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Current Control Strategy for Grid Connected Inverter

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Abstract- **In recent years, grid connected photovoltaic system has emerged with its simplicity, reliability and endurability. The ranges of grid tie inverters (GTI) are classified as small scale as several tens of kilowatts and large scale as hundreds of megawatts. Accordingly, the standard of interconnecting to the grid is made higher extent in improving its power system reliability, efficiency and cost. Moreover, the working of grid connected inverter primarily depends on robustness in control strategy, even working in abnormal grid conditions such as deviation of voltage and frequency. This review focuses on updating grid standard codes and regulations, in addition overview of recent control strategies and direct power control.**

I. INTRODUCTION

Solar photovoltaic (PV) energy conversion system has shown increase at a moderate annual rate of 60% in the last five years. This is possible because of alternate clean energy sources, reduction of cost, efficiency increase of PV modules and subsidy scheme of political regulations. PV installation is classified according to their functional and operating requirements named standalone and grid connected. With standalone system, remote area is supplied by DC or AC power with converters and energy storage devices. On the other hand, in grid connected, generated power supply to the utility services without any energy storage equipments that have made added advantage of 99% benefit than stand alone system. In grid connected inverter, the power generated by PV plant is directly given to the transmission line and it is distributed. Henceforth, the use of batteries and other energy storage devices is not required that makes the arrangement less space, reduced investment cost and maintenance than stand alone system.

Power inverter is an important part of many DC to AC conversion equipments such as uninterrupted power supply (UPS), induction motor drive and automatic voltage regulator (AVR) systems. In these systems, it is the major requirement for the power inverter to be capable of producing and maintaining a stable and clean sinusoidal output voltage waveform regardless of the type of load connected to it. The main key to successfully maintain this ability is to have a feedback controller.

Current controlled PWM inverters are widely used in high performance AC drivers because they offer substantial advantages in eliminating stator dynamics in those systems. The main objective of current controller is to force the load current vector according to reference current trajectory. The performance of converter systemis mainly dependent upon the type of current control technique is used. In current controller load currents, the errors are used as an input to the PWM modulators, which provides inverter switching signals

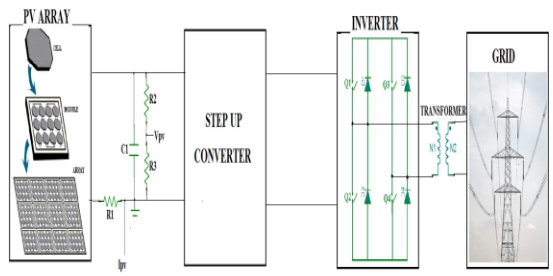


Fig.1.Ideal circuit of single phase grid connected inverter

Fig.1. shows the equivalent circuit of a single-phase full bridge inverter with connected to grid. When pv array provides small amount DC power and it fed to the step-up converter. The step-up converter boost the pv arrays output power and its fed to the inverter block. In the inverter converts DC into AC with help of pwm gate switching pulses.Finally synchronization of the phase and frequency of the inverter output voltage with the grid voltage.

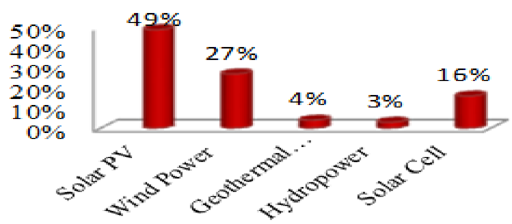
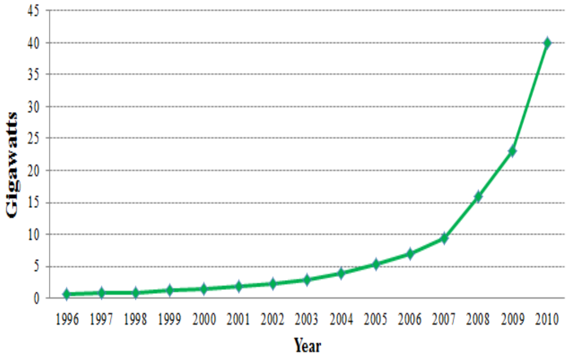


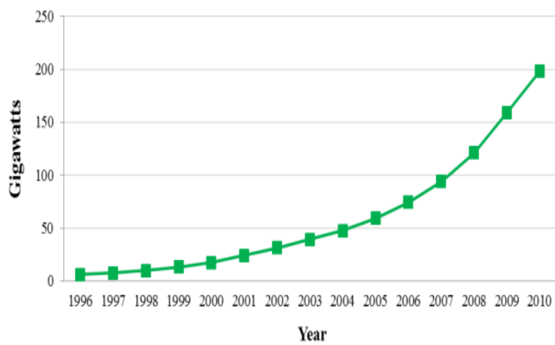
Fig.2: World Average Annual Growth Rates of Renewable Energy Capacity Between 2005-2010

Fig.2: World Capacity (a) Solar/ PV



(a)

Fig.3: World Capacity Solar/ PV



(b)

Fig.4: World Capacity Wind

It is important that any inverter system connected to the grid does not in any significant way degrade the quality of supply at the point of connection. It is also important to consider the effects of a poor quality of supply on an inverter added to the system. Unbalanced input supply voltages and impedances make odd harmonics in ac current. The harmonic content of the most modern pulse width modulated sine wave inverters is typically less than 3% THD. According to the IEEE standards and IEC, the total harmonic distortion (THD) of the current injected to the grid should be lower than 5%. Then, different current control methods are proposed to obtain lower harmonic distortion. IEC harmonic distortion limits details for distributed generation system is presented. The important aim of this paper is to give a comprehensive description of current control techniques for grid connected converters and comparison them according to their performance like steady state error, transient response and harmonic compensation.

1.1Linear Current Control Techniques

1.1.1 Proportional Integral (PI):

Proportional (P) controllers were used as former grid connected controller. However this kind of controllers has an inherent steady-state error. The P controller's steady state error was eliminated by adding integral component to the transfer function. Therefore, the average value of current error reduced to the value of zero by changing the integral components. Even so, the current errors can appear in transient conditions. Transient response of the proportional integral (PI) controller is limited by the proportional gain.Then the gain must be set at a value that the slope of the error is less than the slope of the carrier saw tooth waveform required for generating the firing pulses of the inverter. Most of the PI controller's applications are in dq control, since they have an acceptable performance while regulating the dc variable.

1.1.2 Proportional Resonant (PR):

The ideal proportional resonant controllers (PR) [18–21] widely used in abc directly when the control variables are sinusoidal. PR controllers present a high gain around the natural resonant frequency of ω ,which is presented.

$$G(s) = K_p + \frac{K_i s}{s^2 + w^2} \qquad (1)$$

Where ω , K_p and K_i represent the resonance frequency, proportional and the integral gain of the PR controller. This controller achieves a very high gain about the resonance frequency. Therefore it can omit the steady state error between the reference and the controlled signal. The width of the frequency band about the resonance point, depends on the integral time constant of K_i. A low K_i can cause a narrow band, while a high K_i causes a wider band. The high dynamic performances of a PR controller have been described in different papers. The PR controller harmonic compensation can be achieved by cascading several generalized integrators, which are tuned to resonate at the specified frequency. Therefore, selective harmonic compensation at different frequencies can be achieved.

$$G(s) = \sum_{h=3,5,7} K_{ih} \frac{s}{S^2+(h,\omega)^2} \quad (2)$$

Where is the natural resonance frequency, h is the harmonic's number and K_{ih} is the integral gain of the related harmonic. Then it is simple enhance to the abilities of the scheme, by adding harmonic compensation properties with more resonant controllers in parallel to the main controller. In this case, the harmonic compensator works on both positive and negative sequences of the selected harmonic. Therefore, only one HC is needed for one harmonic order. Moreover, another advantage of the HC is that it does not affect the dynamics of the PR controller, and it just has an effect on the frequencies that very close to the resonance frequency. However, since the distorted currents usually contain more than one order harmonics, it would be preferable to use many resonant compensators, which are tuned at different harmonic frequencies, and cascaded together or nested in different rotating reference frames to achieve the multiple harmonics compensation.

1.1.3 Repetitive Controller (RC):

Another kind of the grid connected controllers is repetitive controller (RC) which can omit the steady state error by periodic controlling of the components. The RC controllers achieve a large gain at the integral multiples of fundamental frequency. The RC controllers like sliding mode, odd-harmonic repetitive controller and dual-mode repetitive controller are introduced to obtain the dynamic response. These repetitive controllers are implemented as harmonic compensator and current controller, to track the fundamental reference current. However, RC controllers can cause a slow dynamic response and they are applied only in the static mode.

2.2Nonlinear Current Control Techniques

2.2.1 Predictive Control:

Current controller based on prediction is one of the nonlinear grid connected controllers. The predictive control strategy is based on the fact that only a finite number of possible switching states can be generated by a static power converter, and that models of the system can be used to predict the behavior of the variables for each switching state. To select the appropriate switching state to be applied, a selection principle must be defined. This selection principle is expressed as a quality function that will be evaluated for the predicted values of variables to be controlled. Prediction of the future value of these variables is calculated for each possible switching state. The switching state that minimizes the quality function is also selected.

A predictive current control block which is shown in Figure 5, is applied to predict the next value of the output current by using the existing output current. Then, the quality function determines the error between the predicted output current and the reference current. Finally, the voltage which minimizes the current error is selected and applied to the output current. This kind of controller is well known for their possibility to include nonlinearities of the system in the predictive model. Predictive controllers give a better performance while the mathematical model is accurate, linear and time invariant. Because of complicated computationally of the predictive controller, it needs a large control loop time period.

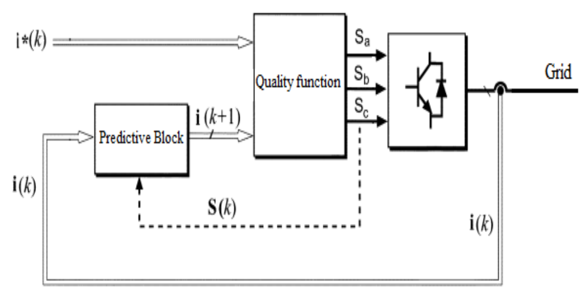


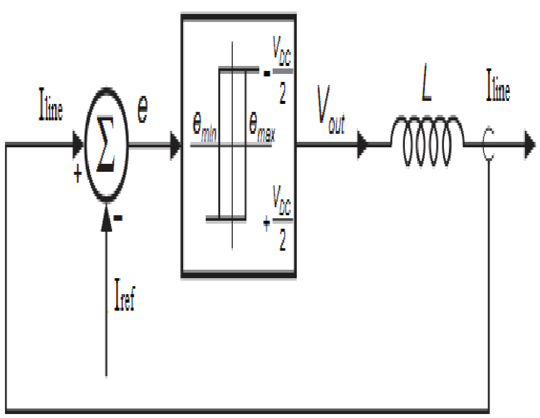
Fig. 4 Predictive Current Control Block Diagram

2.2.2 Dead-Beat Control:

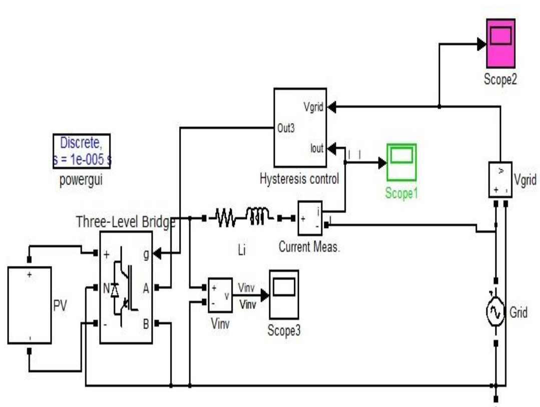
When the choice of the voltage vector is ordered to a null error with a one sample delay, the predictive controller called dead beat controller. In this case, among the additional information given to the controllers, non-available state variables like flux and speed can be included. Therefore, observer or other control blocks are needed to determine these variables which often may be shared in the control of the complete scheme.

2.2.3 Hysteresis Control

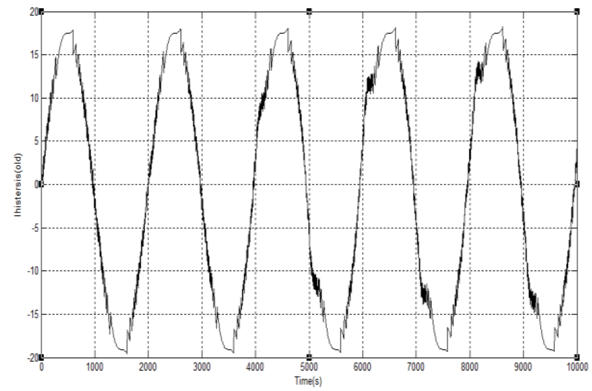
Hysteresis current control is a method for controlling a voltage source inverter to force the grid injected current follows a reference current. The line current and reference current are used to control the inverter switches. Lower and upper hysteresis band limitations are related to the minimum and maximum error directly (e_{min}, e_{max}) When the reference current is changed, line current has to stay within these limits. The range of the error signal $(e_{max} - e_{min})$ directly controls the amount of ripples in the output current from the inverter which is called the hysteresis band. The ramping of the current between the two limits is shown in Figure 5. These kinds of controllers not only are robustness and simple but also have a good transient response. Due to the interaction between the phases, the current error is not limited to the value of the hysteresis band. The switching frequency of this controller changes by load parameter's variations which is changed the bandwidth and it can cause resonance problems. Moreover, the switching losses resist the application of hysteresis control to lower power level. This problem can be solved by employing variable limitation as mentioned in . However, it requires system parameter's details.

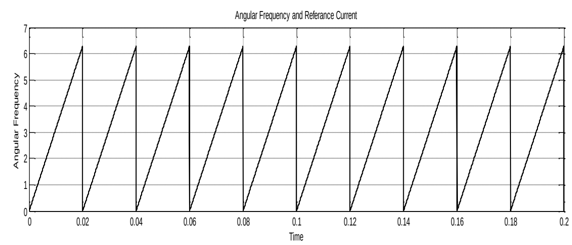


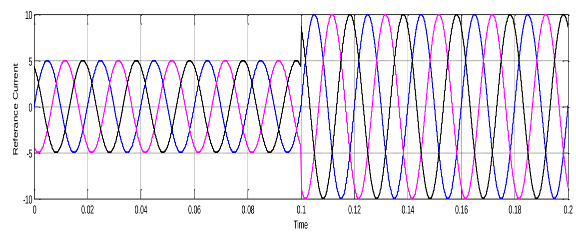
Simulation:



Waveform:







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