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Comparison of Voltage Control and Current Control Methods in Grid Connected Inverters

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Abstract: This study presents the comparative evaluation of the performance of the two main control techniques for Grid Connected Inverters. Sinusoidal Pulse Width Modulation voltage controller and hysteresis current controller are considered here. The main control innovations, determined by industrial applications, are presented. Finally, suitable criteria for the comparison are identified and simulations investigation differences in the performance of the controllers in a typical static synchronous var compensator setup.

Key words: SPWM, STATCOM, VSI, hysteresis

INTRODUCTION

Usage of Grid-Connected Inverters (GCI) increased dramatically nowadays. These systems are used in Active Power Filters (APF), static synchronous var compensators (STATCOM), grid connected photovoltaic systems, grid connection of wind turbines and in Fig. 1 general topology of the grid connected inverter is shown. This simple topology is capable of bidirectional real and reactive power flow. When viewed from the utility side, the VSI can act as an ac source, a resistive load, an inductor or capacitor all at the same KVA ratings.

Situation of the DC link depends on the application. For example, in APF and STATCOM, that no real power flows between grid and inverter, it is impossible to connect the separate DC power to the DC link. In Voltage Source Inverters (VSI), there are two basic mechanisms by which the power flow between GCI and grid can be controlled. The first method is through the control of switching instance of inverter so as to produce a fundamental 50 Hz voltage in the output of inverter (Schauder, 1995; Mori, 1999). In this method, the power flow is controlled by adjusting the amplitude and phase of inverter output voltage relative to the line voltage. Since the grid is invariably a rigid voltage source with very low line impedance, power flow from the inverter to the grid, reduces to being simply current flow control and voltage source inverters have been proposed for use as current sources in number of applications (Moon, 1999; Borle and Nayar, 1995; Malesani and Kazmierkowski, 1993; Borle and Nayar, 1996; Jovcic *et al*., 2006; Xiang-lian, 2006).

This study is aimed at both summarizing the main implementation refinements which characterize the latest versions of the voltage source inverter controllers and

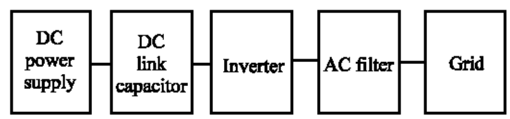

Fig. 1: General topology of the grid connected inverter

comparing the different performance of these two control mechanisms, through simulation. The organization of this study is as follow. This study initially focuses on the identification of proper criteria for correctly comparing of the voltage control and current control mechanisms. Then after a short description of the principles of these methods and the presentation of the main refinements the simulated system is briefly described. Finally the results of comparison that is done according to the chosen criteria are discussed.

MATERIALS AND METHODS

Criteria for comparison of current and voltage controllers: This study was done in lab of electronic, Khaje Nasir Toosi University for 4 month in 2007. The first criteria considered here, is the evaluation of the inverter output current spectrum which identifies the distribution of current harmonics in the different frequency ranges. This is very important point for design of passive filters which smooths the modulation ripple of current and for the evaluation of the capability of the different control mechanisms to meet the International Electro Technical Commission (IEC) standard, requirements. Current spectrum also determines the total harmonic distortion of the output current.

GCI may be used for transient stability improvement, power oscillation damping and increase of voltage

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stability limit and improvement of other dynamic limitations of power transmission (Gyugi, 1994). In these and many other applications (such as reactive power compensation of arc Furnaces) transient response of the GCI should be as fast as possible and for this reason transient response of inverter is chosen as a second criterion (Sood, 2006).

Voltage control and current control of GCI: Power flow between the grid and inverter can be controlled by adjusting the fundamental phase and amplitude of V_{pwm1} relative to V_{an}. (V_{pwm} is output voltage of inverter, V_{pwm1} is output voltage first harmonic of inverter and V_{an} is grid line to neutral voltage). For small angles of δ expressed in radians, the real and reactive power flow can be approximated as:

$$p = (\frac{V1}{Xr})V_{pwm1}\,\delta \quad (1)$$

$$Q = \left(\frac{V1}{Xr}\right)\left[V_{pwm1} - V1\right] \quad (2)$$

In the above equations, V1 is fundamental voltage of grid; V_{pwm} is fundamental output voltage of inverter, X_r is connection impedance and δ is phase angle between V1 and V_{pwm}.

For control purpose it is apparent that the real power varies with δ and the reactive power varies with (V_{pwm1}-V1). This realization lets to the development of voltage phase and amplitude power flow control (VPAC) which uses δ, V_{pwm1} as the control variables.

Power flow control in ac-DC converters can be achieved through the direct control of current in the inductor as shown in Fig. 5. In this method in order to control active and reactive power flow, it is enough to choose ac real current (I_P) and ac reactive current (I_q) as the controlled variables. In this shame, the real and reactive power flow in the inverter can be expressed as:

$$S = V1(Ip + jIq) \quad (3)$$

SPWM voltage controller and hysteresis current controller: It is well known that in order to obtain an approximately sinusoidal voltage in the output of the inverter, usually SPWM voltage control is used. At this method the firing pulses to the switches are constructed using a reference sinusoid compared against a triangular wave. Figure 2 shows the basic control diagram for a single phase SPWM system. Also for current control in the inverter, hysteresis method is usually used since its implementation is easy. At this method the current have two limits, top current and bottom current. The distance of top and bottom limits call Hysteresis (H) bound. Figure 3 and 4 shows the hysteresis current control

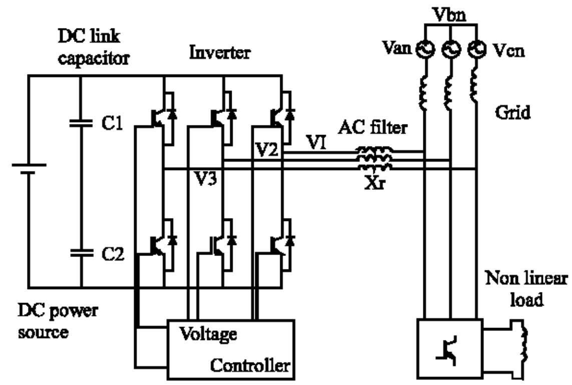

Fig. 2: The basic control diagram for a single phase SPWM system in voltage control

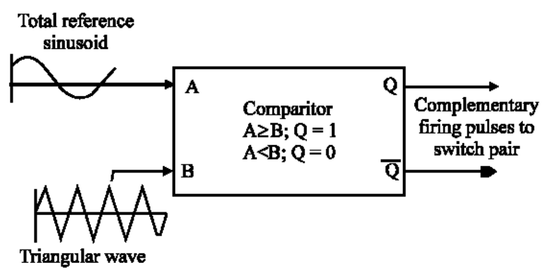

Fig. 3: General format of control system with SPWM method

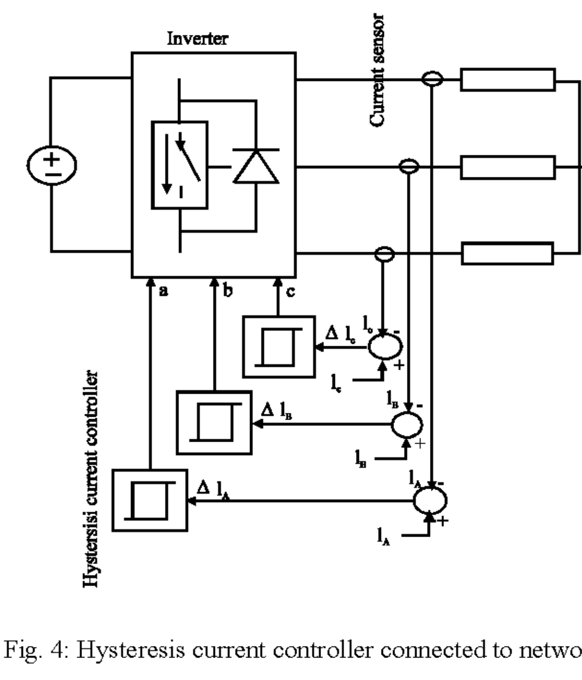

Fig. 4: Hysteresis current controller connected to network

(Brod and Novotny, 1985). As mentioned before, transient response and current spectrum of the inverter are two basic criteria for comparing current control and voltage control; and it will be done through simulation. Moreover, the following comparisons also could be made:

- In voltage control, null wire connection isn't need; this method prefers when null wire may not be accessible. Also in Hysteresis current control, multiple three harmonics are injected to the grid.
- Since in current controlled inverter, output current is directly controlled, there is inherent over current protection; but in voltage controlled inverters external hardware is needed for over current protection.
- According to Eq. 1, in voltage controlled inverters P is directly related to δ. Therefore influence of phase measurement errors will be high (Kazmierkowski and Dzieniakowski, 1994).
- Under voltage control, variation in the real or reactive power commands will result in a cross variance in the other. It means that there is a cross-coupling between real and reactive power control; but in current control, active and reactive power could be controlled separately.
- For satisfactory operation of current control, DC link voltage should be more than maximum peak of the grid voltage; but in voltage control this condition is not necessary.
- In voltage control, DC link harmonics will appear in the output current of inverter; but since in current control, DC link voltage only determines slope of rise and fall of the output current, DC link voltage variation or harmonics will be rejected.
- In current control it is possible to produce harmonic currents of the nonlinear load via inverter in order to grid current be sinusoidal (Active Power Filtering).
- Usually in current control, DC link consists of two separate capacitors; and extra hardware is needed for voltage balancing of these separate DC links.

THE SIMULATED SYSTEM

- **Voltage controlled inverter:** In Fig. 2, grid connected three phase voltage controlled inverter is shown. For transient response analysis, it is better to suppose that the DC link is not connected to a DC Source and is charged via absorbing an active power from the grid. DC link voltage controller is shown in Fig. 6.
- **Current controlled inverter:** Figure 5 shows connection of three phase current controlled inverter to the grid. As mentioned before, in this topology null wire of the grid should be connected to the middle of DC Link. Total DC link voltage controller and DC link voltage balancer are shown in Fig. 7 and 8, respectively. In both control methods, it is supposed that the grid characteristics, coupling inductors and DC link capacitors are the same as shown below.

Grid phase to neutral voltage: 220 V_{rms}
Coupling reactance: 500 μH
DC link capacitors (C1 = C2): 1000 μF

In voltage control, switching frequency of the inverter is 2 KHz. In hysteresis current control, hysteresis band determines the switching frequency of inverter. If fixed hysteresis band current control be used, switching frequency of the inverter will not be constant during a cycle (Bose, 1990; Kazemi and Jalilian, 2006). Some methods are proposed for controlling of the hysteresis band, to obtain a fixed switching frequency. Implementation of hysteresis band controller needs powerful processors and usually tends to be unstable (Malesani and Tenti, 1990; Kale and Ozdemir, 2003). For this reason in this study current control inverter is implemented with fixed hysteresis band to obtain an average 2 KHz switching frequency.

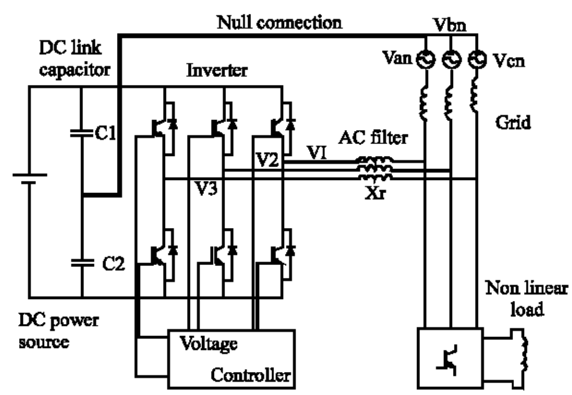

Fig. 5: Current controlled GCI

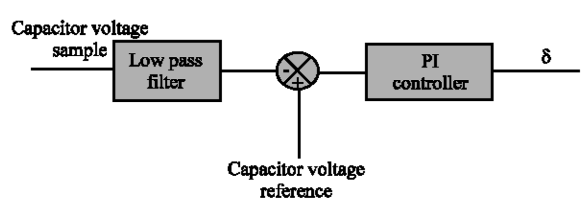

Fig. 6: Capacitor voltage controller in voltage controlled GCI

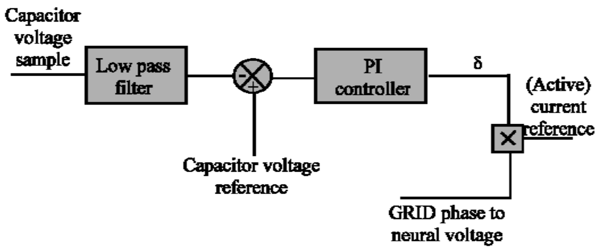

Fig. 7: Capacitor total voltage controller in current controlled GCI

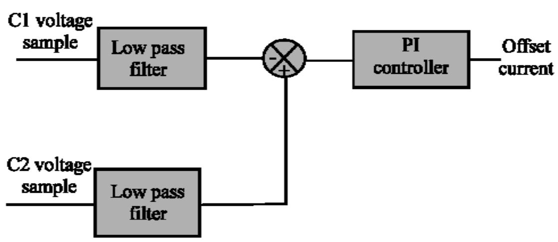

Fig. 8: Capacitor voltage balancer in current controlled GCI

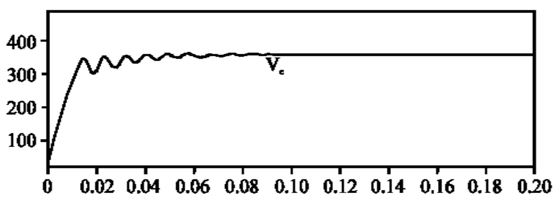

Fig. 9: Capacitor voltage in Voltage Control GCI

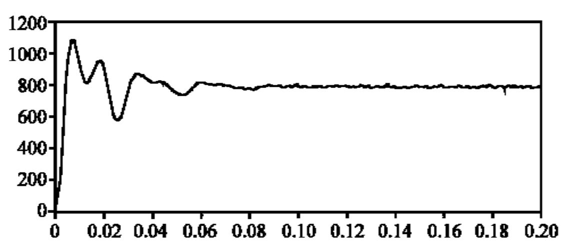

Fig. 10: Capacitor voltage in Current Control GCI

Simulation results: Voltage controlled and current controlled GCI have been simulated with matlab/simulink in static synchronous compensators (STATCOM). First we consider the transient response. As mentioned before, these voltage and current controllers are examined in reactive power compensator. In these systems usually DC link do not connect to a separate DC power and voltage of the DC link is controlled via absorption of a bit active power. When system starts, DC link voltage charges from zero up to the reference value. Figure 9 and 10 show this

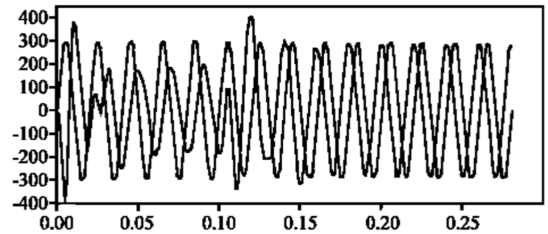

Fig. 11: Transient response in voltage control GCI

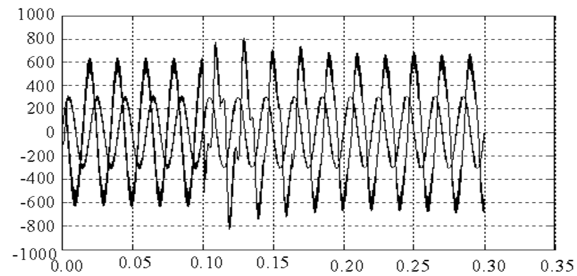

Fig. 12: Transient response in current control GCI

transient response for voltage and current controllers (voltage controller has SPWM controller and current controller has hysteresis controller). As it is obvious, settling time of this response for voltage controller is about ten times more than current controller. In other word, transient response of current controller is faster than voltage controller. Next method for comparing transient response of GCI is considering situation of response when the GCI goes from capacitive mode to inductive mode or vice versa. This is shown in Fig. 11 and 12. It confirms that transient response of current controller is faster than voltage controller. High speed of response in the Hysteresis control at this research is explained in below. Hysteresis band current control is used very often because of its simplicity of implementation. Also, besides fast response current loop, the method does not need any knowledge of load parameters, current regulator techniques based on the Hysteresis control together with switch logic are presented. However, the current control with a Hysteresis band has the disadvantage that the PWM frequency varies within a band because peak-to-peak current ripple is required to be controlled at all points of the fundamental frequency wave.

The output current spectrum is another more important criterion for comparing. This spectrum for voltage and current controller is shown in Fig. 13 and 14. However, in voltage controllers, current harmonics appear around switching frequency and its integer multiples, But in hysteresis current control, harmonics are spread in wide range and also these harmonics appear in low frequencies too. This problem may increase size and cost

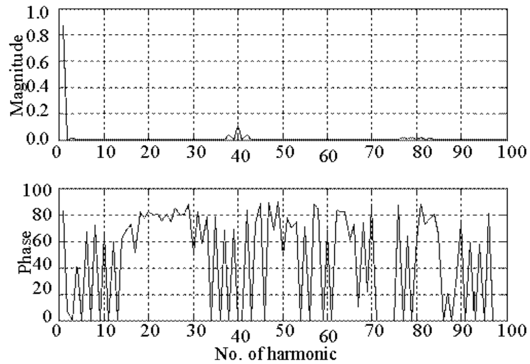

Fig. 13: Harmonic spectrum in SPWM control method

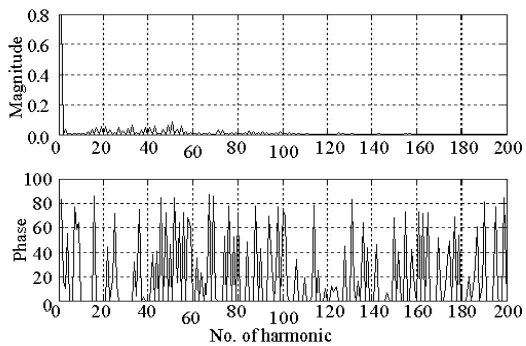

Fig. 14: Harmonic spectrum in Hysteresis control method

of output ac filter. Although some methods have been proposed for solving of this problems in hysteresis current control, but these methods usually suffer from instability problem and do not be used. If switching frequency of the inverter increase, output current harmonics may satisfy IEC harmonic standards and filtering may not be needed. At the SPWM control if the frequency be high, the switches switching losses are high and around switching frequency, the harmonic be high. Therefore at the SPWM voltage control cannot increase frequency than switching frequency, although the using PI controller can recovery this problem. From other differences at Hysteresis current control can adjust Hysteresis bound and other parameters cannot adjust, but SPWM voltage control can adjust amplitude and frequency the triangle signal.

DISCUSSION

Among the various PWM techniques, the Hysteresis band current control is used very often because of its simplicity of implementation. Also, besides fast response current loop, the method does not need any knowledge of load parameters. However, the current control with a fixed Hysteresis band has the disadvantage that the PWM frequency varies within a band because peak-to-peak current ripple is required to be controlled at all points of the fundamental frequency wave. The method of adaptive Hysteresis-band current control PWM technique where the band can be programmed as a function of load to optimize the PWM performance is described in (Malesani and Tenti, 1990). In this study has been result that the Hysteresis current control is very simplicity of implementation.

In voltage controllers, current harmonics appear around switching frequency and its integer multiples. But in hysteresis current control, harmonics are spread in wide range and also these harmonics appear in low frequencies too. This problem may increase size and cost of output ac filter (Kale and Ozdemir, 2003). For transient voltage stability a large number of disturbances, some with pre fault outages were considered (Kale and Ozdemir, 2003). Results of this study show harmonics appear in the spectrum of frequency in the Fig. 13, 14.

The transient voltage recovery times were tabulated for the lowest bus voltage to recover to 0.95 pu of its pre fault value. Transient security simulations indicated that the duration of transient voltage recovery increased significantly for some disturbances when Holly Power Plant was removed. The worst situation occurred at Holly 138 kV bus, indicating it as the best location for installation of dynamic shunt compensation (John *et al*., 2005). Figure 9, 10 shown at this research the STATCOM inject or absorb the reactive power to network that the capacitor voltage is higher or lower than network voltage and when the capacitor reach to steady state. Figure 11, 12 show change of state STATCOM that hysteresis current control is faster than voltage controller.

CONCLUSION

This study has discussed the differences in two most popular control methods of GCIs. The comparison is performed by simulating a typical reactive power compensator. When switching frequency of the inverter is not high enough (in large scale GCI), filtering of the output current may be difficult and expensive. For this reason, in these applications, Voltage Control is preferred.

Regardless of undesirable harmonic spectrum, if null wire connection be accessible, Hysteresis current controller, which could be implemented easily, will be a good choice because of its transient response.

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