Control Methods for Three Phase PWM Inverter in Distributed Generation a Survey

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Abstract— This paper presents the effective control strategies for the control of three phase PWM inverter connected to the distributed generation. This inverter is used to convert the DG output to the alternating quantity as required by the load and also to interface the DG unit to the grid. The different schemes can be used to control the inverter are studied and summarized for both the islanded and grid connected mode of operation. Finally hybrid voltage and current mode control method and unified control method are simulated in MATLAB and their results are discussed.

Key words: Distributed Generation, PI controller, PLL, PWM inverter, SRF

I. INTRODUCTION

DISTRIBUTED generation (DG) is emerging as a viable alternative when renewable or nonconventional energy resources are available, such as wind turbines, photovoltaic arrays, fuel cells, micro turbines. Most of these resources are connected to the utility through power electronic interfacing converters, i.e., three-phase inverter. Therefore Inverter-based distributed power generation systems (DPGSs) have received much attention recently due to flexible power-controlling capability. Usually, the inverter with the grid-following control is used to accomplish power conversion between the grid and DPGSs. However, this method may suffer from voltage stability, frequency variation, voltage harmonics, and cannot work in the islanding situation. Instead of the grid-following control, the grid-forming inverter is preferred because it is able to provide many ancillary services defined in IEEE Std. 1547[5], such as load regulation, reactive power compensation, and power quality improvement.

Distributed generation offers many advantages such as

1) Peak shaving to reduce the overall cost of power by generating during peak load hours when the cost of electricity is high and
2) Standby generation to provide power during system outages until service can be restored. Both of the above advantages can be effectively utilized if the distributed generation system is utility-interactive.

In the grid-tied operation, DG deliveries power to the utility and the local critical load. Upon the occurrence of utility outage, the islanding is formed. Under this circumstance, the DG must be tripped and cease to energize the portion of utility as soon as possible according to IEEE Standard 929-2000[7]. However, in order to improve the power reliability of some local critical load, the DG should disconnect to the utility and continue to feed the local critical load. The load voltage is key issue of these two operation modes, because it is fixed by the utility in the grid-tied operation, and formed by the DG in the islanded mode, respectively. Therefore, upon the happening of islanding, DG must take over the load voltage as soon as possible, in order to reduce the transient in the load voltage. And this issue brings a challenge for the operation of DG.

This paper presents a survey on the techniques to control the three phase inverter in distributed generation to operate in both the islanded and grid connected mode. Those controlling methods are, Hybrid voltage and current mode control [1], droop controlled strategy [2], unified control strategy [3].

The remaining paper is structured as follows. Firstly, the inverter control block diagram is presented in Section II. A detailed description of the three methods used to control is discussed in III. Section IV shows the simulation and results. The paper is concluded in Section V.

II. BLOCK DIAGRAM OF THE SYSTEM TO BE CONTROLLED

The block diagram for the system to be control is as shown in Fig. 1

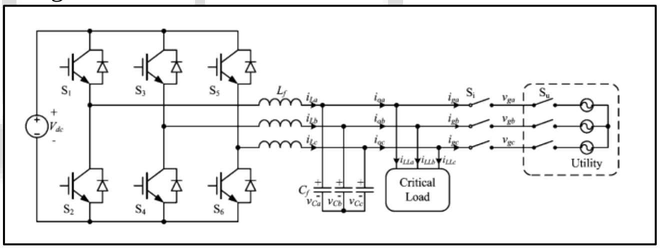

Fig. 1: Block Diagram

The DG is equipped with a three-phase interface inverter terminated with a LC filter. The primary energy is converted to the electrical energy, which is then converted to dc by the front-end power converter, and the output dc voltage is regulated by it. Therefore, they can be represented by the dc voltage source V_{dc} in Fig. 1. In the ac side of inverter, the local critical load is connected directly. It should be noted that there are two switches, denoted by S_u and S_i, respectively, in Fig. 1, and their functions are different. The inverter transfer switch S_i is controlled by the DG, and the utility protection switch S_u is governed by the utility. When the utility is normal, both switches S_i and S_u are ON, and the DG in the grid-tied mode injects power to the utility. When the utility is in fault, the switch S_u is tripped by the utility instantly, and then the islanding is formed. After the islanding has been confirmed by the DG the switch S_i is disconnected, and the DG is transferred from the grid-tied mode to the is landed mode. When the utility is restored, the DG should be resynchronized with the utility first, and then the switch S_i is turned ON to connect the DG with the grid.

III. METHODS TO CONTROL THE INVERTER

A. Hybrid voltage and current mode control

In the grid connected mode a desired condition is that the load voltage must be synchronized with the grid voltage. In unity power factor operation, it is essential that the grid reference current signal is in phase with the grid voltage. This grid synchronization can be done by using a PLL.

Using the current control method the output power of DG and the voltage at the PCC is measured and compared with a reference signal which has been transformed into a synchronous reference frame by Park's transformation is given in eq1 and regulated DC quantity, is fed back and compare with the reference current I_{DQref}. This generates a current error that is passed from the current regulator and feed to PI controllers. The output of the PI controllers is used for calculating the modulation index and the angle of the modulating signal. The real and reactive power is regulated by the current controller and it is performed in d-q frame transformation. The real and reactive power is controlled by the line current values. The feedback and feed forward signals are first transformed to the d-q frame and then process by controllers to produce the control signals in d-q frame transformation. The reference voltage in DC contents V_{DQref} is changed into a stationary structure by the inverse of Park's transformation is utilized as control voltages in generating high-frequency pulse width-modulated voltages (SPWM).

At the time of fault occurs in the main grid the voltage and frequency deviates from its standard allowable values hence the islanding of DG will happened. Throughout this condition the control mode changes. The frequency is set fixed at a particular standard value. The voltage at the PCC is measured and compared with the standard values. The error is accepted to a PI controller to find out the modulation index value.

Three sinusoidal waveforms shifted by 120 Degrees are produced using the modulation index and are compared with a high frequency triangular waveform to find out the on-off signals of the inverter switches.

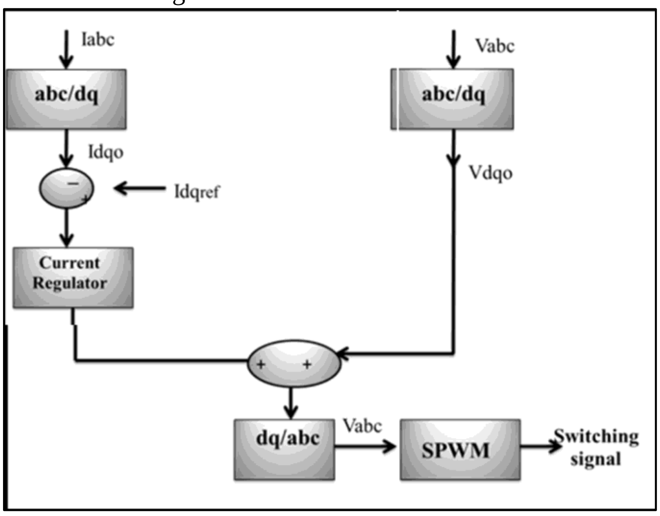

Fig. 2: Current Control for Grid-Connected form of Operation

As shown in the Fig. 3, the load voltages (V_D and V_Q) are forced to follow its reference signal by using a PI compensator (voltage control device). The outputs of this compensator (I_{Dref} and I_{Qref}) are compared with the load current (I_D and I_Q), and the error is transferred to current regulator (PI controller). The output of the current compensator acts as the reference voltage signal that is fed to the sinusoidal pulse width modulator to generate the high frequency gating signals for driving the three-phase voltage source inverter.

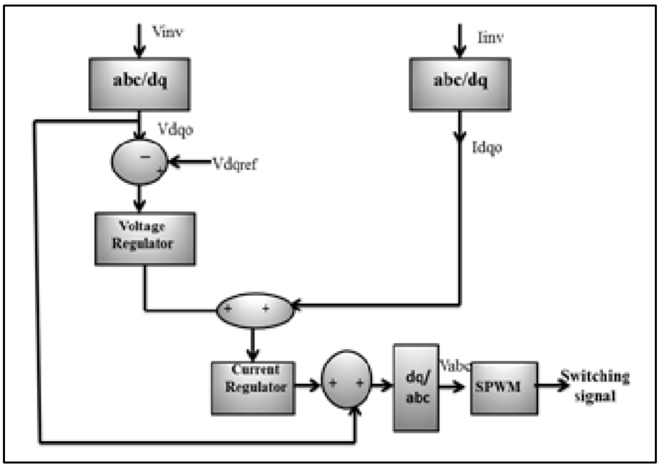

Fig. 3: Voltage Control for Islanded form Of Operation

B. Droope Control Stategy

Fig. 4 shows a droop-controlled voltage source inverter intended to supply power to the local load as well as the utility.

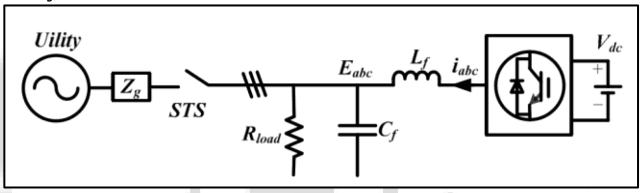

Fig. 4: Droop-controlled voltage source inverter

The voltage command is determined according to both frequency-real power and voltage-reactive power droops. Droop equations and their definitions are given in (1). Thus, various inverters are able to share workloads if their droop coefficients are chosen in inverse proportion to their rated capacities, as given in (2).

$$\omega = \omega_0 - m.(P_0 - P); E = E_o - n.(Q_o - Q) \quad (1)$$

$$\left. \begin{array}{l} -m_1 P_{o1} = -m_2 P_{o2} = -m_3 P_{o3} \cdots \\ -n_1 Q_{o1} = -n_2 Q_{o2} = -n_3 Q_{o3} \cdots \end{array} \right\} \quad (2)$$

Where the ω_o is the nominal frequency, P_o is the output rated real power, E_o is the nominal voltage, Q_o is the rated output reactive power, m is the P-f droop coefficient and n is the Q- v droop coefficient. Based on the voltage command, a proportional control plus the feed forward of the voltage command is realized to regulate output voltage in the stationary reference frame. Due to the feed forward, inverter voltage can be controlled with acceptable steady-state and transient behavior. In addition, the differentiating of capacitor voltage is fed back in order to reduce the resonance on the filter capacitor C_f. As can be seen, a proportional gain K_d can be designed to accomplish a critical damped response for the voltage control loop of the inverter. Finally, PWM is realized to produce the switching signals of the inverter.

C. Unified control Strategy

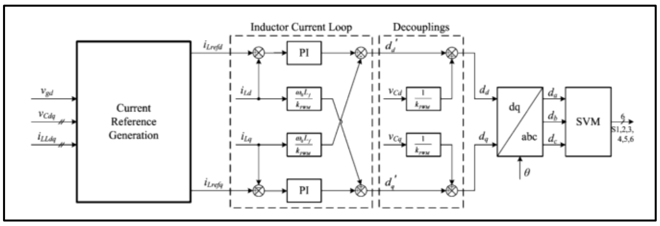

Fig. 5: Block diagram of Unified control Strategy

In the inductor current loop, the PI compensator is employed in both D- and Q-axes, and a decoupling of the cross coupling denoted by ω_{0L_f}/k_{PWM} is implemented in order to mitigate the couplings due to the inductor. The output of the inner current loop d_{dq}, together with the decoupling of the capacitor voltage denoted by $1/k_{PWM}$, sets the reference for the standard space vector modulation that controls the switches of the three-phase inverter. It should be noted that k_{PWM} denotes the voltage gain of the inverter, which equals to half of the dc voltage. Fig. 5 describes the overall block diagram for the unified control strategy, where the inductor current i_{Labc}, the utility voltage v_{gabc}, the load voltage v_{Cabc}, and the load current i_{LLabc} are sensed. And the three-phase inverter is controlled in the SRF, in which, three phase variable will be represented by dc quantity. The control diagram is mainly composed by the inductor current loop, the PLL, and the current reference generation module.

IV. SIMULATION RESULTS AND DISCUSSION

To verify the control methods discuss above, hybrid voltage and current control strategy and unified control strategy are simulated in MATLAB and their results are discussed below. The power rating of a three-phase inverter is 3kW, The RMS of the rated phase voltage is 115 V, and the voltage reference V_{max} is set as 10% higher than the rated value, rated utility frequency is 50 Hz.

In the grid-tied mode grid current reference from 9A to 5A to check the grid disturbance condition. And the simulation results are shown in Fig. 6 and Fig.7.

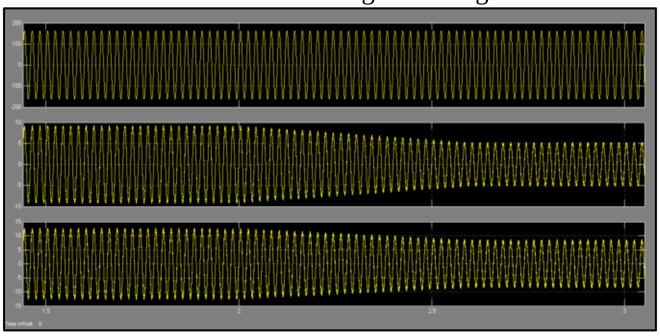

Fig. 6: Simulation results of hybrid voltage and current mode control in grid tied mode.

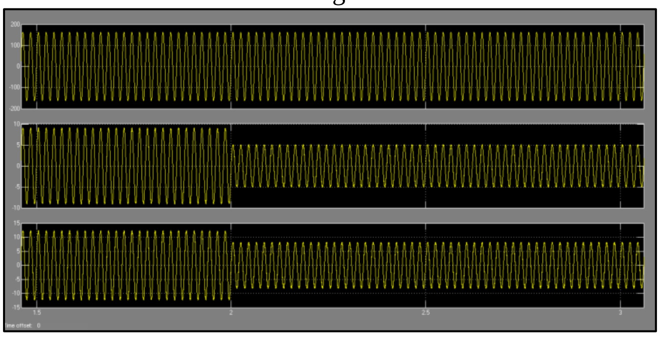

Fig. 7: Simulation results of unified control method in grid tied mode

Also the transition condition from grid connected mode to the islanded mode is simulated and the results of simulation are shown in Fig. 8 and Fig. 9

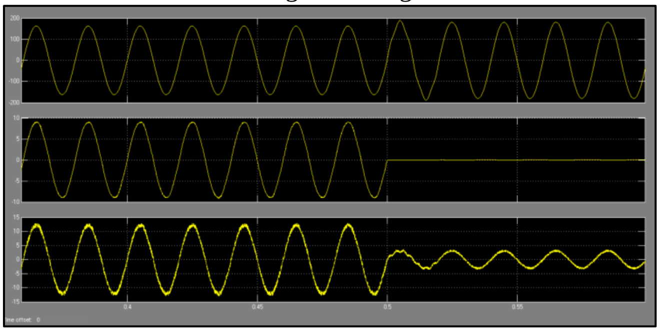

Fig. 8: Simulation results of Hybrid voltage and current mode control

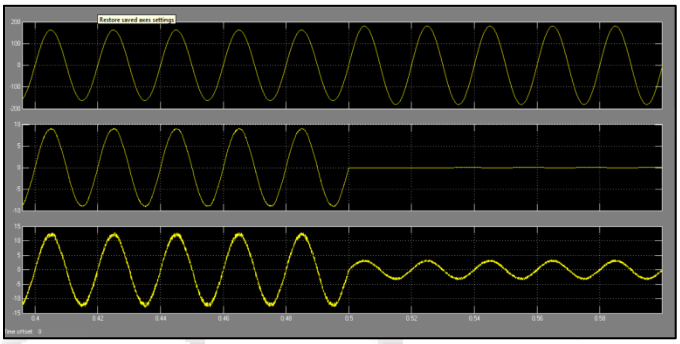

Fig. 9: Simulation results of unified control Strategy

V. CONCLUSION

In this paper, a review of control methods of three phase inverter in distributed generation is done. The hybrid voltage and current control method, droop control method and unified control method are explained. In the last the hybrid voltage and current control method and unified control method are simulated to get the results. The results of inverter switching using these two methods are compared for the effectiveness. The studies and research are been carried out to improve the regulation of output power of DG during the switching from grid connected mode to the islanded mode islanded mode.

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