Reactive Power Controller Design for Single- Phase Grid- Connected Photovoltaic Systems

EhsanRezapour, Md. Tavakoli Bina, Amin Hajizadeh

Abstract-Lack of adequate transmission capacity is a major impediment in connecting more of renewable energy sources (wind, solar) into the transmission grid.This paper at first presents a control algorithm for a single-phase grid-connected photovoltaic system in which aninverter designed for grid-connected photovoltaic arrays can synchronize a sinusoidal current output with a voltage grid. The power provided by the PV panels is controlled by a Maximum Power Point Tracking (MPPT) algorithm based on the incremental conductance method specifically modified to control the phase of the PV inverter voltage. The controller feeds maximum active power intogrid at unity power factor, whereas it also allows the adjustment of reactive power injected into the grid. Simulation results show that the control system has good performances.

Index Terms — grid connected, photovoltaic system, reactive power,MPTT Algorithm

I. INTRODUCTION

PHOTOVOLTAIC (PV) solar energy as an alternative resource has been becoming feasible due to enormous researches and development work being conducted over a wide area (Bahu, 1996), (Chiang, 1998), (Hirachi, 1996) and (Yamaguchi, 1994). Some researchers spent efforts in developing PV inverter systems with grid connection and active power filtering features using sensors to measure the load current (Wu, 2005), (Kim, 1996), (Cheng, 1997) and (Kuo, 2001). This paper presents a single-phase topology, without load current sensor, composed by a dc-dc converter in cascaded with an inverter, as shown in Fig. 1. The system aims transferring the photovoltaic (PV) power to the ac load and paralleled with the utility. The dc-dc converter is used to boost the PV voltage to a level higher than the peak of the voltage utility such that the inverter can provide the ac voltage without requiring the transformer. The dc-dc converter is also responsible for tracking the maximum power point (Koutroulis, 2001) and (Zhang, 200) of the PV modules to fully utilize the PV power. The shortage of load power from the PV module is supplemented by the utility. On the contrary, the excessive power from the PV module to the load can be fed to the utility. The balance of power flow is controlled through the inverter. The inverter also is used to act always as an active power filter to compensate the load harmonics and reactive power such that the input power factor is unity (Fig. 2).Iconverts the DC output voltage of the solar modules intothe AC system.

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The grid-connected photovoltaic (PV)system extracts maximum power from the PV arrays. Themaximum power point tracking (MPPT) technique is usuallyassociated with a DC-DC converter. The DC-AC injects thesinusoidal current to the grid and controls the power factor.An important aspect related to the photovoltaic systemconnected to the electric grid is that it can operate the doublefunctions of active power generator and reactive powercompensator. The proper power factor is selected accordingto active power and reactive power that the grid demands.At the same time, it can supply reactive power to theelectrical grid when there is little or no solar radiation. Thatis important for compensing the reactive power at peakhours, when the main grid needs a amount of reactive powerhigher than average consumtion. Although the photovoltaicsystem does not generate active power in such period oftime, it can supply reactive power up to its maximum.This inverter control strategy is not only capable tocontrol the active power, but also dynamically reconfiguredto change the magnitude of the reactive power injected intothe grid. Some solutions are proposed [1-6], [10], to obtain ahigh reliability inverter. The basic idea of the proposecontrol is to obtain a low cost and simple controller. In thismethod, the active power is controlled by load angle and thereactive power is controlled by inverter output voltagemagnitude. The controller feeds maximum active power intogrid at unity power factor, whereas it also allows theadjustment of reactive power fed into the grid.

II. OPERATIONAL PRINCIPLES

The power stage of the single phase inverter connectedto the grid in the Fig.1 explains the inverter output current.

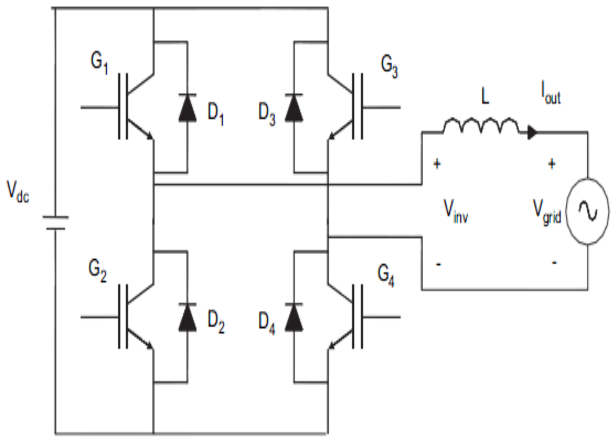

Fig.1.Single-phase inverter connected to the grid

The current of the inverter connected to the grid must begot from a PV panel. The analysis is based on inductorcoupling and applied for other types of output filterconfigurations, such as L, LC, LCL, etc [1,4,9].

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In order to explain the circuit characteristics, the Fig.2 represents the phase diagram of the undamentalcomponents, including the inverter output voltage (E), theinverter output current (I), the drop voltage on theinductance L (jXsI=jωLI), and the fundamental componentof the grid voltage (U). [8].

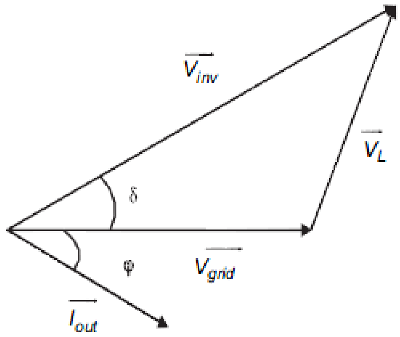

Fig.2.Phase diagram with Vinv, VL, Vgridand Iout.

φ is represented as the power angle between the grid voltage and the inverter output current. And, δ is representedas the load angle between the grid voltage and the inverteroutput voltage. The phase diagram is shown in Fig. 3. Thefollowing relations can be represented:

$$E = U + jX_s I \quad (1)$$

$$E\sin(\delta) = X_s I\cos(\varphi) \quad (2)$$

The active power (P) provided by the converter to thegrid can be expressed as:

$$P = UIcos(\varphi) = \frac{UE}{X_s} sin(\delta)\ (3)$$

And the reactive power (Q) provided by the converter tothe grid, can be expressed as:

$$Q = \frac{UE}{X_s} cos(\varphi) - \frac{U^2}{X_s} = \frac{U}{X_s}(E\ cos(\delta) - U)(4)$$

According to figure 3, equations (3) and (4), the powerflow adjustment of the inverter is parallel connected to themain grid, can be performed by controlling the inverteroupput voltage magnitude (E) and load angle (δ). On theother hand, to inject power to the grid, the value of the DCvoltage must be high enough so that the output voltage Ecan get a value which is equal or greater than the grid peakvoltage.From equation (3) and (4), the active and reactive powerdepend on both the inverter output voltage magnitude E andthe load angle δ[6]. So, the active power injected into thegrid can be controlled by the phase difference between gridvoltage and inverter output voltage δ. At the same time, thereactive power can be controlled by the inverter outputvoltage magnitude E.

III. PROPOSED CONTROL IMPLEMENTATION

The proposed control structure for a single-phaseinverter connected to the grid is shown in Fig.4. The photovoltaic system consists of photovoltaic generator (PVarray), DC/DC converter with maximum power pointtracking (MPPT), a single phase inverter and an active andreactive power controller. The control circuit has two parts: the first one controls the active power injected into the grid by the load angle δ, and the second one controls the reactivepower through the inverter output voltage magnitude E.

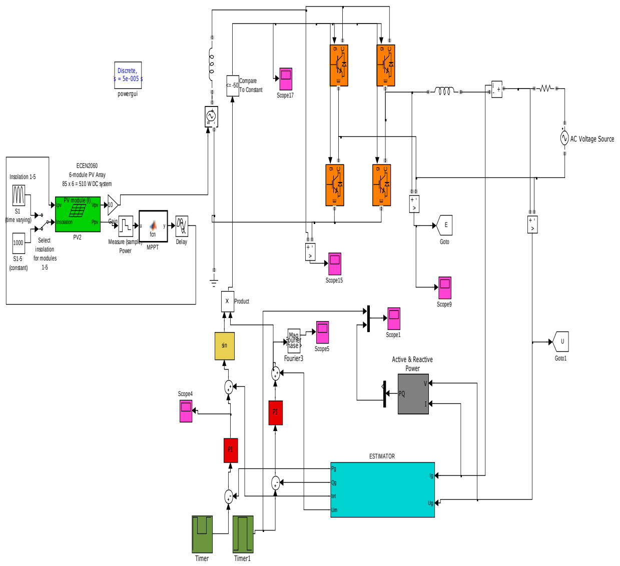

Fig.3.simulink diagram of case study system

As show in figure 3, the controller compenses thereactive power injected into the grid (Qg) and compares itwith its reference (Qr), originating an reactive power error.This error passes through an PI controller and it is added togrid voltage amplitude (Um≈const), resulting the inverteroutput voltage amplitude (Em). On the other hand, the controller produces the active power generated by theinverter (Pg) and compares it with a reference signal (Pr),generating an active power error. This error passes throughanother PI controller, originating reference load angle (δ).The load angle is added to grid voltage phase angle (θu),generating inverter output voltage phase angle (δ+θu). Theinverter output voltage amplitude (Em) is multiplied bysin(δ+θu), resulting the instantaneous value of the inverteroutput voltage (e) – the DC/AC inverter reference signal.The grid voltage:

$$u = U_m sin(\omega t) = U_m sin(\theta_u) \quad (5)$$

And$\delta \sim P\ and\ \Delta E \sim Q$

Inverter output voltage:

$$e = E_m\ sin(\theta_u + \delta) \quad (6)$$

Where:

$$E_m = \Delta E + U_m (7)$$

The main advantage of this control strategy is itssimplicity related to the computational requirements of thecontrol circuit and hardware implementation. By anotherway, it allows controlling not only an active power needs tobe injected but also a reactive component. When the reactivepower reference is zero, the power factor will approach tothe unity.

IV. SIMULATION RESULTS

MATLAB/Simulink software were used in allsimulations accomplished here which show the resultsobtained for voltage and current waveforms, active, reactiveand apparent powers on the AC side supplied to the grid.The rate value of grid voltage (U=220Vrms) and the inverteris connected to the grid through a coupling inductanceL=10mH. Simulations at low-power scale (1 kVA) isimplemented in predicting the behaviour of the system forthe experiments to be performed on the laboratory testbench.

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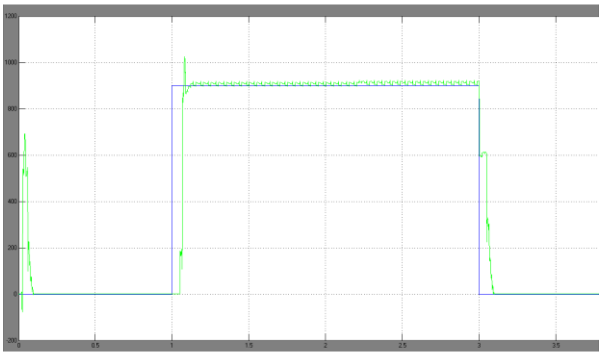

Fig. 4: Reactive Power supplied by the inverter with 100%-50%-100% of photovoltaic system power.

The simulation results obtained for steady-stateoperation are shown in Fig. 4. Active and reactive powerresponse has good performance. The active power andreactive power injected into the grid for four generationconditions: [P,Q]=[0%, 0%], [100%, 0%], [50%, 0%], [50%,87%].

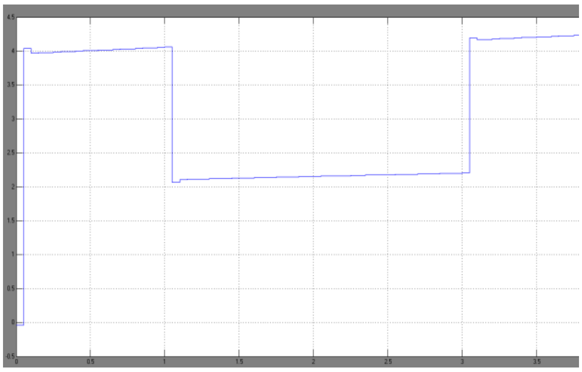

Fig.5.Load angle δ[degree]

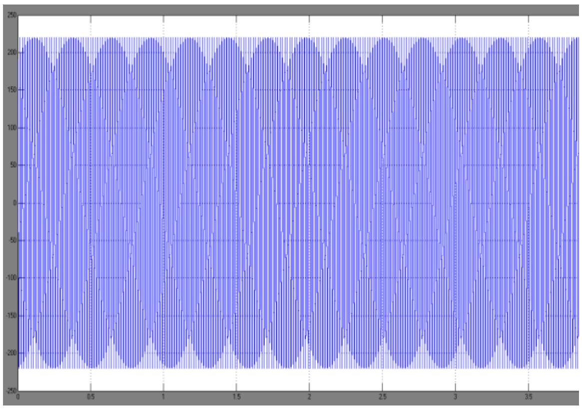

Fig. 6.Inverter output voltage E [Vrms].

As observed in figures 4 to 6, when the active power isreduced, the control is adjusted to increase the reactivepower supplied capacity. Hence, the values of invertercurrent and the apparent power injected into the grid can getthe rate values whereas the solar radiation is low. [7].The active power supplied by the photovoltaic system tothe grid presented a agreeable performance, due to a resonablesystem response. When there is sunstroke variation, thesystem adjusts to a new reference of active power with a goodperformance. Moreover, it was observed an interactionbetween the active and reactive powers delivered to the grid.So, the system takes advantage of the moments of little activepower generation to accomplish the compensation of reactivepower.

V. CONCLUSION

GPL shows its effectiveness and attraction when it draws areal interest of students majoring in Power. Engineering.Students are really interested in new concepts, newtechnologies introduced into the curriculum. In addition, theintroduction of micro electronics and DSP techniques intothe renewable energy field really makes the subject state-oftheart and more interdisciplinary. Power electronics,electrical machines, dsp, microelectronics, controltechniques, all integrated in the discipline gives even moreattractiveness to students.

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