AN IMPROVED GRID CONNECTED PV GENERATION INVERTER CONTROL SYSTEM

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AN IMPROVED GRID CONNECTED PV GENERATION INVERTER CONTROL SYSTEM

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in "Electrical Engineering"

By

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CERTIFICATE

This is to certify that the thesis entitled "**An Improved Grid Connected PV Generation Inverter Control System**", submitted by Nishant Singh **(Roll. No. 109EE0531),** in partial fulfilment of the requirements for the award of **Bachelor of Technology** in **Electrical Engineering** during session 2012-2013 at National Institute of Technology, Rourkela. A bonafide record of research work carried out by them under my supervision and guidance.

The candidates have fulfilled all the prescribed requirements.

The Thesis which is based on candidates' own work, have not submitted elsewhere for a degree/diploma.

In my opinion, the thesis is of standard required for the award of a bachelor of technology degree in Electrical Engineering.

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ABSTRACT

We are going to study the operational principle and the structure of the present grid-connected photovoltaic system.

It describes the two inverter control methods.

a) voltage source inverter control method

b) power type PWM inverter control method

On the basis of above two kinds of inverter control methods, we will present an improved PWM inverter control system that can be applied in grid-connected PV generation and uses MATLAB/Simulink software to simulate and analyze. The result of the simulation shows that the improved inverter control system can effectively control the grid current waveform which tends to sine wave, meanwhile it can achieve the maximum power point tracking, besides it is able to put the arbitrary power out to the load or to the grid, while the control system has a good stability.

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CHAPTER 1

1.1 INTRODUCTION

With the increasingly urgent energy issues, the world attach great importance to begin the development of new energy and related technology. At present, large scale photovoltaic power generation and scale of renewable energy has become parts of development strategy, meanwhile it is the way to guide the development of photovoltaic industry[1]. However, because of its own characteristics different from conventional power generation grid connected PV power station and its security, stability, reliable operation become new challenges which power grid and PV power plant need to face.

Grid connected photovoltaic power systems are power system energised by photovoltaic panels which are connected to the utility grid. Grid connected power systems comprise of

- PV panels
- MPPT
- Solar inverters
- Power conditioning units
- Grid connection equipments

Here two inverter control methods are described.

A) Voltage source inverter control method

B) Power type PWM inverter control method

Voltage source inverter control method regulates phase angle of the grid mainly through receiving voltage signals from the dc side of the inverter which is called the outer loop to control the grid voltage while it regulates voltage reference from ac side load voltage to control inverter output current which is called inner loop[2]. However the process of inner loop won't affect results of the outer loop. Power type PWM inverter bridge circuits is formed by two groups, which uses two reverse diodes synchronized transformation. Required power can be got by changing the modulation rate of PWM inverter.

Thus, even the grid-connected PV generation inverter control system is able to achieve maximum power point tracking(MPPT) and to ensure the high power quality of the photovoltaic cells or not are key issues in the electrical power system.

CHAPTER 2

2.1 Grid connected PV generation system

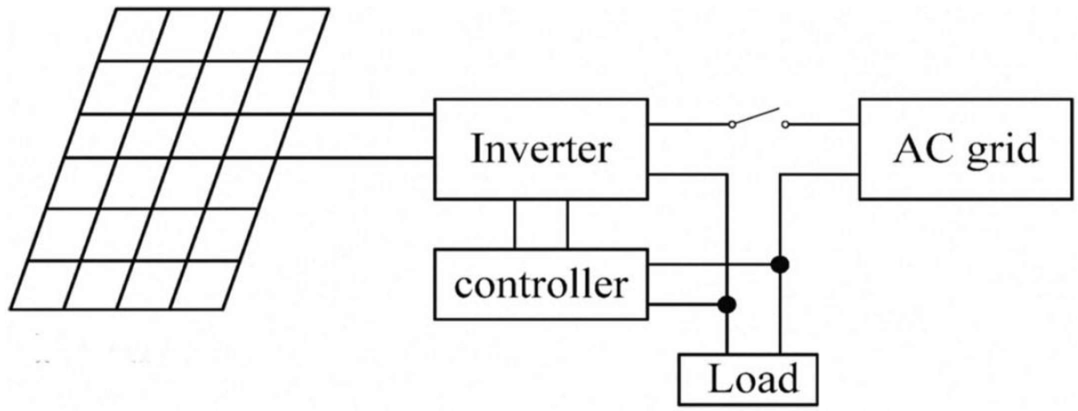
Grid connected PV generation system is mainly composed of the PV array, the inverter device with the function of maximum power tracking and the control system.

Photovoltaic system use solar panels to convert sunlight into electricity. A system is made up of one or more solar PV panels, an ac or dc power converter that holds the solar panels, and the interconnections and mounting for the other components.

2.2 Photovoltaic modules or solar panels

Due to low voltage of the individual solar cell (mainly 0.5v) several cells are wired in series for manufacture of a laminate. Then the laminate is assembled into a protective weather proof enclosure thus making a photovoltaic module or solar panel. Modules are then strung together into a photovoltaic array.

A photovoltaic array is a linked assembly of PV modules. Most PV array use an inverter to convert the dc power produced by the modules into alternating current. The modules in a PV array are connected in series to obtain the desired the voltage, the individual string are then connected in parallel to allow the system to produce more current.



2.1 Grid connected PV power generation structure

A solar or PV inverter converts variable direct current(DC) output of the photovoltaic solar panel into a utility frequency alternating current that can be fed into a commercial electrical grid or it is used by the local or off grid electrical network. It is a critical component in the photovoltaic system allowing the use of ordinary commercial appliances. Solar inverters have special functions adapted for use with the photovoltaic arrays including maximum power point tracking and anti islanding protection.

2.3 Maximum power point tracking

Solar inverters use maximum power point tracking to get the maximum possible power from PV array. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency known as the I-V curve. It is the purpose of a MPPT system to sample the output of the cells and determine a resistance to obtain maximum power for any given environmental conditions.

A typical solar panel converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Maximum power point technique is used to improve the efficiency of the solar panel. The inverter device with the function of maximum power point tracking can inverse the electrical power into sinusoidal current and connect to the grid. The control system mainly controls the maximum power point tracking of photovoltaic, current waveform and power of the output of grid connected inverter, which makes the output of the grid corresponding with the export by PV array. MPPT is not a mechanical tracking system that “physically moves” the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power. current.

2.4 Characteristics of solar array

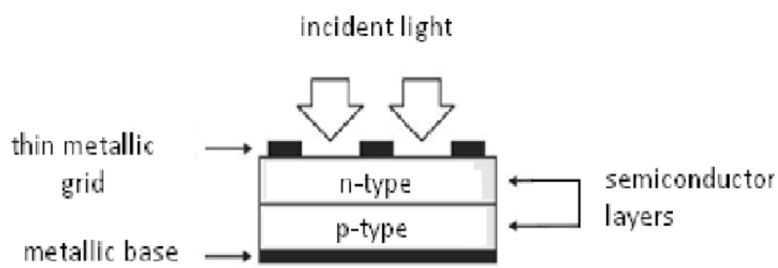
A photovoltaic system uses one or more solar modules or solar panels to convert solar energy to electrical energy. Basically, its components include solar panels, mechanical and electrical connections and means of modifying the electrical output we get.

2.4.1 Photovoltaic cell

solar cells are the building blocks of PV array.

These are made up of semiconductor materials like silicon etc. A thin semiconductor wafer is specially treated to form an electric field, positive on a side and negative on the other.

Electrons are knocked loose from the atoms of the semiconductor material when light strikes upon them. In an electrical circuit is made attaching a conductor to the both sides of the semiconductor, electrons flow will start causing an electric current. It can be circular or square in construction. It is made up of various semiconductor materials. But mono-crystalline silicon and polycrystalline silicon are mainly used for commercial use.



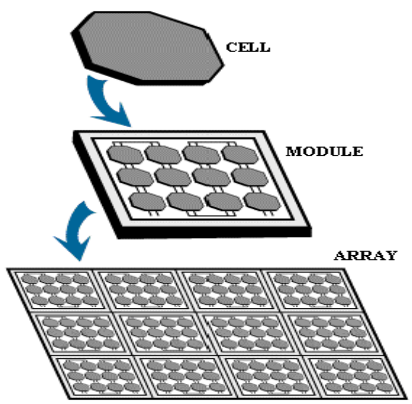
2.2 Basic PV cell structure

2.4.2 Photovoltaic module

The voltage generated by a single solar cell is very low, around 0.5v. So a number of solar cells are connected both in series and parallel connections to achieve the desired output. In case of partial shading, diodes may be needed to avoid reverse current in the array. Good ventilation behind the solar panels are provided to avoid the possibility of less efficiency at high temperatures.

2.4.3 Photovoltaic array

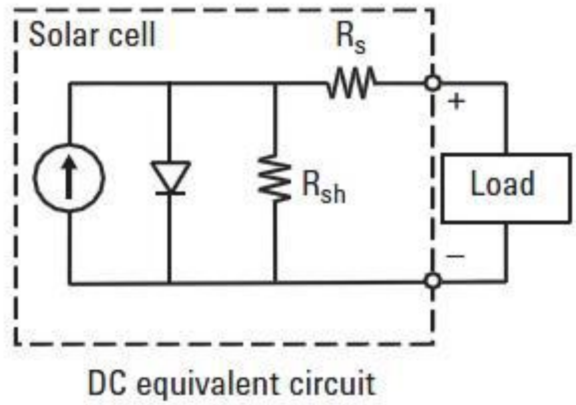
Again the power produced by a single photovoltaic module is not sufficient to meet the power demands for most of the practical purposes. PV array can use inverters to convert the dc output into ac and use it for motors, lighting and other loads. The modules are connected in series for more voltage rating and then in parallel to meet the current specifications.



2.3 Photovoltaic Hierarchy

2.5 Working of PV cell

Working of PV cell is based on the basic principle of photoelectric effect. Photoelectric effect can be defined as a phenomenon in which an electron gets ejected from the conduction band as a consequence of absorption of the sunlight of certain wavelength by the matter. So, in a photovoltaic cell when sunlight strikes its surface, some portion of the solar energy is absorbed in the semiconductor material. If absorbed energy is greater than the band gap energy of the semiconductor, the electrons from the valence band jumps to the conduction band. By this, pair of hole electrons are created in the illuminated region of the semiconductor. The electrons thus created in the conduction band are now free to move. These free electrons are forced to move in a particular direction by the action of electric field present in the PV cell. These flowing electrons constitutes current and can be drawn for external use by connecting a metal plate on top and bottom of PV cell. This current and voltage created because of its built in electric fields produces required power.



2.4 DC Equivalent circuit

The photovoltaic cell output voltage is basically function of the photocurrent which is mainly determined by load current depending on the solar irradiation level during the operation.

$V_C = (A*K*T_C/e)\ln[(I_{ph}+I_0-I_C/I_0)-R_S*I_C$

The symbols used are

V_C = cell output voltage

T_C = reference cell operating temperature

R_S = series resistance of cell

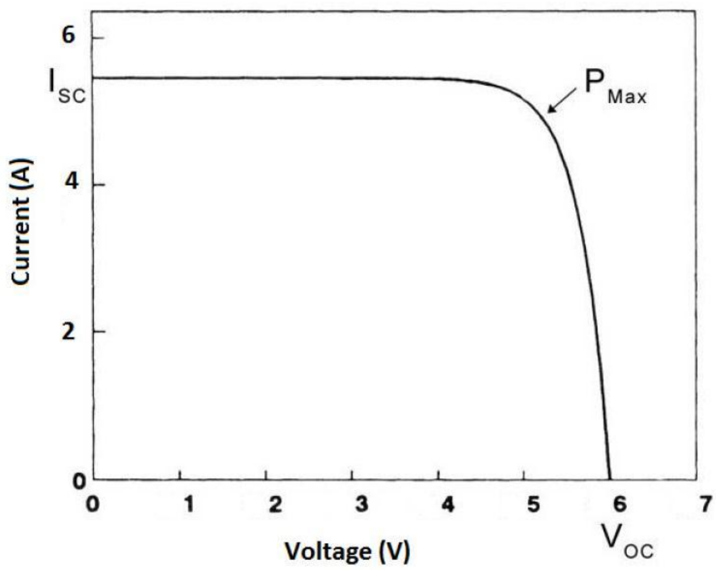
I_{Ph} = photocurrent, function of irradiation level and junction temperature

I_0 = reverse saturation current of the diode

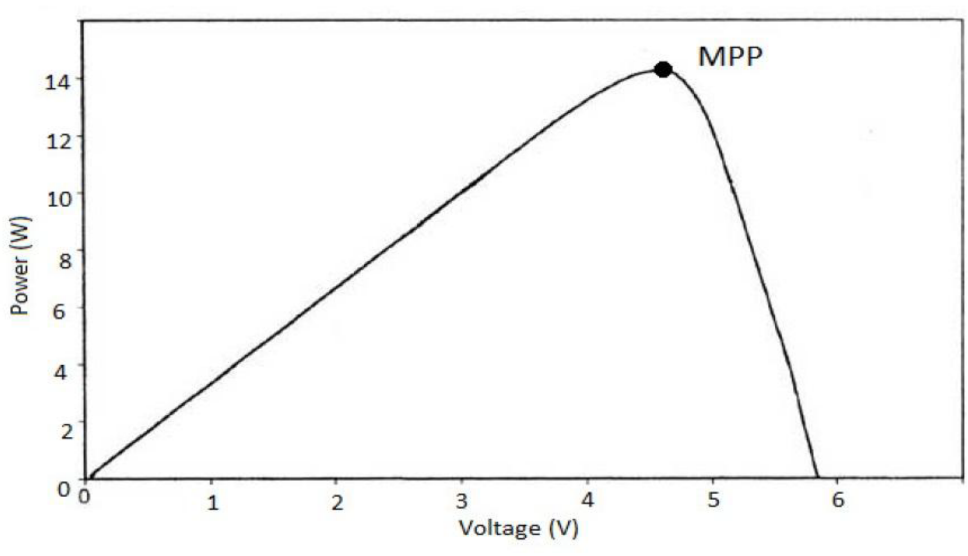
I_C = cell output current

K = Boltzmann constant ($1.38*10^{-23}$ j/k)

e = electron charge ($1.602*10^{-19}$ c)



2.5 Typical I-V CHARACTERISTICS OF SOLAR PANEL



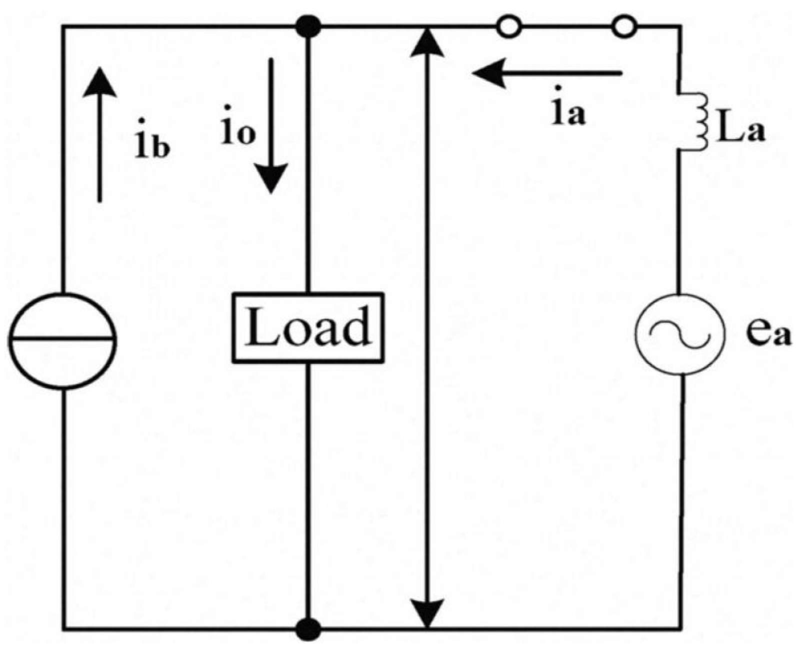
2.6 Typical P-V characteristics of a solar panel

CHAPTER 3

3.1 Inverter control theory

Inverter can control the switch state of shut and conduct, thus the system may form two different working ways which are parallel operation and independently operation. When the system is working in parallel operation way, the inverter belongs to the current mode.

Equivalent circuit of the inverter in parallel operating operating mode is shown in figure below.



3.1 Equivalent circuit of the inverter in parallel operating mode

$e_b = e_a – L_{a(}di_a/ dt)$ (1)

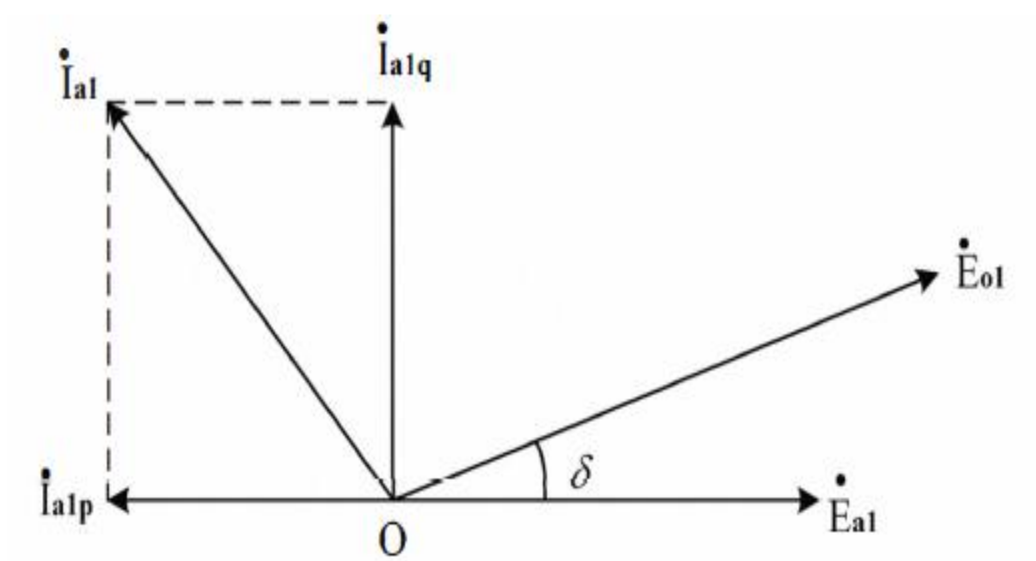
$i_a = i_0 - i_b$ (2)

where e_a is the source voltage, e_0 is the AC voltage of the load, i_a is the contact current, i_0 is the load current, i_b is the output current of the inverter.

According to above equations, the relation equation of fundamental component of voltage and current is easily got, as in equation (3).

$$e_{01} = e_{a1} – L_a[d(i_{01}-i_{b1})/dt] \qquad (3)$$

The voltage fundamental E_{a1} seen as the base line vector, thus the fundamental value E_{01} by the output of inverter and its phase is δ. Based on factor starting above, the vector figure in parallel mode can be drawn as shown below



3.2 The vector figure in parallel mode

From fig (3), the relation equation of the active component Ia1p and reactive component

I_{a1q} of contact current I_{a1} can be reach as in (4),(5).

$$I_{a1p} = -(E_{01}\sin\delta)/x_a \qquad (4)$$

$$I_{a1q} = (E_{01}\cos\delta - E_{a1})/x_a \qquad (5)$$

where, $x_a = \omega L_a$ the equation of active power P_a and reactive power Q_a in parallel mode are shown in (6), (7)

$$P_a = E_{a1}I_{a1p} = -(E_{a1}E_{01}\sin\delta)/x_a \qquad (6)$$

$$Qa = E_{a1}I_{a1q} = E_{a1}(E_{01}\cos\delta - E_{a1})/x_a \qquad (7)$$

where, I_{a1p} is the substraction of active component which stand for the load current and the inverter current.

Thus the value of the active component received by the ac grid will be controlled by the phase between the output voltage of the inverter and the source voltage. Additionally, the load voltage can be written as

$$E_{01} = (E_{a1} + I_{01q}\, x_a - I_{b1q}x_a)/\cos\delta \qquad (8)$$

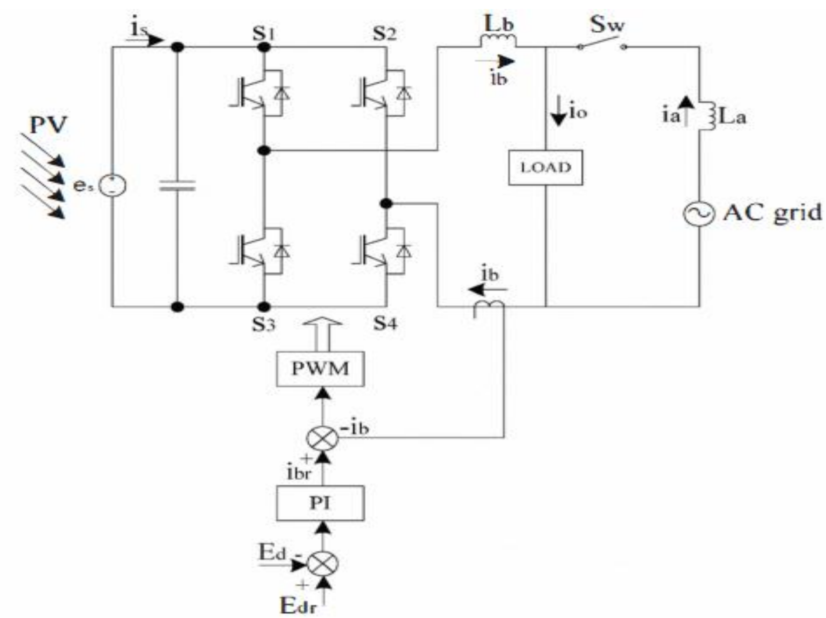
The reactive component I_{b1q} is produced by inverter, which can be compensated through controlling E_{a1} and I_{01}.

3.2 Introduction of two typical inverter control methods

3.2.1 Voltage source inverter control method

The pv array working voltage is set to E_d, the standard voltage E_{dr} should be matched with the working voltage when the pv array is in the maximum power output state. The standard current I_{br} should be kept to sinusoidal while the power factor should be kept to one which can be realized by PWM control method. S_w is a switch which mainly protects the inverter and cuts the inverter from the system when the system power is off.

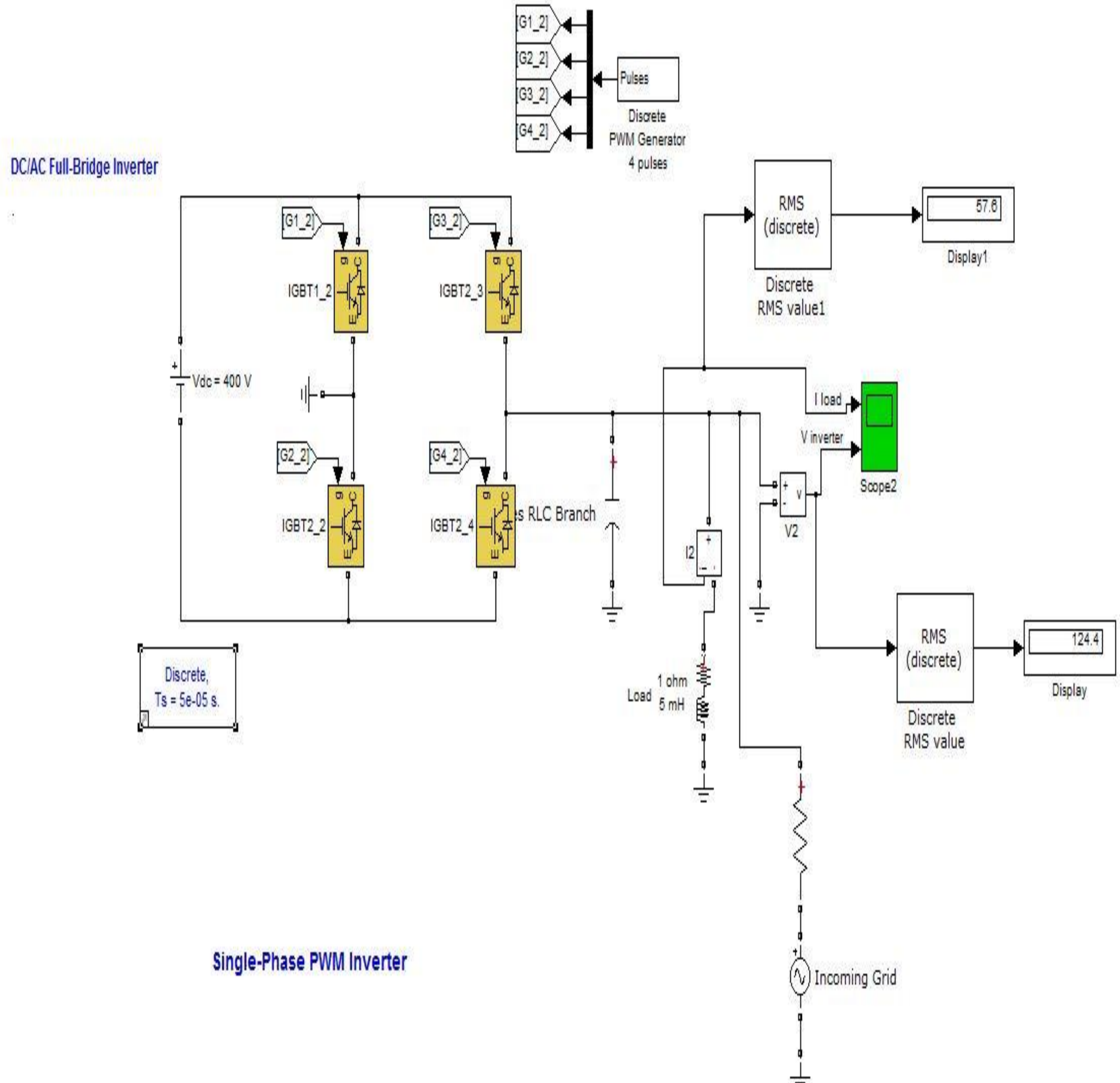
The voltage source inverter and its control method are shown below.



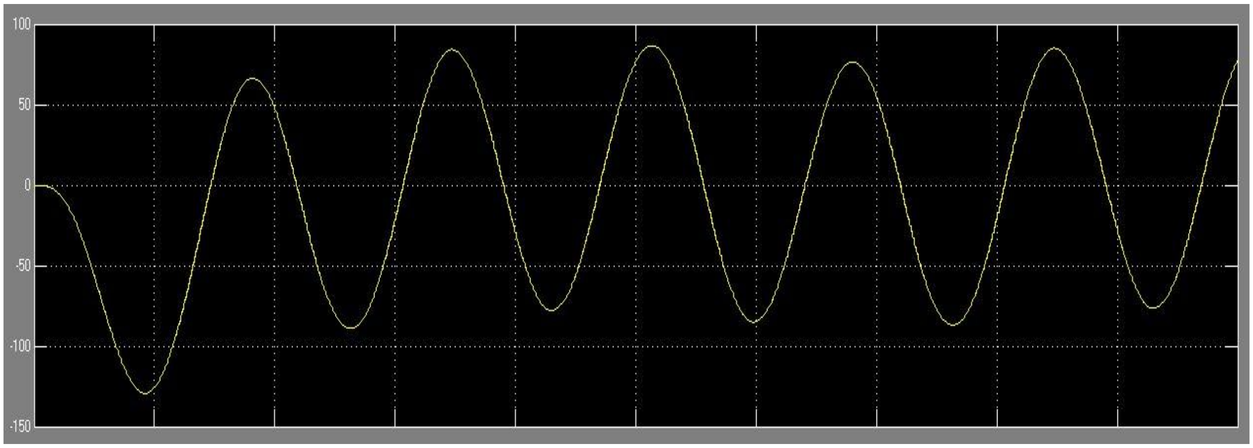
3.3 Voltage source inverter with control method

From above figure the process of inverter control system is complex which uses the former class system voltage fluctuations and waveform distortion signal to control the next class system. To ensure power supply the switch or reenter of inverter output will make frequency management control complex and difficult. It will increase the complexity of the control system of the main circuit if setting another AC switch, meanwhile the single phase system will have big power fluctuation.

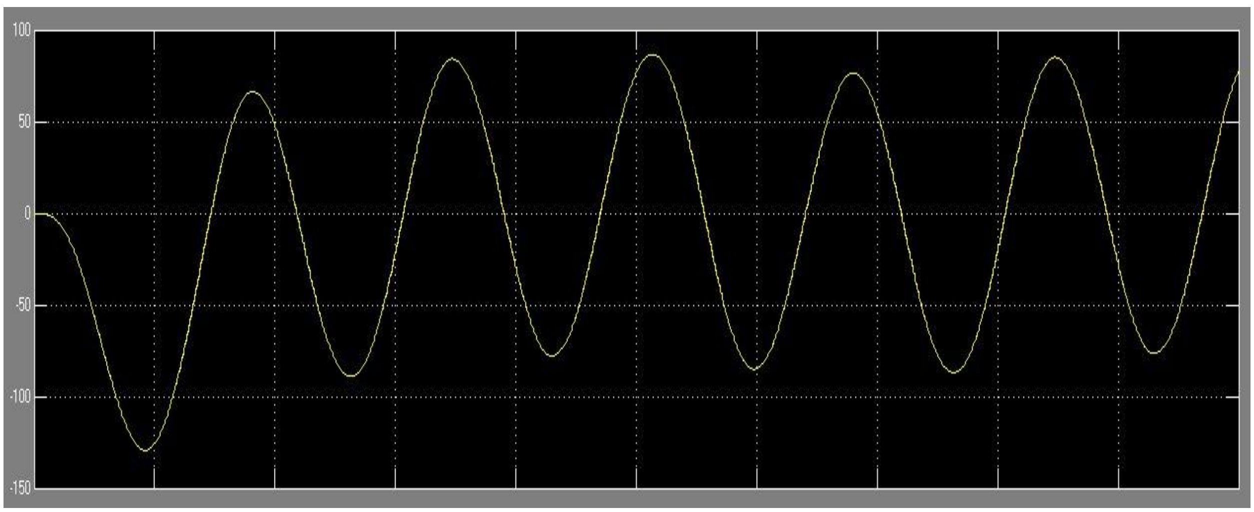
In photovoltaic applications the grid interface between source (solar array) and load (utility grid) consists of the inverter. To maximize the system efficiency the inverter must be optimized in design and control. For a 2.5kw photovoltaic power system a single phase voltage source inverter is developed which requires only a minimum number of components. Most commercial inverters for photovoltaic applications include a transformer and several sections of power conversion. To reduce the degree of complexity it is proposed to omit the transformer and to use only one section of power conversion. Thereby system losses, size and costs decreases. By the mode of operation of a voltage source inverter, the solar array voltage is not free eligible. For the voltage source inverter and the current source inverter, the use of gate turn-off thyristor or the IGBT which has self-extinguishing capability, has several merits.



DC/AC Full-Bridge Inverter
[G1_2]
[G2_2]
[G3_2]
[G4_2]
Pulses
Discrete
PWM Generator
4 pulses
IGBT1_2
IGBT2_3
IGBT2_2
IGBT2_4
Vdc = 400 V
Series RLC Branch
RMS
(discrete)
Discrete
RMS value1
57.6
Display1
I load
V inverter
Scope2
V2
I2
Load
1 ohm
5 mH
RMS
(discrete)
Discrete
RMS value
124.4
Display
Discrete,
Ts = 5e-05 s.
Incoming Grid
Single-Phase PWM Inverter



current waveform



voltage waveform

3.2.2 Power type PWM inverter control method

It is composed of two bridge circuits having two reverse diodes to carry out synchronous transformation. It applies discontinuous current manipulating technique to increase or decrease output voltage of PV, getting needed power which will be controlled through changing modulation rate of PWM.

For one thing, it is unrelated with the delivery voltage of PV cells, it can put arbitrary power out to the load or system, for another, the value of power factor is high due to the control signal is in phase with the system. Finally, the circuit structure is simple and the cost is low. The greatest advantage of power type PWM inverter is that it can put power overall to the system. First of all, it should set the input signal U_i and the grid voltage e_{ac} to the same phase when PV system connect with grid, and then U_i drive PWM power type inverter, getting the output voltage U_o, locked to $e_{ac} = \sqrt{2}E_{ac} \sin\omega_i t$, so the generation power can transfer to the load or power grid.

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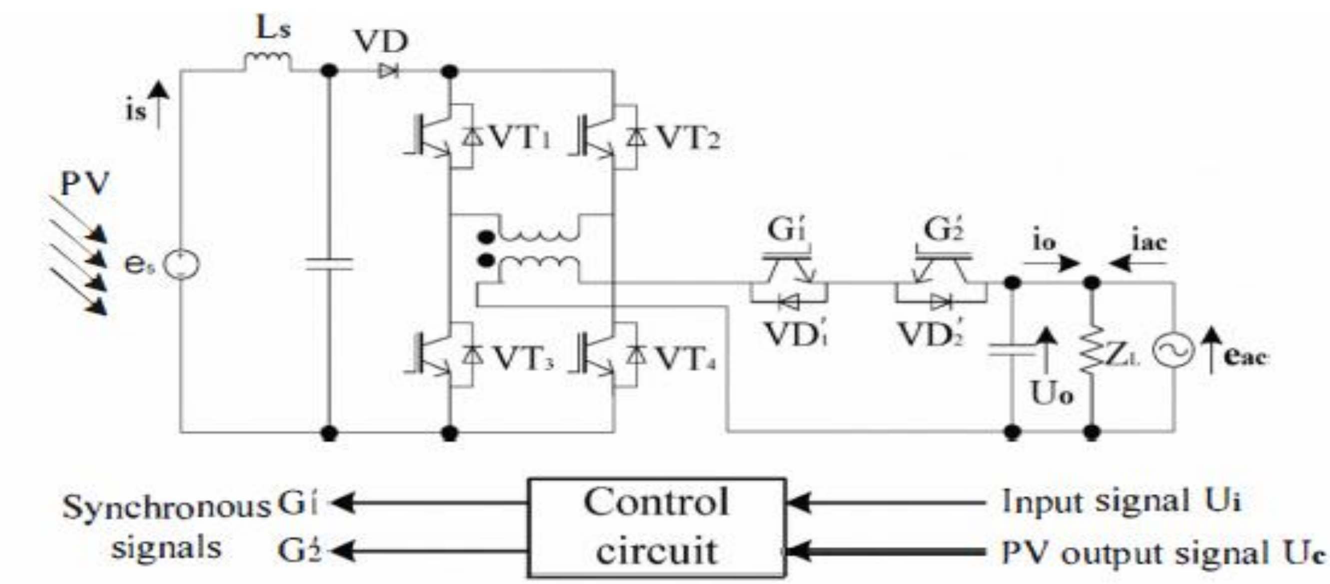
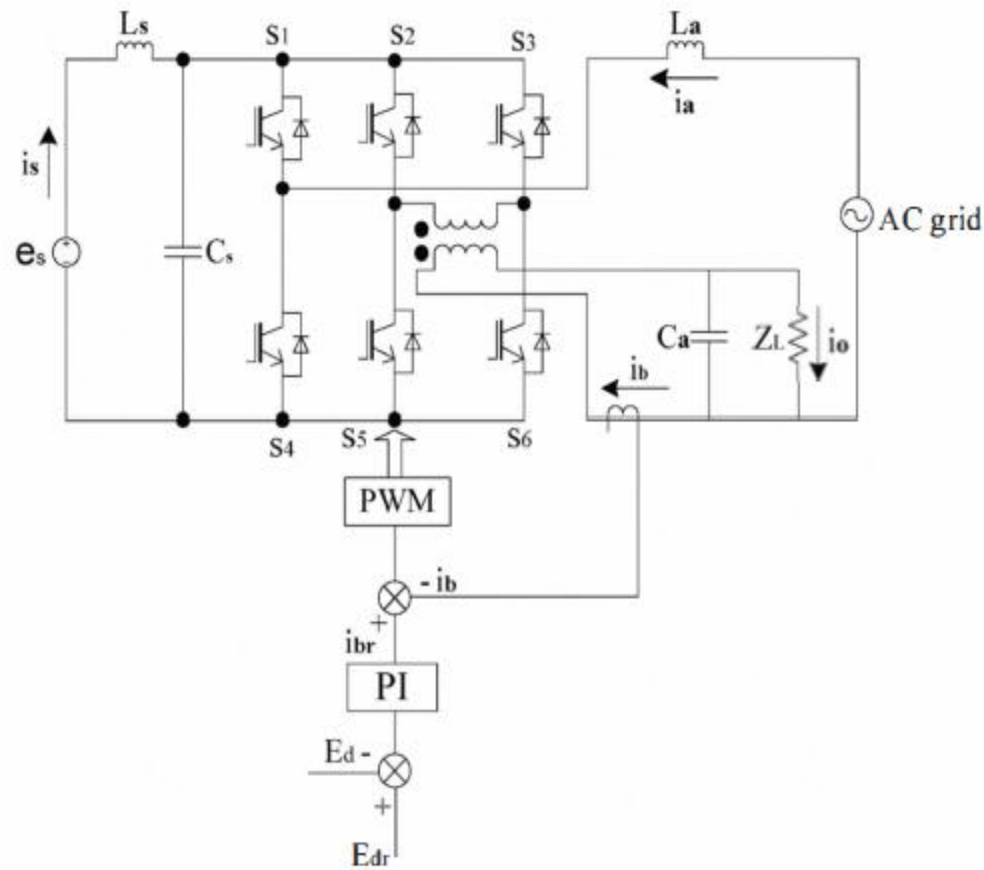


3.4 Power type PWM inverter control system

3.2.3 Improved PWM inverter control method

In improved PWM inverter control method the two reverse diodes used in power type PWM is removed. And the setting of the drive voltage phase of the inverter is based on the grid voltage phase which means the output power factor will be kept to a high value. The improved PWM inverter control system also use the outer loop to control voltage and the inner loop to control current which is the same with the voltage source inverter control, and then it tracks the maximum power point after using the output current transforms to a fit type, which can ensure maximum power output of the battery. In this way, the system inverter structure is simpler than the power-type PWM, and ensures the stability of the power output. The improved PWM inverter circuit can realize the following mode. For one thing, work as AC switch. Using the switch S_1 and S_4 of the three-phase inverter module, it can separate the system from grid when power off, instead of the AC switch S_W. For another, work as inverter. Single-phase PWM inverter is composed of switch S_2. S_3. S_5. S_6. When it is in parallel operation mode, $S_1 = S_2$, $S_4 = S_5$, so the output port P_1 and P_2 are connected. However, when the system is in independent mode, the port S_1 and S_4 are not conducted, the inverter related to the load will be cut off from the grid. The requirement for the system is the inverter output power shouldn't be delivered from DC side to the AC grid in any circumstance. This improved type PWM inverter control method adopted the isolated transformer to allow the load to achieve the required voltage, which plays an important role of separating AC system from DC system.



3.5 Improved type PWM inverter control system

The control system is composed of three parts which are AC voltage control, DC voltage control and phase angle control. As to the AC voltage control part, let's set the AC output voltage to E_o, and its standard voltage is E_{or} , this signal reflect the phase of source voltage, directly impact power transmission between AC grid and DC system. Additionally, it should add a control signal which maintains a certain DCvoltage. Based on the two signals, sine function generator produces the AC control standard voltage.Inside of the voltage control loop contains current control loop which it is not directly impact the result of voltage control. In actually fact, the PV output current is not the same with DC source. Because this current contains the high frequency component including output of active filters, time constant of current regulator should not choose too large.

As to the DC voltage control part, the AC output power of inverter is set to P_b which corresponds with the power P_d of the DC side. P_a is the power received from grid.

$$P_a = P_o – P_b = P_o - P_d$$

According to the power symbol, the direction of power can be determined. As to the phase angle control part, the DC voltage E_d will change once unbalance between the output power P_s of PV cell and output power Pd which produce $\Delta P = P_s - P_d$. Through using DC feedback method, E_{dr} and standard value are the same, and then the phase θ which is related with the operating angular frequency will be determined.

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

The relationship among operating angular frequency ω, standard frequency ω_o and slip angular frequency Δω is shown here.

$$\omega = \omega_o + \Delta\omega$$

Δω can also be calculated through determining power deviation, the equation is shown

$$\Delta\omega = K_p(E_{dr} – E_d)$$

If Δω is too large, the control system may be unstable, so saturation circuit should be set to restrict Δω to change too large.

CHAPTER 4

CONCLUSION

Improved PWM inverter control system is based on the voltage type control method and the PWM power type control method. The result of simulation and conclusions shows that the improved PWM inverter control method can make the voltage and the current waveform of the grid tend to sine wave effectively and quickly, and the power factor will reach to one. The power can be sent to the grid or load arbitrary through controlling the PWM regulator, while the control system has a good stability. It also shows that as the increasing number of inductive load penetrate the grid, the load waveform distortion is produced, but it will not affect the reliability of power supply.

There are many inverter control system which are used at present but there are several problems which is to be solved for better stability of the grid connected system. So, it’s very important and researches are being done for grid connected pv generation inverter control system.

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