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Active & Reactive Power Control for Three Phase Inverter

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ABSTRACT

This paper acknowledges about the active and reactive power control for three phase system. The active and reactive power strategy is proposed to control three phase grid inverters with proportional resonant. By current loop on stationary reference frame both active and reactive powers are controlled and regulated. The design methodologies of proportional resonant controller and lowpass filtering are presented. Finally, the proposed method is evaluated by simulation.

Keywords - instantaneous power, instantaneous reactive power theory, inner current control loop, spwm technique.

1. INTRODUCTION

Three phase power system consisting of sinusoidal voltages and sinusoidal currents. Due to sinusoidal wave present in ac wave only hence active, reactive, apparent power present in ac circuit not in dc circuit. For resistive load reactive power is absent. For inductive and capacitive (non-linear) load reactive power is present.

A grid-connected inverter with an inner current control loop plays an important role in order to inject the high power quality to the grid. The current control approach in dq rotating frame is simple and easy to design and implement with low gain, however, the main drawback is the poor ability to attenuate high frequency noise. As a result, the associated noise that may be considered by the controller as errors can be amplified and feedback into the system.

Active and reactive control of three phase inverter is the most important topic to utilize renewable source of energy and technique which is used is called as sinusoidal pulse width modulation (SPWM).

2. INSTANTANEOUS POWER

To understand what is active, reactive power we should first know what is instantaneous power. If want to measure instantaneous power at one particular instant, then simply multiply voltage and current at that particular instant is called as instantaneous power.

$$P = VI$$

This power can be positive or negative. If power flowing from source to load is called as positive power.

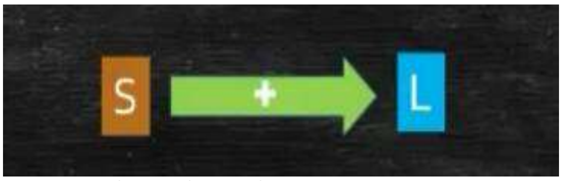

Fig. (1) Positive power If power flowing from load to source is called as negative power.

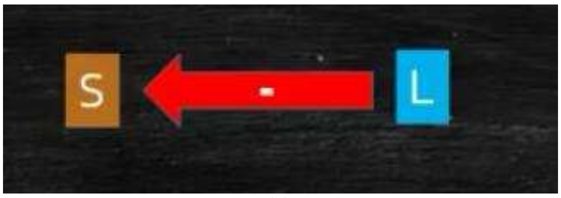

Fig. (2) Negative power

3. ACTIVE POWER

To understand active power consider resistive load circuit. In case of resistive circuit voltage and current in phase means both voltage and current will reach there positive peak, zero, negative peak at the same time. If both voltage and current is multiply at any instant then power remain positive at every instant this type of power is called as active power.

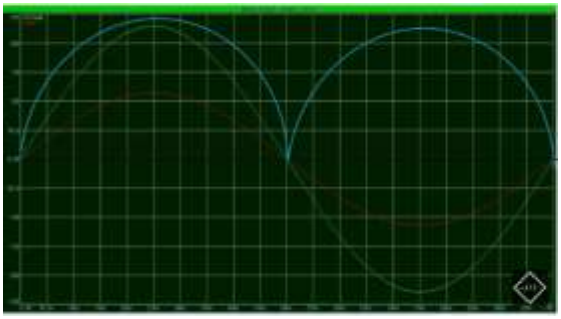

Fig. (3) Waveform of resistive circuit

Properties of Active Power:

- Power is always positive.
- It does not change its direction.
- Power always flowing from source to load
- It is denoted by letter "P" and measured in "WATTS"

4. INSTANTANEOUS REACTIVE POWER THEORY

The instantaneous reactive power theory is also called as instantaneous power theory. This theory is used in time domain and it also uses park transformation. There are no limitation on imposition of current or voltage waveforms. Thus, three phase current and voltage waveforms are obtained by applying park transformation to the three phase system with or without neutral wire. Thus this theory is also applicable to steady state as well as transient state. The efficiency of this theory is relatively high and used for designing controller for power conditioner.

This technique is used to calculate active and reactive according to the requirements of the load. To calculate the reference current of series and shunt active filter are also calculated by using this method. The theory is also known as p-q theory. This theory is based on Clarke transformation in which tree phase current and voltages are in a-b-c co-ordinates are converted into α-β-0 co-ordinates.

The formulae for active and reactive power in Clarke transformation are as follows:

$$\text{Active power} = \frac{3}{2}\left[V_d I_d + V_q I_q + V_0 I_0\right]$$

$$\text{Reactive power} = \frac{3}{2}\left[V_q I_d - V_d I_q\right]$$

5. GRID CONNECTED THREE PHASE INVERTER STRUCTURE

Below Fig. (5) represents the structure of grid-connected three-phase inverters consisting of various components. These components are dc source, a three-phase inverter, a digital controller, a low-pass filter and an isolated transformer. Where dc source is represented by V_{dc}, switches represents three phase inverter, digital controller is internally connected and low pass filter (i.e. combination of C_f ,R_d and L_f)

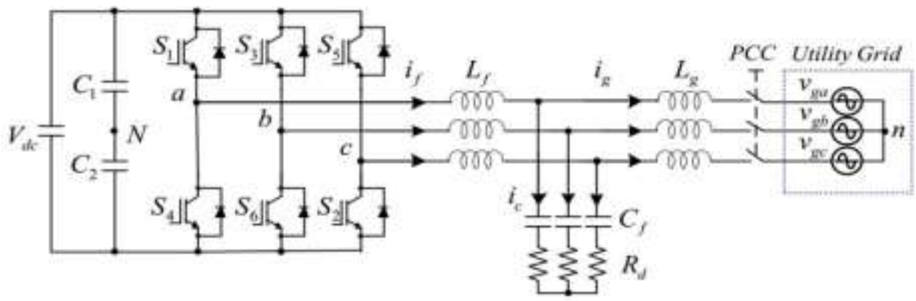

Fig. (5) Grid Connected Three Phase Inverter Configuration

The simulation parameters are as shown below:

Parameter	Value	Unit
Inverter three phase voltage source, VSI	3000	W
DC source programmable, v_{DC}	750	V
Line-to-Line voltage, v_{L-to-L}	380	V_{rms}
Grid frequency, f	50	Hz
Inductor filter inverter side , L_f	2.3	mH
Capacitor filter ,C_f	10	μF
Damping Resistor , R_d	5	Ω
Inductor Grid side , L_g	1.8	mH
Switching frequency , f_s	16	kHz
Gain k_p ,k_i	10, 5000	-

6. Inner Current Control Loop

The block diagram of inner current control loop is shown in below Fig. (6) The block diagram consists of three main components. These components are proportional plus PR controller, time delay (from signal processing) and the plant that represents the filter. The transfer function of the PWM is given by

$$G_d(s) = e^{-1.5T_d s}$$

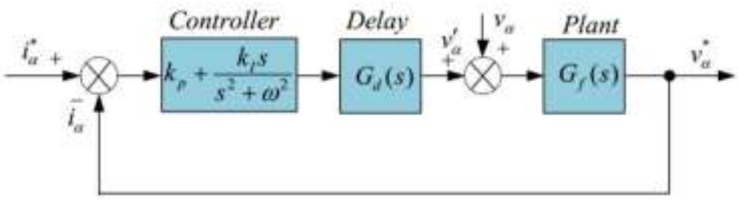

Fig. (6) Block Diagram of Inner Current Control Loop

The open loop transfer function of the current loop in above figure is given by

$$G_{OL}(s) = G_{PR}(s)\; G_d(s)\; G_{LCL}(s)$$

The associated closed loop transfer function is given by

$$G_{CL}(s) = \frac{G_{PR}(s)\; G_d(s)\; G_{LCL}(s)}{1 + G_{PR}(s)\; G_d(s)\; G_{LCL}(s)}$$

The reference current for the design of the resonant-based control system is determined in order of the reference voltage v_α^*. Consider the open loop frequency response of the control loop in below figure.3. In the design, we chose $\omega_0 \approx 2500\ rad/sec$ and $\omega_{cn} \approx 20\%$ of ω_0. Therefore, $K_p = 9.6$ and $k_i = 5000$ are obtained, which meet the appropriate phase margin and gain margin of 52.6deg and 13.2dB.

7. SINUSOIDAL PULSE WIDTH MODULATION TECHNIQUE (SPWM)

The SPWM stands for sinusoidal pulse width modulation. Constant dc input voltage is given to inverter which is converted into ac output. The PWM technique is used to control the voltage magnitude and frequency of the output. There are various method used for pulse width modulation. The SPWM technique is designed to control the inverter output voltage and output voltage and output frequency directly.

The SPWM technique is mostly used in power electronic because of its simple construction and easy to control. In this technique the power switches are used to generate the voltage pulse which is used to represent the power. In SPWM technique the pulses of constant amplitude with different duty cycles for each interval(period) are used. The inverter output voltage with the reduction in harmonics are obtained by modulation of width of pulses. The SPWM are used in various types of applications. Examples: Industrial, solar EV application, inverters and motor control etc.

In SPWM technique a high frequency carrier wave and three sine waves are 120° phase shifted and used for $3\emptyset$ inverter. These sine wave are also called as reference signal whose frequency is dependent on the output frequency of inverter. The comparison between sine waves and carrier wave gives the switching signal.

When the sine voltage is greater then carrier(triangular) voltage then comparator gives a pulse. With the help of pulses triggering of inverter switches are takes place. In inverter switches of any leg cannot be switch off directly continuously in order to avoid undefined switching.

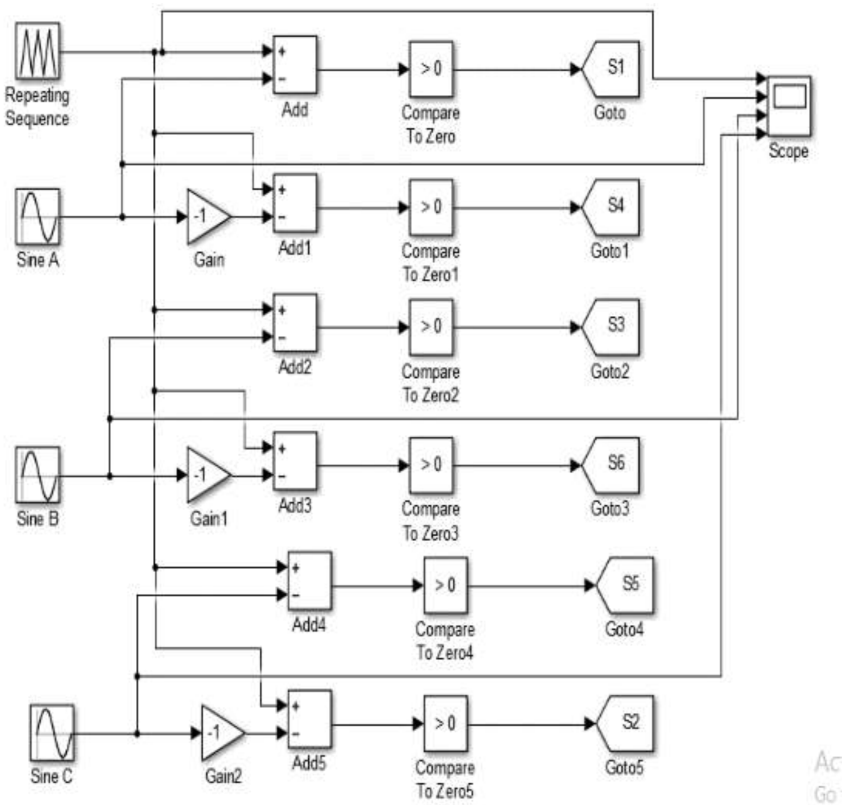

Fig. (7) SPWM Block

8. FILTER

This section represents the analysis and design of a low-pass filter for three-phase grid-connected inverters. The main problem when connecting the inverter to the grid is the current quality that often violates the constraints imposed by the standards. This is due to the ac output voltage and current of an inverter that normally operates at high switching frequency are subject to high frequency noise. A low-pass filter, i.e. LCL-filter, is normally used to suppress harmonics generated by grid-connected inverters that results in the improvement of voltage and current qualities. The LCL filter design procedure is presented as follows:

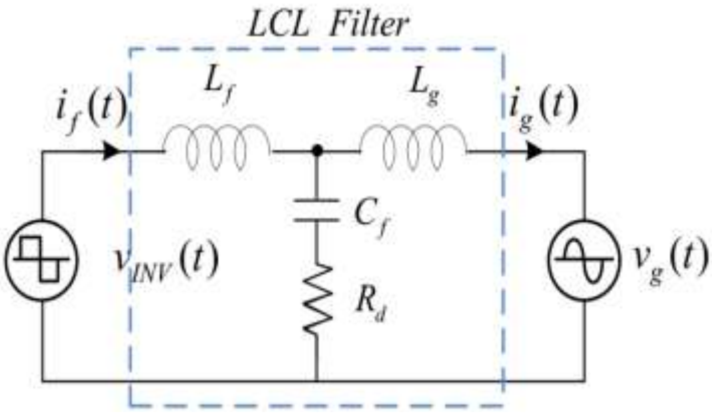

Fig. (8) LCL FILTER

The transfer function of the filter for the output current of the inverter when the grid voltage is set to zero can be expressed as

$$H_{LCL} = \frac{i_g}{v_i}$$

The transfer function of LCL filter as shown in below figure is then

$$G_{LCL}(s) = \frac{1}{L_1 C_f L_2 s^3 + (L_1 + L_2)s}$$

8.1 Without Filter:

In the absence of filter the large content of harmonic are present at the output. These will distort the output and the output which is obtain is not accurate. Fig.(8.1) shows the block diagram of without filter model and waveform.

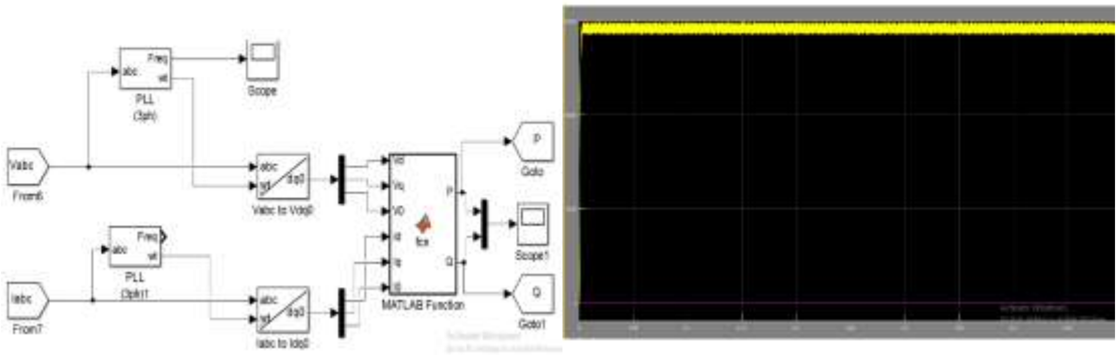
Fig. (8.1) Without Filter Model & Waveform

8.2 With Filter:

In order to attenuate harmonics filter are used. There are various types of filters are available such as RC, LC filter which are known as passive filter. An LCL filter are used to reduce harmonic distortion with lower switching frequencies. It also remains the higher order harmonic from the inverter output to obtained frequency (i.e. 50/60 Hz). Fig.(8.2) shows the block diagram of with filter model and waveform.

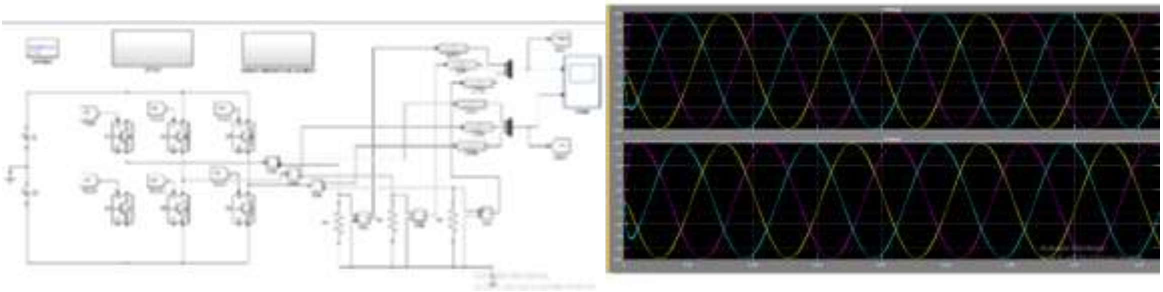

Fig. (8.2) With Filter Model & Waveform

9. Conclusion

This paper presents the design procedures for both proportional plus PR current controller and LCL filter are also detailed. The instantaneous reactive power theory is also discussed. With the help of simulation, the performance of the proposed method is confirmed. With the proposed method, the smooth transition and fast response of the system under various dynamic conditions are achieved. Moreover, the designed LCL filter are also can reduce not only current ripple, but also current harmonics as well.

10. References

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