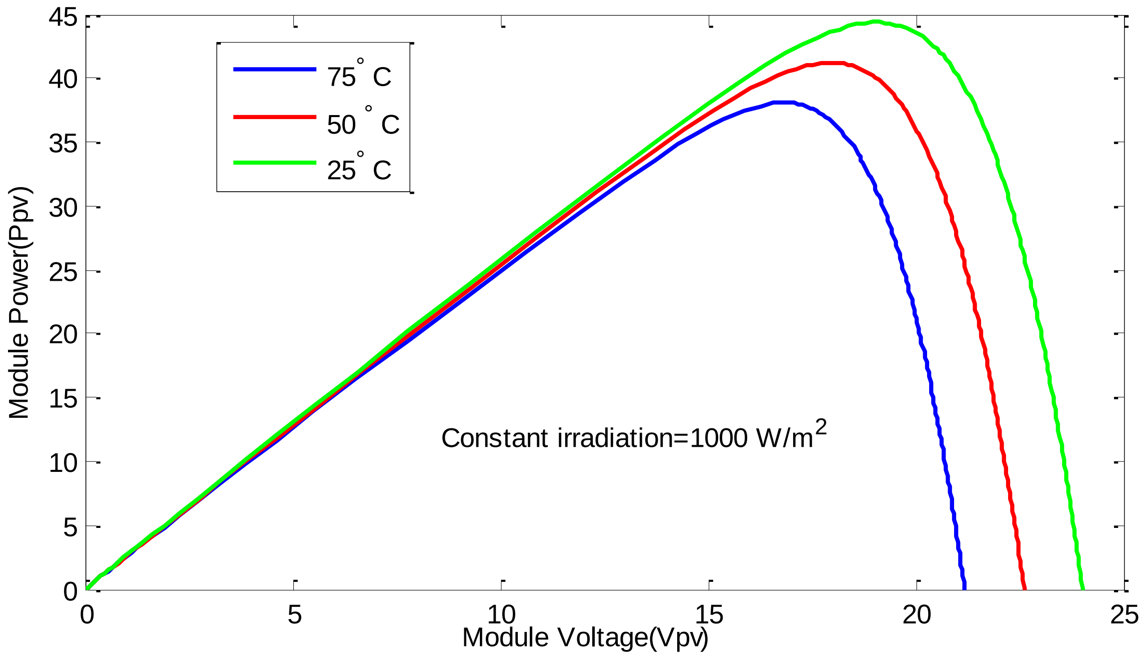


Fig.2.5 P-V characteristics with different temperature

CHAPTER 3

3.1 Boost Converter

DC-DC Converter is advice that accepts a dc input voltage and produce a desired dc output voltage. The output produce is at a different voltage level then the input. There are three types of DC-DC converters that are buck, boost and buck-boost Converter and hear in this Boost converter is used to step up the PV output. Also DC-DC converters are used to provide noise isolation and power bus regulation.

In general transformer is used to step up the voltage, but there is some losses in the transformer. To overcome these problems DC-DC converter is used to get a desired output .It consists of a inductor, capacitor diode and a IGBT as a high frequency switch .Due to this type of arrangement power supply to the load at a greater voltage. According to the duty cycle of the switch the output voltage change.

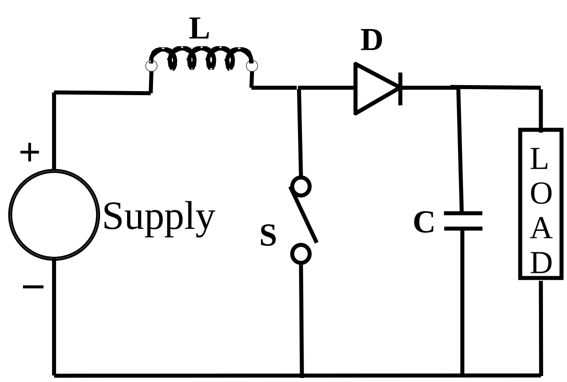


Fig.3.1 Circuit diagram of a boost converter

3.2Modesof Operation

There are two operating modes for the DC-DC converter, and the mode of operation depends up on the short circuiting and opening of the high frequency switch. When the switch is closed, the inductor will charge. This is mode-1 operation and is known as charging mode. Similarly in the second mode the switch is open and the inductor start discharging which is known as the discharging mode.

3.2.1 First Mode Operation

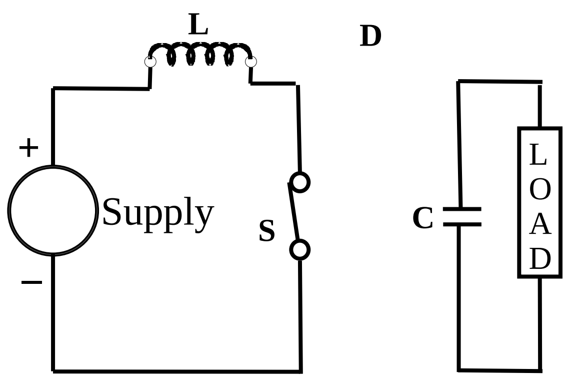


Fig.3.2 first mode operation

In the first mode the IGBT is closed and the inductor start charging due to the supply trough the switch.. Diode used in this circuit to restrict the current flow to the load and the output voltage rises by the discharging of the capacitor.

3.2.2 Second Mode Operation.

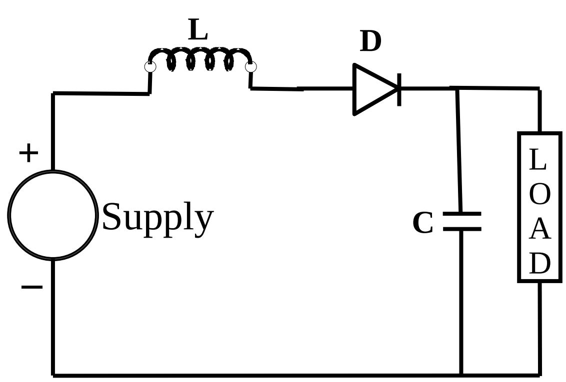


Fig.3.3 second mode operation

In the second mode of operation, the IGBT which is used as a high frequency switch is open so the diode become short circuited. From the first mode there is some energy stored in the inductor now that is discharges through the capacitor. The load current variation is assumed constant throughout the operation because it is very small in many cases.

3.3Waveforms

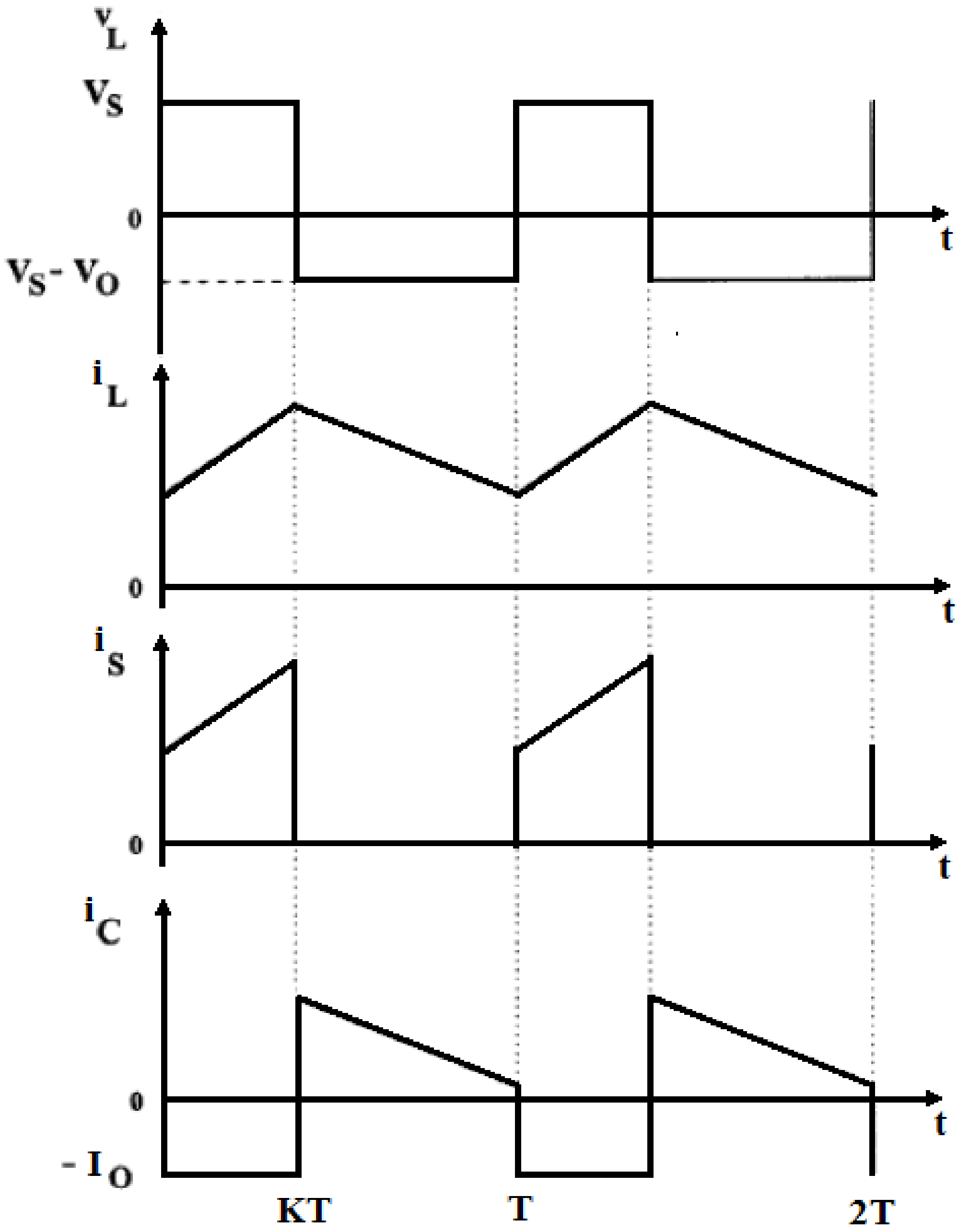


Fig.3.4Waveforms of boost converter

3.4 Mathematical equation of boost converter

From the figure at time $t_1$the inductor current rises linearly from I_1 to I_2 , then

$$V_s = L\,\frac{I_2 - I_1}{t_1} = L\,\frac{\Delta I}{t_1}$$

$$t_1 = \frac{\Delta I L}{V_s}$$

When the inductor current falls linearly from I_2 to I_1 in time t_2

$$V_s - V_a = -L\,\frac{\Delta I}{t_2}$$

$$t_2 = \frac{\Delta I\ L}{V_a - V_s}$$

$$\Delta I = I_2 - I_1$$

$$= \frac{(V_a - V_s)t_2}{L}$$

Substituting $t_1 = kT$ and $t_2 = (1-k)T$

$$V_a = \frac{V_s}{1-k}$$

$$k = 1 - \frac{V_s}{V_a}$$

Similarly for a lossless circuit$V_s\, I_s = V_a I_a$

Then peak to peak ripple current:

$$\Delta I = \frac{V_s(V_a - V_s)}{f L V_a}$$

$$= \frac{V_s k}{f\ L}$$

the peak to peak ripple voltage:

$$\Delta V_c = \frac{I_a(V_a - V_s)}{V_a\ f\ C} = \frac{I_a k}{f\ C}$$

CHAPTER 4

4.1 Maximum Power Point Tracking (MPPT)

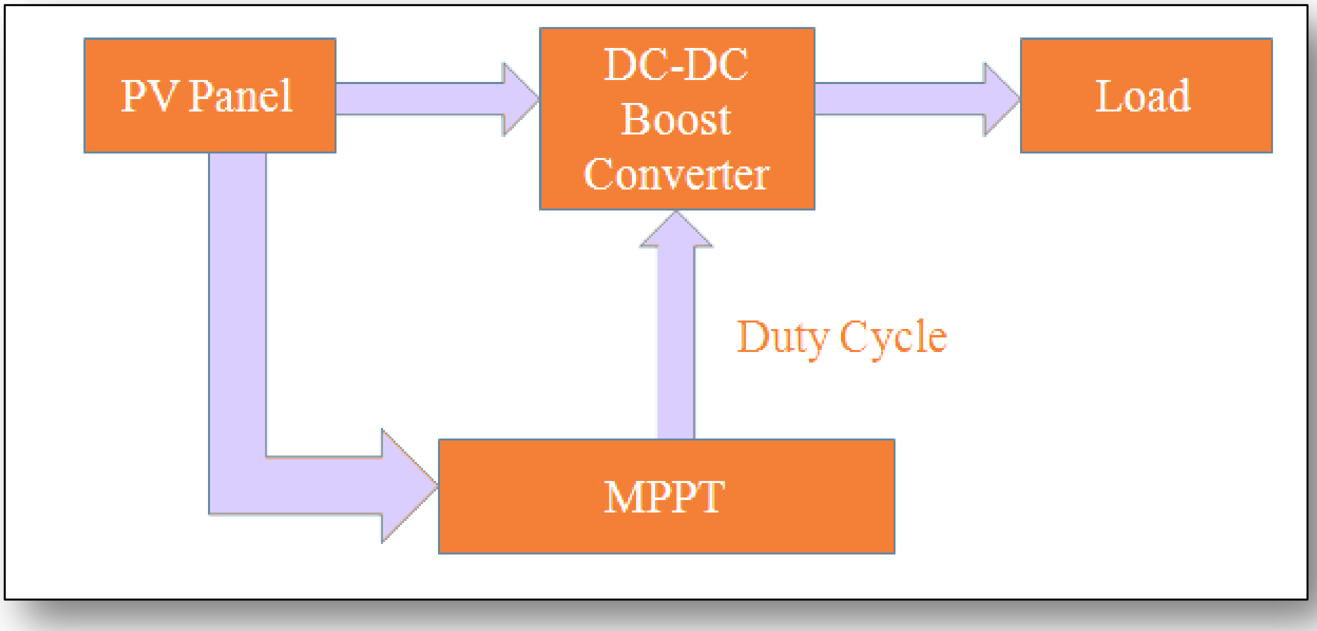


Fig.4.1 Circuit Arrangement of MPPT

In solar panel peak power is archived with the help of a DC-DC boost converter and it is used in between the PV generator and the load by adjusting the duty cycle. Maximum Power Point of a solar module varies with the variation of irradiation and temperature So MPPT algorithms are necessary in PV applications because by the use of MPPT algorithms it obtain the peak power from the solar panel. Previously there are different methods to find the MPP have been published and developed. According many aspects these techniques differ such as required sensors, complexity, range of effectiveness, according to speed, cost, if there is change in irradiation and temperature than also the effectiveness of tracking, requirement of hardware and its implementation. 19 different MPPT algorithms are there among these techniques, the Incremental conductance algorithms and the P&O algorithms are generally used. This is easy to use and simple in operation and required less hardware as compare to other. When there is more than one MPP other MPPT technique are used and it appeared generally when the PV array is partially shaded.

4.2 Perturbation Observation (P&O) Method

According to the change in power the perturbation direction is taken into account. If there is change in power which is positive than the voltage will increase in the right hand side direction similarly if it is negative or decreases than the voltage perturbation will in the opposite that is left ward direction. So the direction of the perturbation is decided whether the voltage at present is higher than voltage at previous one, accordingly due to this change in power control signal of the PWM can be calculated. According to this algorithm, overshoot appear in the starting and slowly decrease till it reaches a stable steady state. The control action will stop only when the output power reach its maximum values.

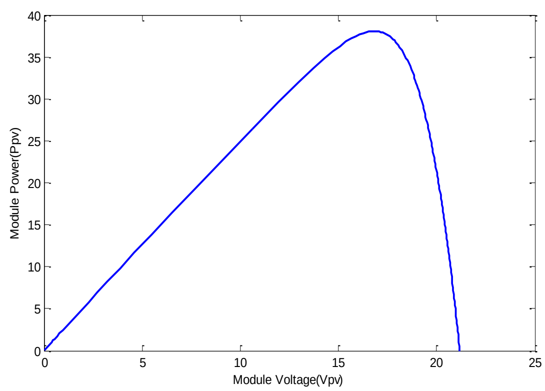


Fig.4.2 PV Curve of the solar module

From the flowchart it is summarized that:

When $dp > 0$ and $dv > 0$, that's means power is in the left side of the maximum power point therefore increase the voltage, similarly when$dp < 0$ and $dv > 0$ power is right side of the maximum power point and therefore decrease the voltage. At $dp = 0$ that is the maximum power point.

4.3 Flow Chart of (P&O) Algorithms

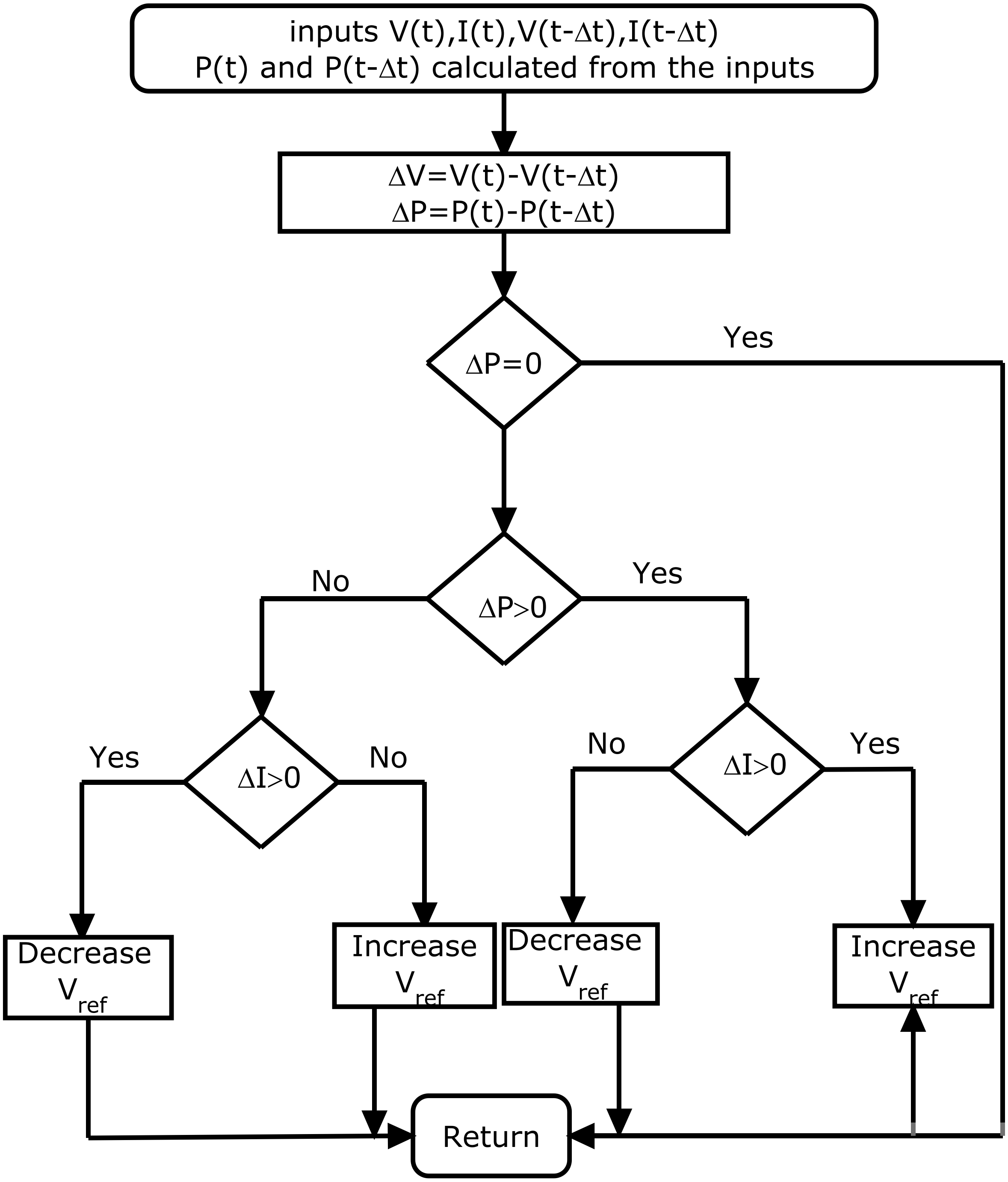


Fig.4.3 Flow Chart of (P&O) Algorithms

4.4 Incremental Conductance Method

This is also a common Maximum Power Point Tracking algorithm. According to this method from the P-V characteristic curve there is a single peak value and the maximum power point exist where

$$\frac{dP}{dV} = 0$$

We know that $P = V \times I$

According to Inccond method

$$\frac{dP}{dV} = \frac{d}{dV}(V \times I) = 0$$

$$= I + \frac{dI}{dV} = 0$$

That is

$$\frac{dI}{dV} = \frac{-I}{V}, \text{this is the MPP}$$

$$dP = P(k) - P(k-1)$$

$$dI = I(k) - I(k-1)$$

$$dV = V(k) - V(k-1)$$

$$= V(k)I(k) - V(k-1)I(k-1)$$

Where k is for present condition and $(k-1)$ is for previous condition.

If

$$\frac{dI}{dV} < \frac{-I}{V}$$

Then the operating point is at the right hand side of the MPP, and in this condition the output voltage of the PV should be reduce. Similarly if

$$\frac{dI}{dV} > \frac{-I}{V}$$

Then the operating point is at the left hand side of the MPP, and in this condition the output voltage of the PV should be increase.

From the above we can summarize that

when$V = V_{max}$,then

$$\frac{dI}{dV} = \frac{-I}{V}$$

when $V > V_{max}$

$$\frac{dI}{dV} < \frac{-I}{V}$$

When $V < V_{max}$,then

$$\frac{dI}{dV} > \frac{-I}{V}$$

According to the relationship between $\frac{dI}{dV}$ and $\frac{I}{V}$ Operating voltage can be adjusted and maximum power point can be achieved.

4.5 Comparison of Two MPPT Techniques

Both the MPPT methods that is P&O and IncCond methods are used for maximum PowerPoint tracking. The Porter and Observer algorithm is simple in operation and required less hardware as compared to other but in this method the power loss is little more as compared to the other Method due to the output of the PV array oscillate around the MPP. Similarly the Incremental Conductance Method has better control and smaller oscillation but the hardware requirement is more. The Incremental Conductance Method achieve its steady state value earlier than P&O method. There are many merits and demerits of the two methods. Therefore all the features should be taken into account to choose a better control algorithm. In this project for comparing these two algorithms three series model and six parallel models is taken and simulated in Matlab/Simulink. From the simulation result it is observed that both the method give nearly same result. So the P&O method is chosen for the grid synchronization purpose because of its simplicity and easy implementation.

4.6 Flow Chart of Incremental Conductance Algorithms

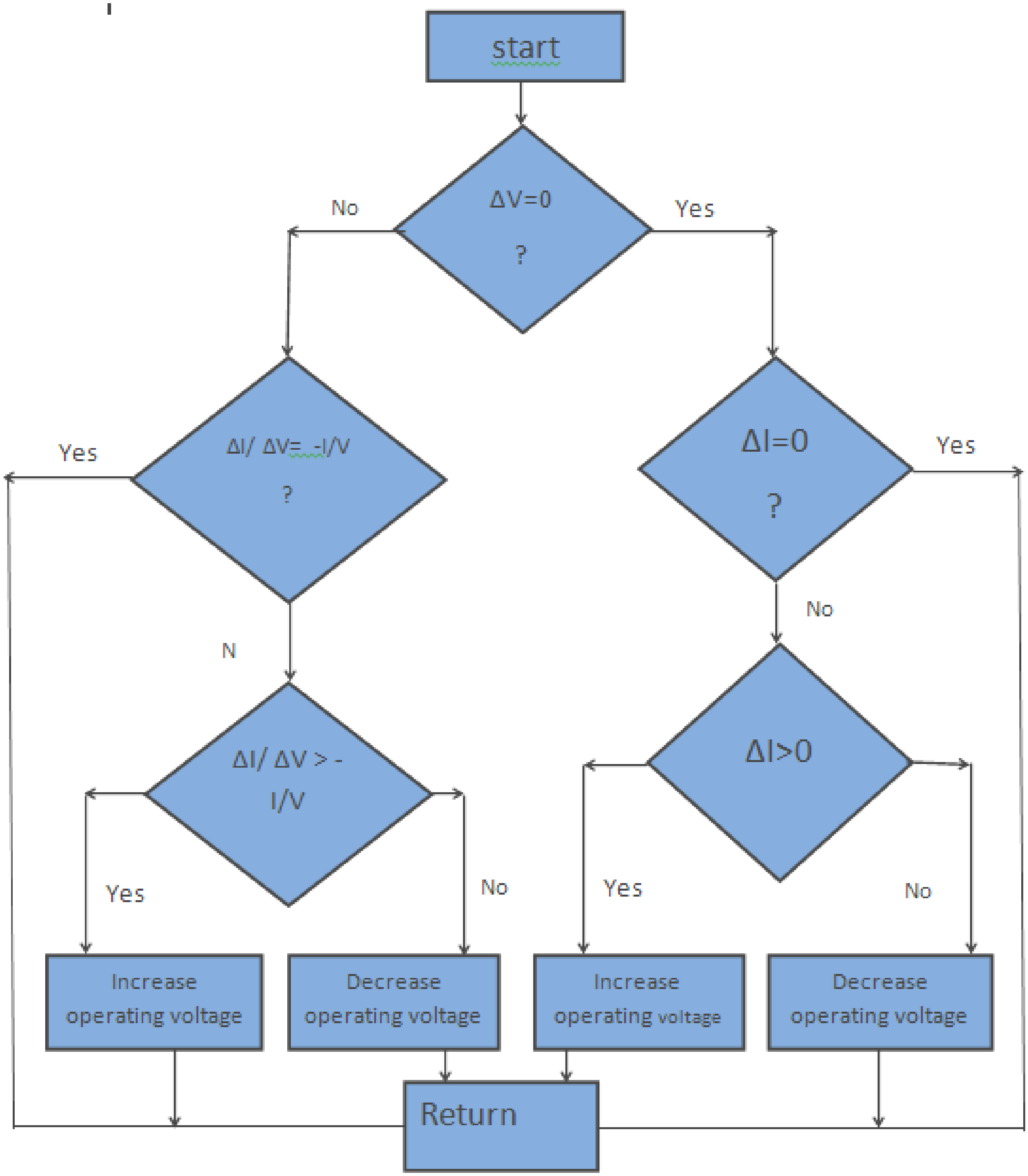


Fig.4.4Flow Chart of Incremental Conductance Method

CHAPTER 5

5.1 Wind Turbine

Wind is a form of solar energy and it is available everywhere. Always wind blows from a higher atmospheric pressure regionto the lower atmospheric pressure region due to the non uniform heat by the sun and due to the rotation of the earth. In other wards we can say that wind is a form of solar energy available in the form of that kinetic energy of air.

Wind energy can change into many form of energy, such as wind turbine is usedto generate electricity, mechanical power windmills for water lifting wind pumps, also in propelling ships. Wind energy is capable of supplying large amount of power and the total amount of obtainable power available from the wind is considerably more than the present human power used from all the sources. Wind power is an alternative of fossil fuels, is plenteous, widely expanded, clean, and renewable and during operation no greenhouse gas produced. Wind power is the fast growing source of energy.

Day by day, the development of the wind energy improving and if it is use properly then it is capable to fulfill the growing demand of the consumer, also growing of the force acting on blades moving through air. There is also development of turbines with two or three blades. For successful electricity generation high speed and high efficiency of turbines were the necessary conditions.

By using the power of the wind wind turbines produce electricity by drive an electrical generator. Amoving force is exerted and generates lift when wind is passing over the blades. The rotating blades rotate the shaft which is connectedwith the gearbox. The gearbox adjusts the rotational speed which is convenient for the generator to get a desired output. The output of the wind generator is fed to the transformer which converts the electricity of the generator up to 33 kv.Which is the appropriate voltage for power system.

From the swept area of the blades a wind turbine extracts kinetic energy. So the power contained in the wind is given by the kinetic energy of the flowing air mass per unit time.

$$P_0 = \frac{1}{2}(air\ mass\ per\ unit\ time)(wind\ velocity)^2$$

$$= \frac{1}{2}(\rho A V_w)(V_w)^2$$

$$= \frac{1}{2}\rho A {V_w}^3$$

The above equation is for power available in the wind, but it is different from power transferred from the wind turbine. The power available and the power transformisdifferent by the factor of power coefficient. So the aerodynamic power generated by wind turbine is given by

$$p = 0.5\rho A c_p {V_w}^3$$

Where

$$\rho = Airdensity(kg/m^3)$$

$$A = sweptareaofturbine$$

$$V_w = windspees(m/sec)$$

$$C_p = powercoefficient$$

$$C_p\left(\frac{\lambda}{\beta}\right) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{-\frac{C_5}{\lambda_i}} + C_6\lambda$$

With,

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

Where,

$$C_1 = 0.5176, C_2 = 116, C_3 = 0.4, C_4 = 5, C_5 = 21, C_6 = 0.0068$$

Some terms frequently used in the wind energy are

5.1.1 Solidity

Solidity is defined as the ratio of the projected blade area to the area of the wind intercepted. The projected blade area is equal to the area projected in the direction of the wind. With torque and speed solidity has direct relationship. High solidity rotors are suitable for pumping water because it has high torque and low speed. Low solidity rotors are suitable for electrical power generation because it has high speed and low torque.

5.1.2Tip Speed Ratio, λ

TSR of a wind turbine is defined as

$$\lambda = \frac{W_T R}{V_w}$$

$$= \frac{2\pi R N}{V_w}$$

Where

$$\lambda - Non\ dimensional$$

$$W_T = Rotational\ speed\ of\ the\ wind\ turbine$$

$$R = Radius\ of\ the\ wind\ turbine.$$

$$N = rotational\ speed\ inrevolutions\ per\ second$$

5.1.3 Power coefficient

In wind energy converter Power coefficient(C_p) is defined as

$$C_p = \frac{\text{power output from thewind machine}}{\text{the power contained in wind}}$$

The power coefficient is differ from the wind machine because there are losses in the mechanical transmission and electrical generation.$C_p$has no dimension and can be used to describe the preference of the size of the rotor.

5.2 Characteristics of wind turbine

Mechanical power transfer to the shaft is equal to

$$P_m = 0.5\rho A c_p {V_w}^3$$

Where power coefficient(C_p) is a function of pitch anglè β and tip speed ratio λ. The characteristics curve show the detail behavior of mechanical power extract from the wind and the rotor speed at different wind speed.

Fig shows the curve between power coefficients $C_p$and tip speed ratioλ at a pitch angle=0^0,from the curve we shows that for any value of wind speed power coefficient reaches a maximum value(C_p) of 0.48 for a maximum tip speed ratio (λ) of 8.1.

In prime mover it is very important for properly matching the load and ensuring stable operation of the electrical generator when we study torque versus rotational characteristics. The relationship between Torque and power is:

$$T_m = \frac{P_m}{\omega}$$

Using optimum value of$C_p$and , the torque change in to

$$T_{max} = 0.5C_{p-opt}\pi(\frac{R^5}{\lambda_{opt}^3})\omega^2$$

From the curve we can find out that at any wind speed the torque is it's maximum value at a definite rotational speed, and it varies as the square of the rotational speed. The torque can vary as the square of the speed by choosing the load properly because load torque depends on the electrical load.

Table 2 : Wind Turbine Specification	
Rating	10 kW
Diameter	8 m
Number of blades	3
Cut in speed of wind	3 m/s
Cut out speed of wind	25 m/s
Rated Wind speed	10 m/s
Air density	1.225 kg/m^3

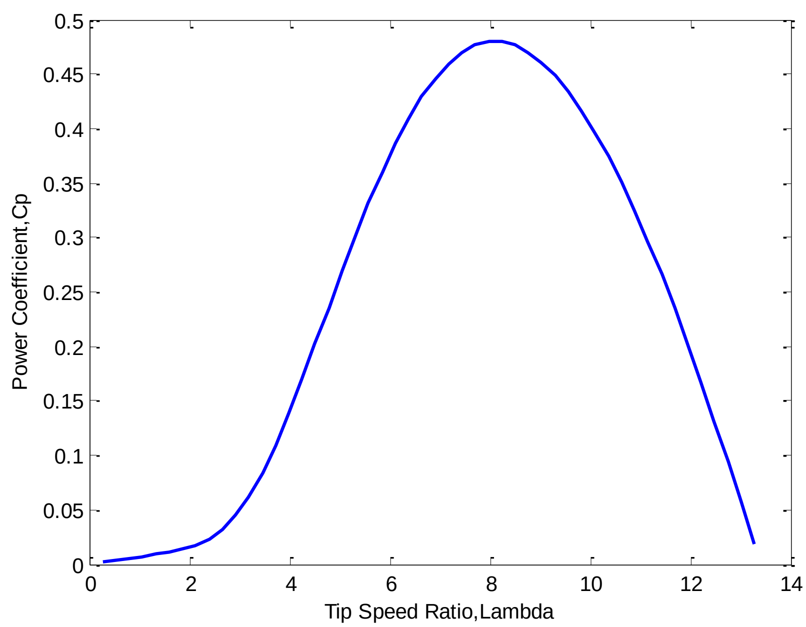


Fig.5.1 Characteristics of $C_p$vsλ curve

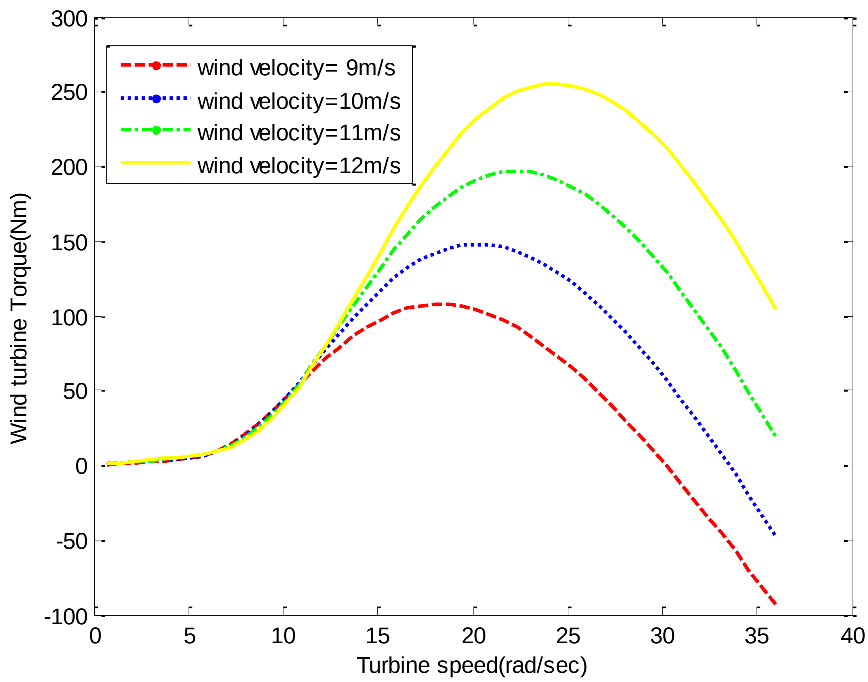


Fig.5.2 Characteristics of torque vs speed with different wind speed

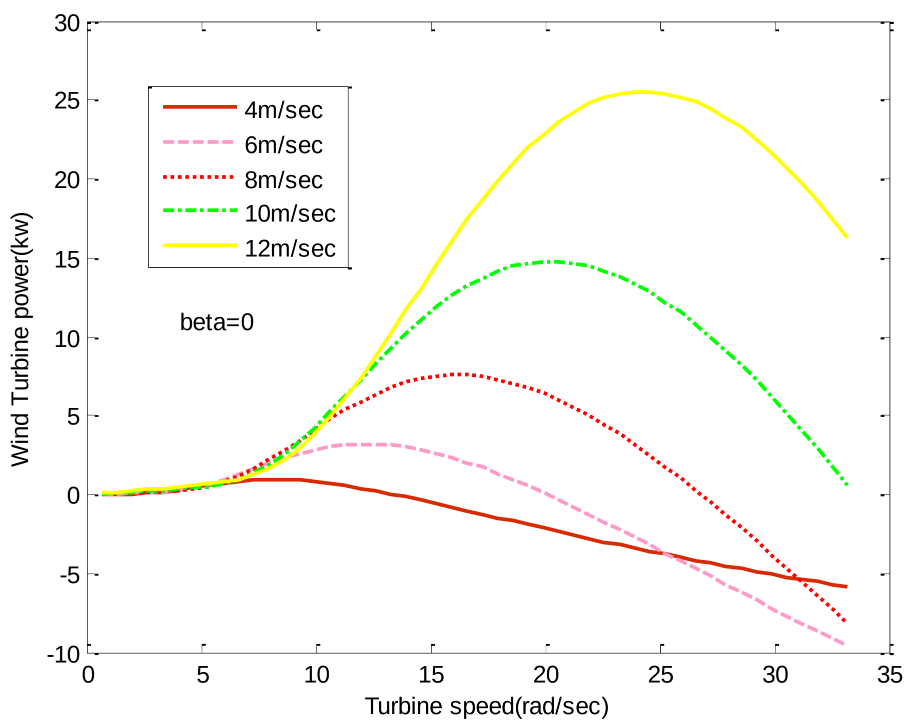


Fig.5.3Characteristics of power vs speed with different wind speed

5.3 Permanent Magnet Synchronous Generator

Variable speed wind turbine are popular due to their capability to capture maximum power from the wind. It is possible due to maximum power point tracking algorithm. and improved efficiency. Now days the doubly feed induction generator (DFIG) is used as a variable speed wind turbine. This required a gear box for matching the wind turbine speed and the wind generator rotor speed. The gear box requires regular maintenance and many times suffer from faults making the system unreliable. To solve this problem permanent magnet synchronous generator (PMSG) is used because it is a self-excited machine and It has high power factor and good efficiency. To maintain the output AC voltage at a constant magnitude and frequency a AC to DC wind side converter and a DC to AC voltage source inverter is used. The common DC linked voltage (V_{dc}) is directly affected if there is any change in wind speed or load. The output voltage of the system is constant if the DC linked voltage is maintained at a constant level.

The relation between dc voltage and the output ac voltage is given by

$$V_{LL1}=\frac{\sqrt{3}}{2\sqrt{2}}kV_{dc}$$

Where

k =Modulation index of PWM inverter = 1

V_{LL1}=Fundamental phase to phase rms voltage on ac side

V_{dc}=dc link voltage

For Grid synchronization the frequency and the magnitude of output voltage is maintain at a specified level by adjusting the modulation index of the PWM inverter.

For Grid synchronization purpose the output frequency and magnitude of the inverter is equal to the grid. For these purpose phase locked loop is used. The DC to AC Voltage Source Inverter (VSI) supply reactive power to the grid when voltage support is required.

CHAPTER 6

6.1 Control Strategy

The Complete Control Strategy to connect the PV system with Grid.

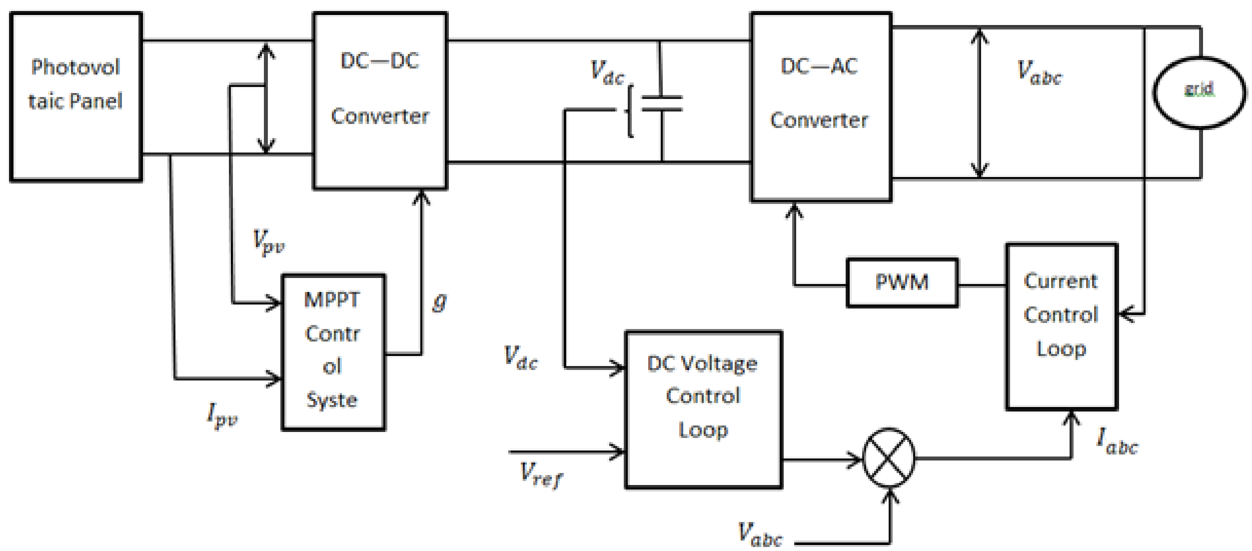
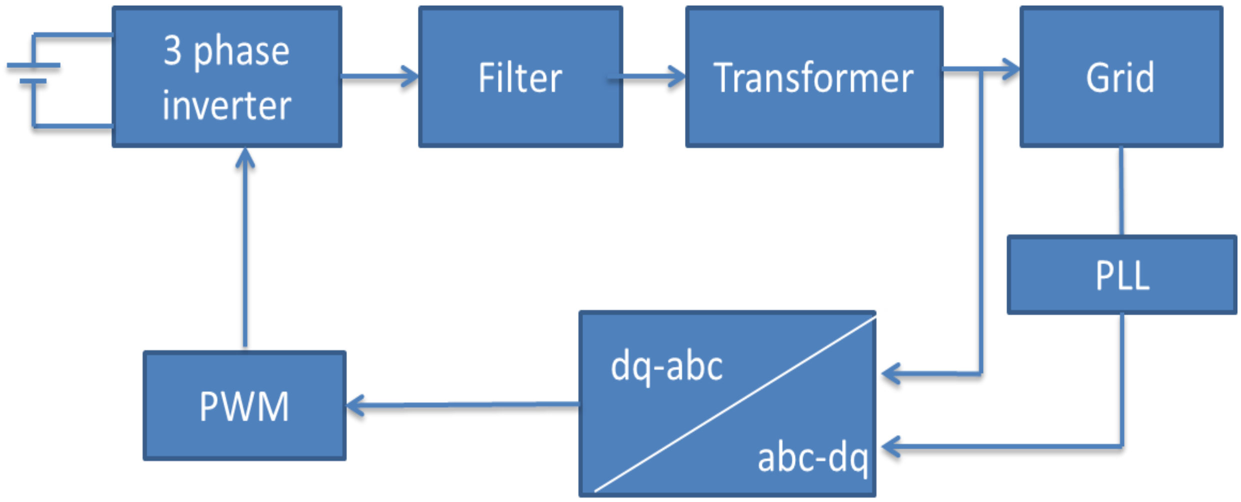


Fig.6.1 Control Strategy to connect the PV system with Grid

MPPT receive the PV voltage and current and generate a reference voltage and this reference voltage is coming from the MPPT. The output of the MPPT is fed to the PWM which gives the gate control signal to the DC_DC converter.

Another control topology is Inverter control which contains outer dc voltage control loop and inner current control loop. This control maintains the dc voltage constant and the dc power is converted to ac before transported to grid.

6.2 Modeling of 3-Φ Voltage source Inverter



Fif.6.2Block diagram of the system

In distribution power generation system three phase VSI are used to interfere between DC & AC system. For the control of active and reactive power along with constant DC link voltage different control technique are used to the three phase grid connected voltage source Inverter. Now a days power electronics converter are widely employed in all the application due to the switches non linearity occur in the system so the power stage must be linearzed. In this paper a three phase grid connected VSI with LC filter has been considered for modeling. It is quite difficult to design a controller for three phase ac system. So first three phase Ac system (abc) is transferred into synchronous rotating reference frame (dq) which is known as parks transformation for simple operation.

6.2.1 Phase Locked Loop

To synchronize the signal, PLL is used. Phase locked Loop is a control system used to generate an output signal whose phase is equal to the input signal. For grid connected system grid synchronization plays an important role. Using different transformation PLL is used to synchronies the phase sequence and the frequency of the grid with the inverter. It is used to reduce the error between the output current and the reference current obtain from the controller. Phase Locked Loop is a feedback signal which locks the two input signal with same frequency and shifted in a single phase. It is used to compare two frequencies and results the input frequency is equal to the output frequency. Also it is used to provide rotational frequency at direct and quadrature components. At the point of common coupling (PCC) the *abc* components are transform into d q component and then force the q component to zero which is used to minimize the error.

Hear the filter used is a low pass filter to eliminate high frequency. It is possible by using a integrator circuit. By integrating the phase angle θ of the PI controller which is a low passed filter a constant frequency is maintained. By using the PLL the phase difference between the inverter and grid is reduced to zero which results V_d = 0 and V_q gives magnitude of the grid voltage. The mathematical equation of the PLL is as follows.

$$\omega = k_p V_q + k_i \int V_q dt$$

$$\theta = \int \omega \, dt$$

6.2.2 abc to dq Transformation

In a three phase system the three phases are 120° apart to each other as shown in figure below. The three phase a-b-c is first transferred into two phase stationary frame i.e. $\alpha - \beta$ referance frame and then to d-q reference frame which rotate at synchronous speed.

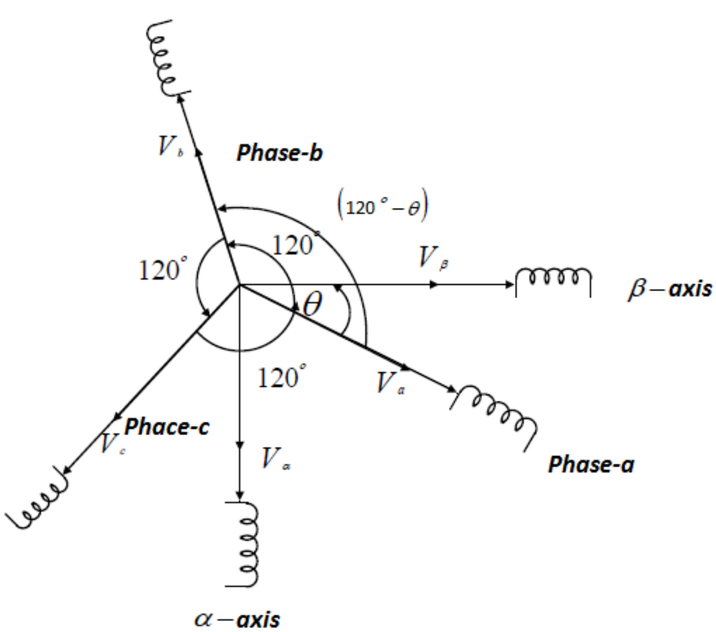


Fig.6.3Transformation of three phase a-b-c to stationary α-β reference frame

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} sin\theta & \sin(\theta - 120^\circ) & \sin(\theta + 120^\circ) \\ cos\theta & \cos(\theta - 120^\circ) & \cos(\theta + 120^\circ) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \times \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

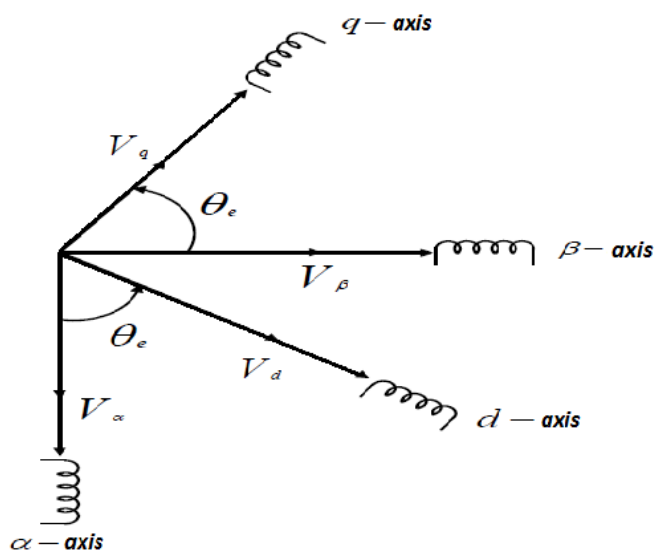


Fig.6.4Transformation of α-β reference frame to d-q reference frame

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} cos\theta_e & -sin\theta_e \\ sin\theta_e & cos\theta_e \end{bmatrix}$$

6.2.3 LC Filter

In grid synchronization due to the PWM inverter ripple current is injected to the grid to overcome this problem LC filter is used. Based on the current ripple the value of L is design. Due to the lower switching smaller ripple result. The change in current is 10% to 15% of the rated value. In this system 10% of the rated current can be considered for the designed value of the inductor L.

$$\Delta i_{max} = \frac{1}{8} * \frac{V_{dc}}{L * f_s}$$

For reactive power supplied from the capacitor at fundamental frequency the capacitor C is designed. So due to the design of reactive power 15% of the rated power is to be taken.

$$C = 15\% * \frac{P_{rated}}{3 * 2\pi f * V_{rated}^2}$$

6.2.4 Pulse Width Modulation

In dc dc converter the power stage configuration depends on output voltage power required efficiency input and weight & size. Pulse width modulation is a way to control average power to the load by controlling the input voltage. The average voltage is equal to

$$V_{0(avg)} = \frac{T_{on}}{T} \times V_{in}$$

At constant T if T_{on} reduce then output voltage also reduce.

V_0 –converter output

V_{in}- converter input voltage, volt

T_{on}- switch on time, sec

T- Device switching time ,sec

In 1964 the first PWM scheme was proposed. The modulation index m_a is define as the ratio of control signal to the triangular reference signal. It is also define as the ratio of switching frequency f_s to the reference signal frequency f_1 .Similarly the frequency modulation ratio m_f is define as the ratio of switching frequency of the PWM inverter to the fundamental frequency.

$$m_a = \frac{V_{control}}{V_{tri}}$$

$$= \frac{V_{LLC}}{V_d}$$

$$m_f = \frac{f_s}{f_1}$$

If we are able to minimize the distortion factor of the output voltage then it is better for the PWM inverter. Distortion is more when $m_a > 1$ that is with the increasing of the modulation index and $m_a \leq 1$in the linear region.

The line rms voltage at the fundamental frequency can be written as

$$V_{LLC} = \frac{\sqrt{3}}{2\sqrt{2}}(m_a \times V_d)$$

That is equal to

$$V_{LLC} = m_a\left[\frac{\sqrt{3}}{2\sqrt{2}} \times \frac{V_s}{1-k}\right]$$

For better result on the control and to reduce harmonic in the output, the modulation index m_a does not exceed one.

CHAPTER 7

7.1 Parameter Specification

Table 3 : PV array Specification	
Rating	8.6 kW
Rating of Module	36 W
Number of series Module	21
Number of Parallel Module	11
Open Circuit Voltage	446 V
Short Circuit Current	28 A
Voltage at Peak	348 V
Current at Peak	24.75A

Table 4 : Wing Generator Specification	
Armature Resistance	0.425 ohm
Magnetic flux leakage	0.433 waber
Stator inductance	8.4 mH
Inertia constant	0.012

Table 5 : System Specification	
System frequency	50 Hz
Grid Voltage (line)	33 kV
Inverter Voltage (Phase)	300 V
Inter facing Transformer	380/25 kV
Inductive load	
Real Power	4700 kW
Reactive Power	1000 KVAR
Grid specification	
Short Circuit Level	30mV
Base voltage	25kV
X/R ratio	10

7.2 Results and Discussion

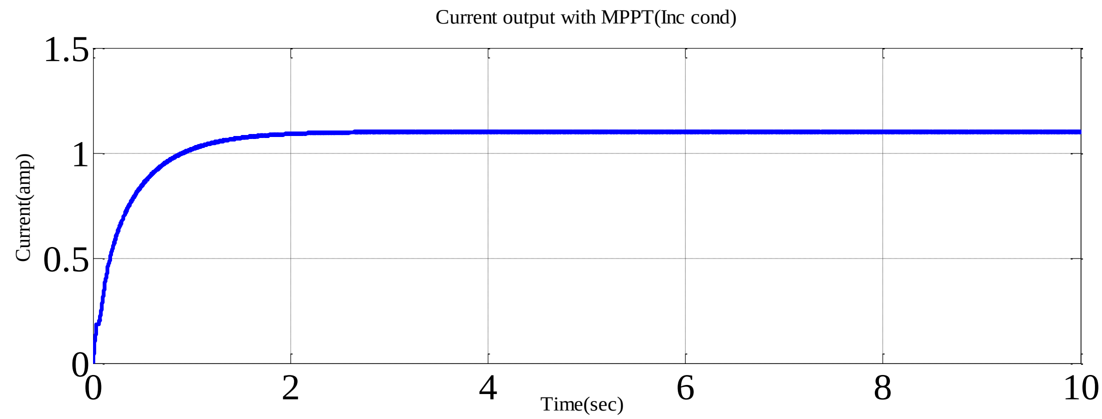


Fig.7.1 Output current of the boost converter with IncCond

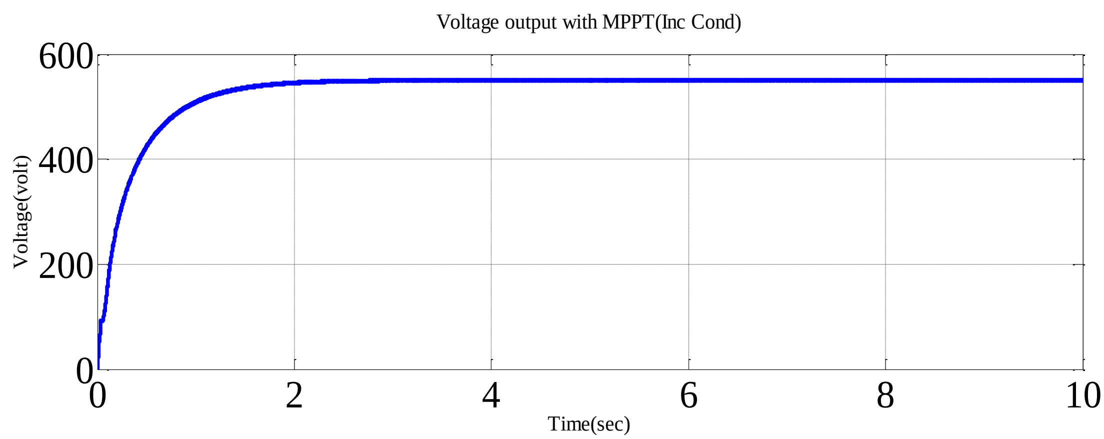


Fig.7.2 Output voltage of the boost converter with IncCond

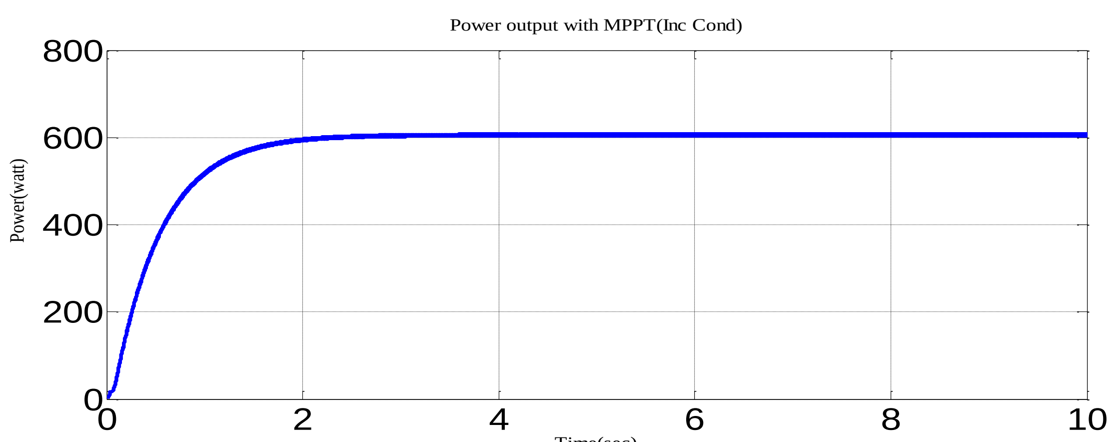


Fig.7.3 Output power of the boost converter with IncCond

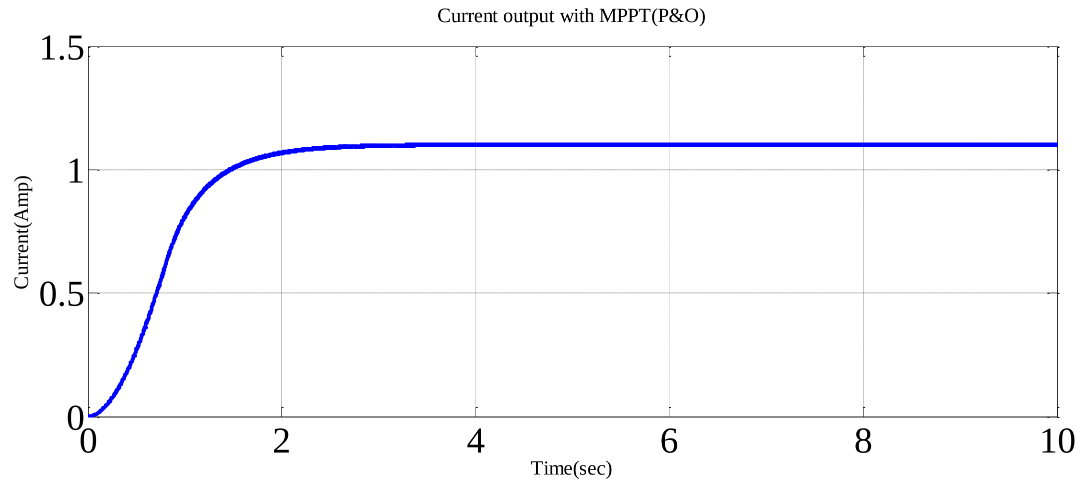


Fig.7.4 Output current of the boost converter with P&O

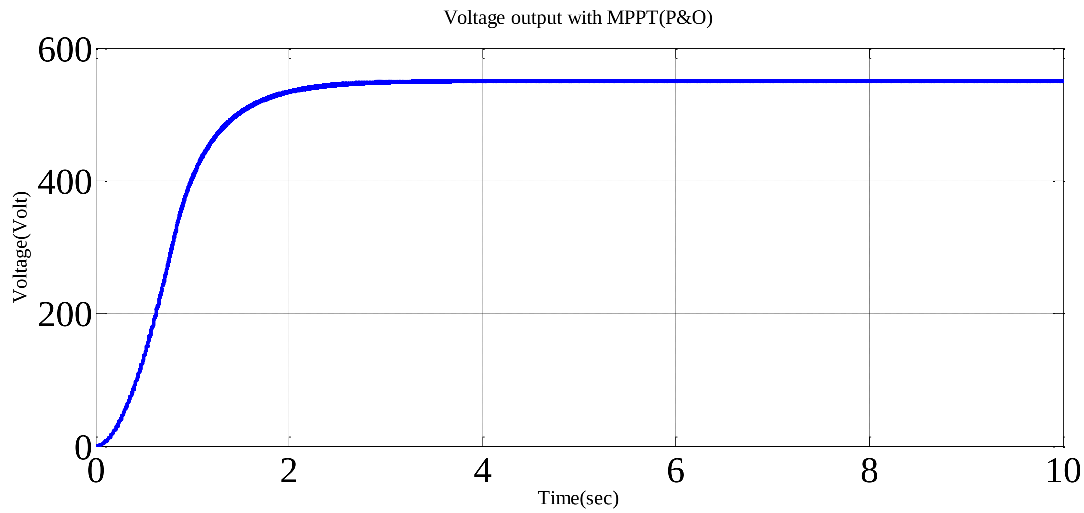


Fig.7.5 Output voltage of the boost converter with P&O

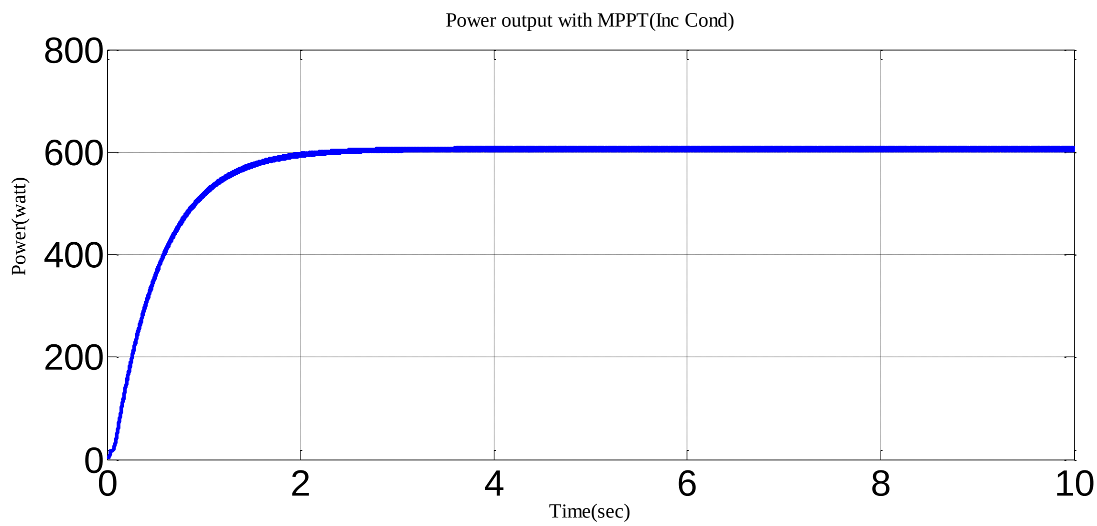


Fig.7.6 Output power of the boost converter with P&O

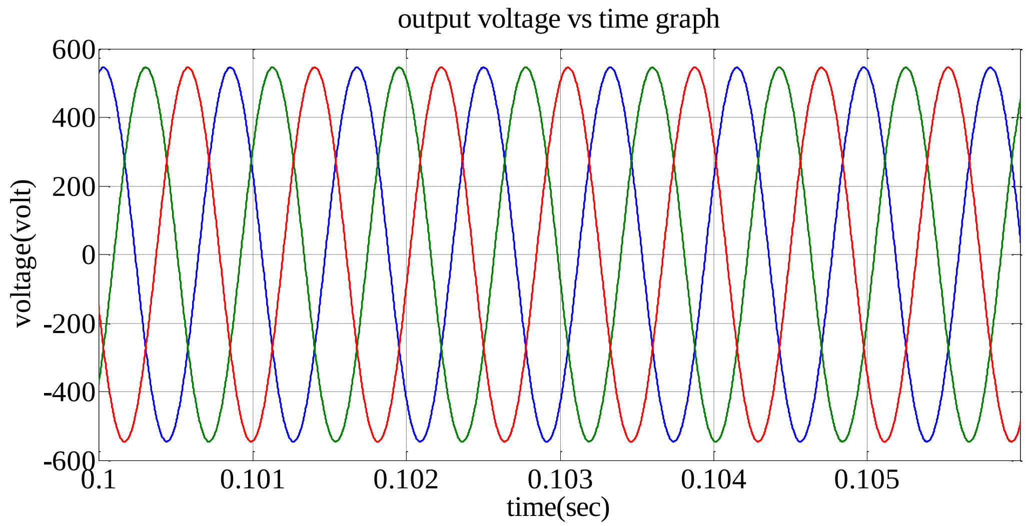


Fig.7.7 Output line voltage of the PMSG

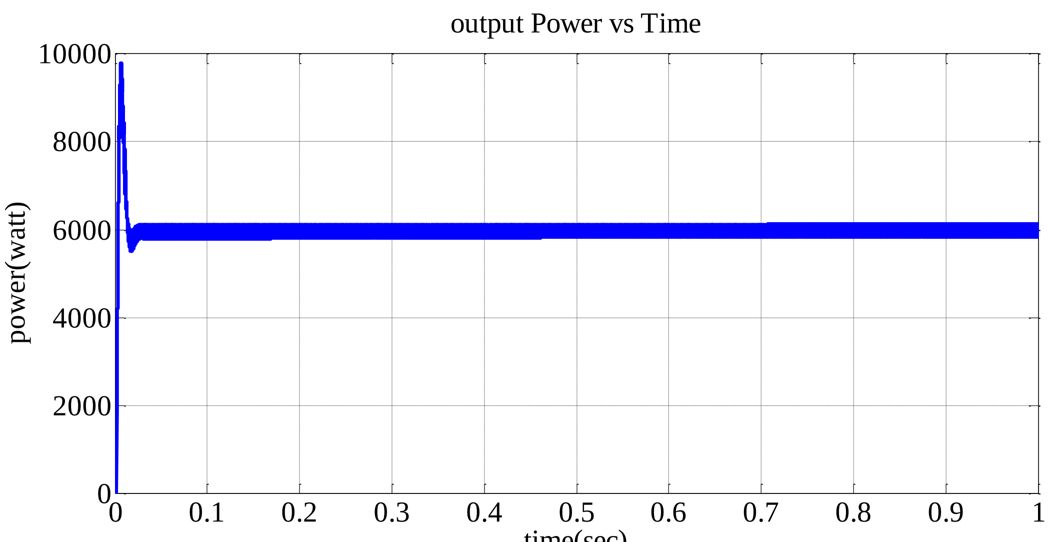


Fig.7.8 Output power of the PMSG

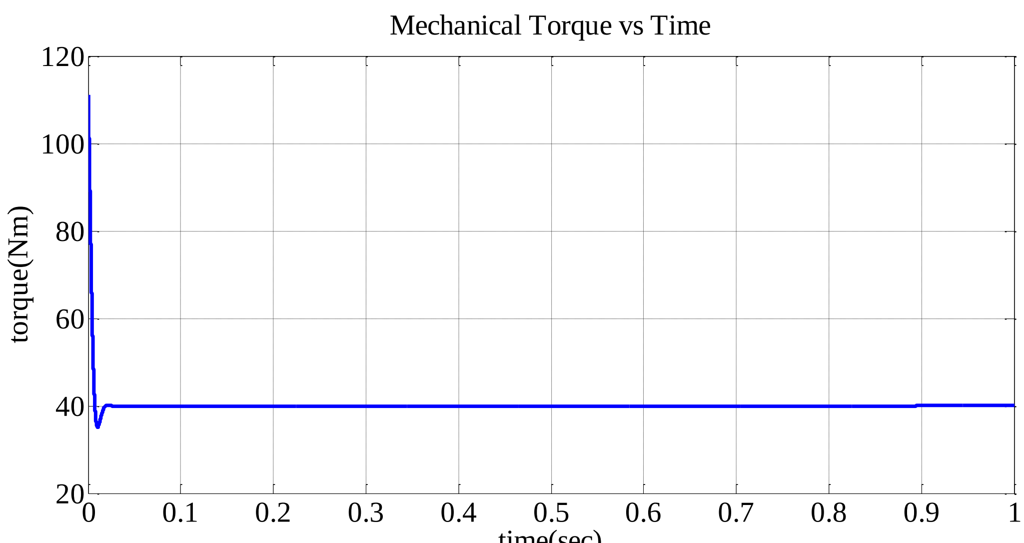


Fig.7.9 Mechanical torque develop from the PMSG

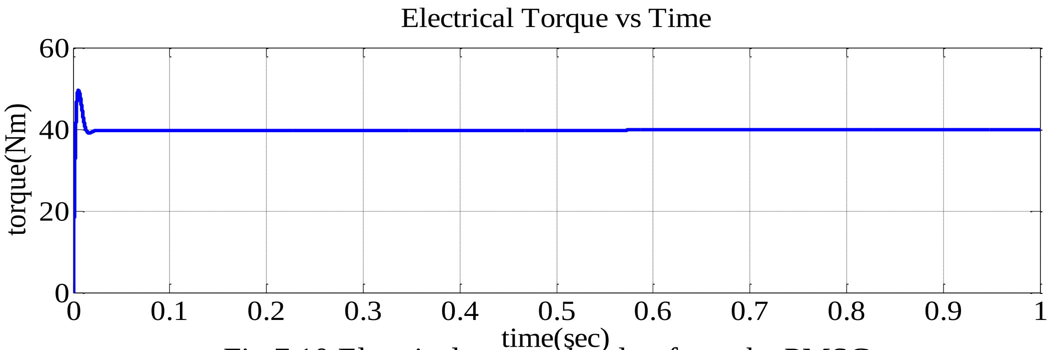


Fig.7.10 Electrical torque develop from the PMSG

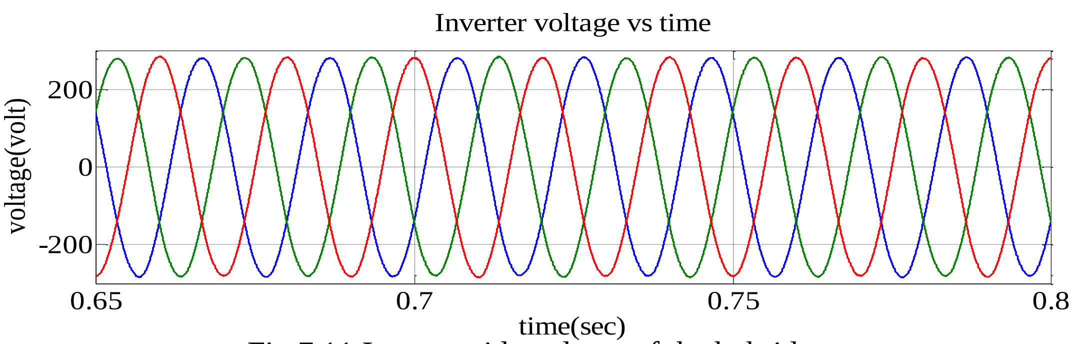


Fig.7.11 Inverter side voltage of the hybrid system

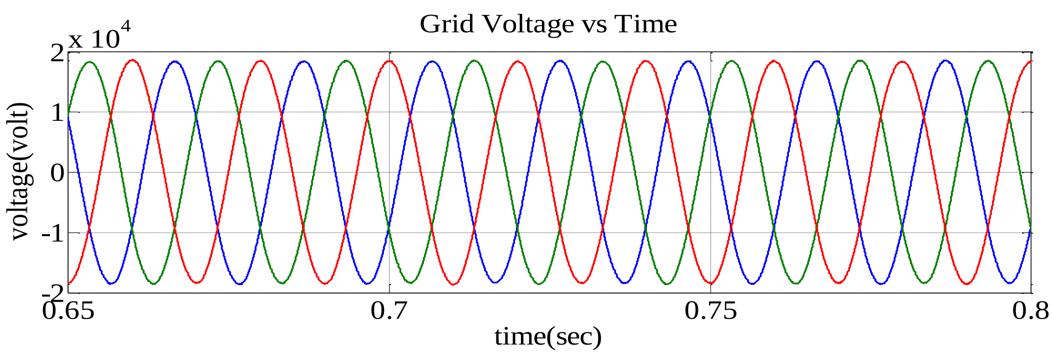


Fig.7.12 Grid side voltage of the hybrid system

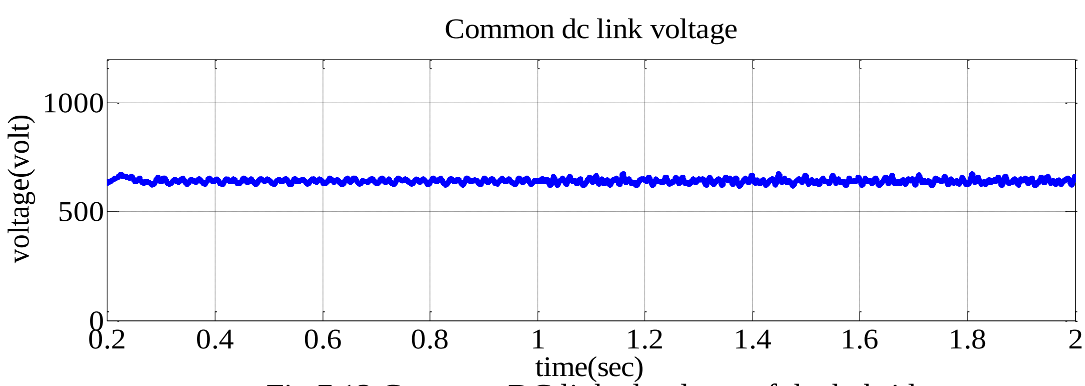


Fig.7.13 Common DC linked voltage of the hybrid

CHAPTER 8

8.1 Conclusion and future work

8.2 References

8.1 Conclusion and Future Work

A 36W PV module is modeled and simulated with varying irradiation and temperature. A boost converter is designed and simulated. To control the gate pulse of the high frequency switch of the boost converter MPPT algorithm are used.

Both the MPPT methods that is P&O and IncCond methods are used for maximum PowerPoint tracking. The Porter and Observer algorithm is simple in operation and required less hardware as compared to Incremental Conductance Method but in this method the power loss is little more as compared to the Incremental Conductance Method due to the output of the PV array oscillate around the MPP. Similarly the Incremental Conductance Method has better control and smaller oscillation but the hardware requirement is more. The Incremental Conductance Method achieve its steady state value earlier than P&O method. There are many merits and demerits of the two method. Therefore all the features should be taken into account to choose a better control algorithm. In this project for comparing these two algorithms three series model and six parallel model is taken and simulated in Matlab/Simulink. From the simulation result it is observed that both the method give nearly same result. So the P&O method is chosen for the grid synchronization purpose because of its simplicity and easy implementation.

A dynamic model of wind turbine is model and simulated. PMSG is used in this paper as a wind generator due to its self excitation capabilities and requires less maintain. A 6kW out power is generated from the PMSG. A greed side VSI is used to synchronize the wind-PV hybrid system. The various waveform of this system were obtained by using the software Mat lab/Simulink. The simulation result showed excellent performance and the DC linked voltage is able to maintain at a constant level at 640 V from the wind –PV hybrid system with varying condition of wind and with different irradiation and temperature.

In future we can combine other hybrid system with this existing one like fuel cell or battery system can be added and by using matlab it can be analyzed.

8.2 References

[1] Seul Ki Kim, Eung Sang Kim, Jong Bo Ahn, “Modeling and control of a Grid connected Wind/PV Hybrid Generation System”, 2005/2006 IEEE PES Transmission and Distribution Conference and Exhibition,21-24 May 2006,pp.1202-1207.

[2] N. Pandiarajan, RanganathMuthu, “Mathematical Modeling of Photovoltaic Module with Simulink”, First International Conference on Electrical energy system(ICEES),3-5 january 2011,pp.258-263.

[3] Munish Kumar, “Simulation and Analysis of Grid Connected Photovoltaic System with MPPT” , 2012 IEEE 5th Power India Conference,19-22 dec.2012,pp.1-6.

[4] Kun Ding,XinGaoBian, “A MATLAB-Simulink-Based PV Module Model and its Application Under Conditions of Non uniform Irradiance”, IEEE Transactions On Energy Conversion,Vol.27,NO.4,December2012.

[5] Ling Lu, Ping Liu,“Research and Simulation on Photovoltaic Power System Maximum Power Control” nternational conference on Electrical and control Engg (ICECE),16-18 sept.2011,pp.1394-1398.

[6] DezsoSera,LaszloMathe, TamasKerekes, “On the Perturb-and-Observe and Incremental Conductance MPPT Methods for PV Systems”,july2013 IEEE Journal of Photovoltaics,VOL.3,no.3,pp.1070-1078.

[7] Sibasish Panda, Anup Kumar Panda, “Fault Analysis on Grid Connected MPPT based Photovoltaic System”,2013 International journal of Current Engineering and Technology.

[8] Natshes,E.M, “Modeling and Control for Smart Grid Integration of Solar/Wind Energy Conversion System” ,Innovative smart Grid Technologies(ISGT Europe),2011 2nd IEEE International Conference and Exhibition,5-7 Dec.2011,pp.1-8.

[9] D.Sera,R.Teodorescu,andP.Rodriguez, “PV panel model based on datasheet values” ,IEEE International Symposium on Industrial Electronics,ISIE,PP.2392-2396,2007.

[10] J.G.Slootweg,H.Polinder,W.L.Kling “Representing Wind Turbine electrical generating system in fundamental frequency simulation”,IEEETrans.on energy conversion,Vol.18,No.4,December 2003,pp.516-524

[11] H. Polinder, F.F.A van der Pijl, G.J.de Vilder , P.J.Tavner, "Comparison of direct- drive and geared generator concept for wind turbine " , IEEE Transactions on Energy Conversion , vol., 21, no. 3, pp725-733, Sept. 2006.

[12] T. F. Chan, L. L. Lai, "permanent magnet machines for distributed generation: a review" , Proc. 2007 IEEE power engineering annul meeting , pp. 1-6.

[13] M. Fatu, L.Tutelea, I. Boldea , R. Teodorescu, " Novel motion sensorless control of stand alone permanent magnet synchronous generator (PMSG) : harmonics and negative sequence voltage compensation under nonlinear load " , 2007 European conference on Power Electronic and Application, 2-5 Sept. 2007.

[14] M. E. Haque, K. M. Muttaqi and M. Negnevitsky, "Control of a Stand alone variable speed wind turbine with a permanent magnet synchronous generator", Proceeding of IEEE power and energy society general meeting , pp. 20-24 july 2008.

[15] M. E. Haque, M. Negnevitsky and K. M. Muttaqi , " A novel control strategy for a variable-speed wind turbine with a permanent magnet synchronous generator". IEEE Transactions on industry application, vol. 46, no. 1, pp. 331-339, jan/feb 2010.

[16] N. Mohan, T. M. Undeland and W. P.Robbins, " Power Electronic: Converters, Application, and Design" , Wiley, 2002.

[17] W. D. Kellogg, M. H. Nehrir, G. Venkataramanan, and V. Greez, "Generating Unit Sizing and Cost Analysis for Stand-alone Wind, Photovoltaic and Hybrid Wind/PV Systems", IEEE Trans. Energy Conversion, Vol. 13, No. 1, pp. 70-75, March 1998.

[18] Fernando Valencaga, Pablo F. Puleston and Pedro E. Battaiotto, "Power Control of a Solar/Wind Generation System Without Wind Measurement: A Passivity/Sliding Mode Approach", IEEE Trans. Energy Conversion, Vol. 18, No. 4, pp. 501-507, December 2003.

[19] Kurozumi, Kazuhiro et al, "Hybrid system composed of a wind power and a photovoltaic system at NTT Kume-jima radio relay station", INTELEC, International Telecommunications Energy Conference 1998, pp. 785-789.

[20] RiadChedid and SaifurRahman, “Unit Sizing and Control of Hybrid Wind-Solar Power Systems”, IEEE Trans. Energy Conversion, Vol. 12, No. 1, pp. 79-85, March 1997.

[21] Francois Giraud and Zyiad M. Salameh, “Steady-State Performance of a Grid-Connected Rooftop Hybrid Wind-Photovoltaic Power System with Battery Storage”, IEEE Trans. Energy Conversion, Vol. 16, No. 1, pp. 1-7, March 2001.

[22] T. Esram, P.L. Chapman, "Comparison of Photovoltaic Array Maximum Power PointTracking Techniques," IEEE Transactions on Energy Conversion, vol. 22, no. 2, pp. 439-449, June 2007

[23] N. Femia, G. Petrone, G. Spagnuolo, M. Vitelli, "Optimizing sampling rate of P&O MPPT technique," in Proc. IEEE PESC, 2004, pp. 1945- 1949.