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Review of Current Control Technologies in Grid Integration and Power Quality Management of Renewable Energy Sources

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***Abstract-* Various uncertainties arise in the operation and management of power systems containing renewable energy sources that affect the systems power quality and stability. These conditions occur due to system parameter changes. The concept of total harmonic distortion has become a primary power quality issue which could seriously degrade the performance of the grid connected renewable source. For this reason, the control policy must be considered. Therefore, the different types of current control techniques are illustrated in this paper.**

***Index Terms*- Current Control Techniques, Grid Connected Renewable Energy Sources (RES), Total Harmonic Distortion (THD).**

I. INTRODUCTION

The use of power converters has become very popular in the recent decades for a wide range of applications, including drives, energy conversion, traction, and distributed generation. The control of power converters has been extensively studied and new control schemes are presented every year. Several control schemes have been proposed for the control of power converters and drives. Most type of renewable energy systems works in conjunction with the existing electrical grids. The heart of the grid-direct system is a DC to AC inverter which adapts to the power grid voltage and frequency. Inverter technology has an important role to have safe and reliable grid interconnection operation of renewable energy systems. They must be capable to provide high efficiency conversion with high power factor and low harmonic distortion.

II. CURRENT CONTROL TECHNIQUES

A general block diagram of grid connected renewable energy system is shown in figure1. Control of this system can be applying in input-side or grid-side. The main task of the input controller is to extract the maximum power from the renewable energy sources and protect the input side converter while the grid side controller must check the active and reactive power which is transferred from renewable energy systems to the grid. Grid synchronization and controlling the power quality of power injected into the grid are another duty of the grid side controller.

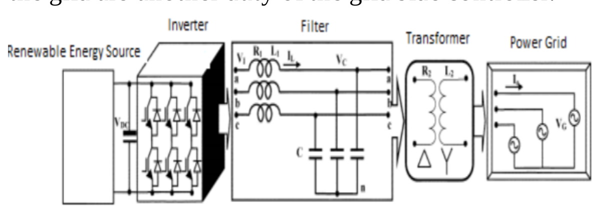


Fig 1: Grid Connected Renewable Energy Sources Block Diagram

By using a simple control circuit, current control scheme inverter can be achieved a high power factor. Therefore, the current control type inverters are more popular (Figure 2).

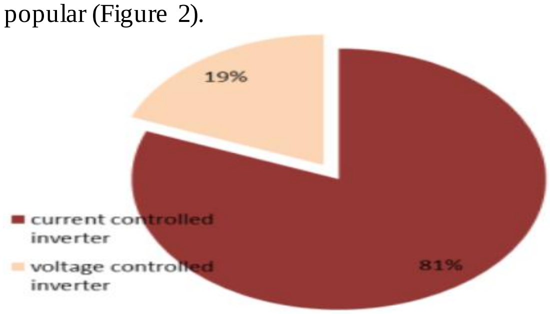


Fig 2 : Current and Voltage Control Scheme Inverter Ratio

In the current control scheme inverter, performing as an isolated power source is difficult, but there are no problems with grid interconnection operation .The operations of the current controlled type inverters are depended on use of the current control technique types. Current control techniques can be classified into two main groups of the linear and nonlinear techniques. The most famous linear current control techniques are proportional integral (PI), Proportional Resonant (PR) and Repetitive Controller (RC); then the non linear current controllers are Predictive dead beat and hysteresis.

III. TYPES OF CURRENT CONTROL TECHNIQUES

3.1 Linear Current Control Techniques:

3.1.1 Proportional Integral (PI):

Proportional (P) controllers are 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. A PI controller gain is determined by the equation below,

$$G_{PI}(s) = K_P + \frac{K_I}{s}$$

Where $K\ P$ and $K\ I$ are the proportional and the integral gain of the PI controller. The controlled current has to be in phase with the grid voltage. Under unbalanced conditions, harmonic compensators for both positive and negative sequences of each harmonic order are required. For instance, four compensators are needed for the fifth and seventh harmonics compensation.

3.1.2 Proportional Resonant (PR):

The ideal proportional resonant controllers (PR) widely used in abc directly when the control variables are sinusoidal. PR controllers present a high gain around the natural resonant frequency of □□and is given by,

$$G(s) = K_p + \frac{K_i s}{s^2 + \omega^2}$$

Where □□, $K\ p$ 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 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. A typical harmonic compensator (HC) has been introduced for compensation of the third, fifth, and seventh harmonics .The transfer function of the HC is shown below,

$$G_h(s) = \sum\nolimits_{h=3,5,7} K_{ih} \frac{s}{s^2 + (h.\omega)^2}$$

Where □□is the natural resonance frequency, h is the harmonics 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. 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.

3.1.3 Repetitive Controller:

Repetitive controller (RC) is another type 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.

3.2Nonlinear Current Control Techniques:

3.2.1 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 3, 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 complication of the predictive controller, it needs a large control loop time period.

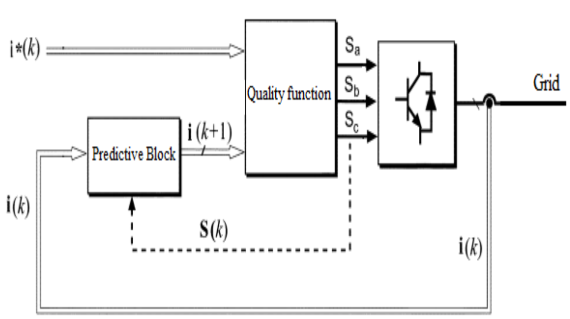


Fig 3: Predictive Current Control Block Diagram

3.2.2 Dead-Beat Control:

When the choice of the voltage vector is ordered to a null error with a one sample delay, the predictive controller is called as a 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. The gain of this controller is given by the formula,

$$G_{DB} = \frac{1 - az^{-1}}{b(1 - z^{-1})}$$

where

$$a = e^{-\frac{R_T}{L_T}Ts}$$

$$b = -\frac{1}{R_T}\left(e^{-\frac{R_T}{L_T}TS} - 1\right)$$

Where R_T and L_T are the equivalent interfacing resistance and inductance seen by the inverter, respectively. Dead beat controller has a sample time delay, since it regulates the current when it achieves its reference at the end of the next switching period. Then, the controller indicates one sample time delay. In some cases, an observer can be used by controller to complicate this time delay which is shows in Figure 4. The transfer function of this observer is be obtained by,

$$F_{DB} = \frac{1}{1 - Z^{-1}}$$

Then, the new current reference is:

$$i^{*'} = F_{DB}(i^{*} - i)$$

This kind of controller is fast, simple and it is suitable for microprocessor-based application.

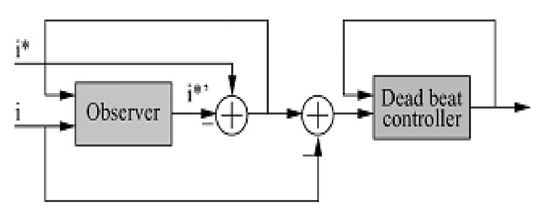
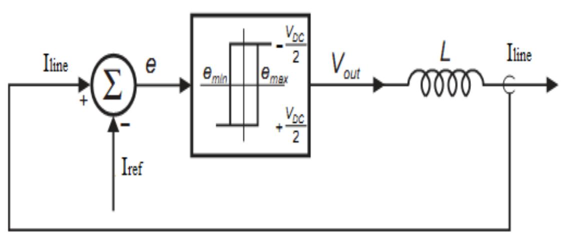


Fig 4 : Block Diagram of Dead-Beat Controller

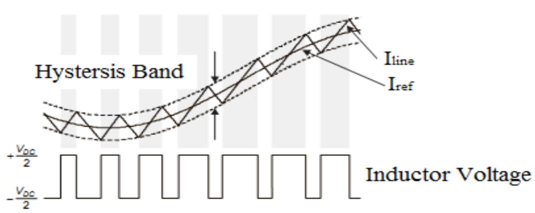
3.2.3 Hysteresis Control:

Hysteresis current control is a method for controlling a voltage source inverter to force the grid injected current follows a reference current. A block diagram of a hysteresis controller is shown. 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 e is changed, line current has to stay within these limits. The range of the error signal (e_{min} - e_{max}), 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 7(b). 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.. However, it requires system parameter's details.



(a)



(b)

(a)Hysteresis Current Controller Block Diagram (b) Hysteresis Current Controller Operational Waveform

4. Performance Overview of Current Control Techniques:

Current control techniques help inverters to provide stability, low steady state error, fast transient response and low total harmonic distortion when renewable energy sources are connected to the grid. Among linear grid connected controllers, the PI controller has a large gain at low frequencies where the PR controller gives the highest gain about resonance frequency, and RC achieves its high gain at the integral multiples of the fundamental frequency. These groups of controllers are well known to eliminate the error. However, their dynamic response is not enough good compared to nonlinear controllers.

Among linear controller techniques RC has the lowest transient response and PR is the fastest one. PR controllers as PI controllers are unable to give a large loop gain at the multiple harmonic frequencies to provide a good compensation for a wide band of harmonics. In linear controller group, RC gives a simple and practical solution for multiple harmonics compensation.

Nonlinear controllers are famous for their dynamic response. This group has a fast transient response. Then, they can eliminate the low order current harmonics. It must be considered that the current waveform will carry harmonics at switching and sampling frequency's order. In this case, fast sampling capability of the hardware used is necessary.

IV.CONCLUSION

This paper has reviewed the most important types of current control techniques used in power electronics and drives. The basic principles and the latest developments of these methods have been systematically described. In this paper, the structure of the important linear and nonlinear current control techniques like PI, PR, RC, hysteresis, predictive and dead beat control were described. Finally, their ability to provide a high power quality generation to the grid was explained.

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