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# A Review on Current Control Techniques for Inverter for Three Phase Grid Connected Renewable Sources

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**Abstract**

*Renewable based power generation system and their grid interconnection has gained attention throughout the world. Due to large penetration of renewable sources into the grid, maintenance of power quality, grid integrity and protection against islanding detection has become a critical issue. One of the most important aspects in the renewable grid interconnection is the adoption and current control techniques for the inverter. These current controlled inverters must meet the grid criteria and international standard while interconnecting to grid. This paper presents a review on different types of current control techniques that have been adopted in the industry as per the best practices and state of the art technology. Various techniques and their control algorithms are discussed in two categories, like linear controller and non-linear controller. New current control techniques such as Artificial Neural Network, Fuzzy logic Controllers are also discussed in the paper. Performance analysis of different types of controllers is also discussed for better understanding of the characteristics of the system. MATLAB/SIMULINK based test has been carried out to study the performance of the system.*

***Keywords:*** *Current Source Inverter (CSI), Distributed Power Generation System (DPGS), Grid Interconnection, Low Voltage Ride through Capability, Total Harmonic Distortion (THD), Voltage Source Inverter (VSI).*

## 1. INTRODUCTION

Most of the power electronic based voltage source PWM techniques uses an internal current controller loop. It is used to maintain required output at the terminal level from where the power is to be evacuated. Hence, the performance of the converter depends upon the characteristics of the controller. Renewable energy based distributed power generation requires some special attention while designing the controller has to perform three number of task normally maintaining the require DC link voltage at the input side through after control loop, meeting the grid parameter at the point of common coupling (PCC) through inner current control loop and to extract the maximum amount of power from the renewable generator like PV, Wind and small Hydroelectric plant (SHEp) [1-2]. In comparison to the traditional open loop control algorithm the current control PWM algorithm are many advantages like protection against injection of peak current, highly dynamic characteristic in response to variable load demand, compensation against DC link voltage and change in grid parameters such as resistance and reactance. Provision of frequency and voltage support is also an essential parameter of inverter control action. This refers to stable operation of controlled inverter both under steady state and transient condition of operation. Steady state refers to the change in characteristics of the controller with low variation in the grid parameters [10]. Whereas, the dynamic performance evaluates how fast a controller may respond to the change in grid parameters. Some international standards such as IEEE 1547 must be maintained while interconnection the inverter with the grid [13-14]. Development in the current control strategy is still under the progress however, the new controlled strategies such as Neural Network, adopted neural network and fuzzy logic based controller are some of the digital areas which needs to be exploded. Micro Electronics manufacturing system is generally used for manufacturing the solar cell and hence the efficiency for the polycrystalline cell is about 10-15% and for mono crystalline system it is about 9-13% [17]. Commercially available solar cells are generally of monocrystalline type or polycrystalline type [18].

In this paper, a brief comparison among the different types of controllers and their characteristics were presented starting from the traditional control method such as bang-bang controller (Hysteresis controller), PI controller as discussed above. The basic concept and their characteristics approaches were discussed above. The basic concept and their characteristics approaches were discussed under second part. Third part discussed about linear controller followed by the forth part stating non-linear controller and their characteristics. The fifth section contains the detailed characteristics of the converter and their discussion part six comprise of conclusion.

### 1.1 Basic Concepts and Characteristics

The purpose of the current controlled technique is to force the injected AC load current to follow the reference current or signal. Triggering pulse of the current controller can be evaluated by comparing the command reference current with that of the instantaneous value of the controller current. So current controlled techniques usually compensates the evaluated error along with the required modulation index for the gates.

Characteristics of the converter can be measured through the modulation index, switching and ripple frequency, phase interference effect and DC link of the converter [6].

Voltage source converter usually produces two different level for each phase in a three phase in a three phase grid connected system. This two level has no effects on the performance of the inverter if hard switching is allowed with no mutual constraints [9-10]. However during higher modulation index it produces mutual interferences among the three phase system and their by creating high order harmonics. This requires additional filters for maintaining phase synchronisation. If the modulation index becomes greater than one then the two groups may be separated from each other. However, it injects higher order harmonics which can be compensated through STATCOM, shunt active power filter and active power filters [8].

Increase in modulation index increases the voltage harmonics, hence the average current also deviates from the instantaneous in a large extent. This ripple current also depends upon the duration of modulation period, the supply voltage, load side parameters and AC voltage [13]. In order to maintain a constant ripple current it is required to vary the modulation frequency which is again controlled by the modulation index. This future requires user filter to maintain the required switching frequency.

Phase interference is produced due to change in phase angle of inverter and the load between which power is being transfer from inverter to load. This arises when the interconnection between inverter neutral point and load neutral point is not established. This leads to variation in phase current which ultimately depends upon phase voltage to which it is connected and other phases in the vicinity.

To force the AC current in the load side, it is required to maintain the DC source at the input side. Converter forces to inject the current into the grid point the grid voltage is less than the DC link voltage [15]. However, when the grid voltage reaches at its maximum value the converter into a six step operation mode where the current controlled is not able to force the command current. Hence it is required to maintain sufficient DC link at the input.

Based on the above performance characteristics the basic requirement of a current control techniques can be summarized as (1) Maintenance of sufficient DC link at the input side. (2) No phase and amplitude error at the point of tracking. (3) Constant switching frequency for the entire operation of the converter. (4) Implementation of power filters for regulating harmonics.

In addition to the above basic criteria the dynamic response of the current controller can be verified through dead time, rise time, settling time, and over shoot factors.

## 2.LINEAR CONTROLLERS

Linear controller consist of conventional voltage type PWM converters or modulation. Linear controller schemes has two separated control action like

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compensation against current error and voltage modulation constant. These linear controllers are suitable for maintaining constant switching frequency, optimum switching patterns and for maintaining better DC link at the input of the controller. In this paper linear controller comprising stationary PI controller, synchronous PI controller, PR controller, State feedback and predictive dead beat controllers are discussed.

(a) Stationary PI Controller:

Stationary PI controller uses three PI error compensator to produce three voltage commands for a three phase sinusoidal PWM. It uses a comparison techniques where it compares a triangular wave with three phase sinusoidal signal to generate the control signal for inverter switches. One of the disadvantages of this controller is that the switching time and its operation is generally affected due to feedback operation of the current ripple.

The integral part present in the PI controller minimises the current error and the proportional part is related to the amount of ripple present in the controller. This controller suffers from tracking of amplitude and phase error. Therefore in order to reduce the error the slope of the command voltage must be maintained below the triangular slope. Presence of multiple crossing of triangular wave also created ripple current error. Therefore to avoid the above problem additional tracking method such as phase locked loop is also used to track the phase angle and frequency.

(b) Synchronous PI Controller:

Controlling the DC variables in a grid interconnection system is the most critical challenge. Industrial drives consisting of precise motor and load requires variable supply system. In such cases d-q control strategies is best suited. d-q control scheme transfer the abc reference frame into d-q control signal. This can be achieved in a two stage conversion system such as step-1 transfers the signal from abc to αβ and the second step transfer the signal from αβ to d-q co-ordinates system. Fig-1 shows the synchronous PI controller. Based on the requirement of active power, DC link can be adjusted to generate the reference current. Similarly, reactive power demand can be adjusted on set to zero depending upon operation.

Gain of the PI controller based on d-q co-ordinate system can be adjusted through equation 1 and the current control of synchronous PI controller as shown in fig-1.

$$G_{PI}^{(dq)} = \begin{bmatrix} k_p + \frac{k_i}{s} & 0 \\ 0 & k_p + \frac{k_i}{s} \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where $K_p$ and $K_i$ represents the potential and integral gain of the controller.

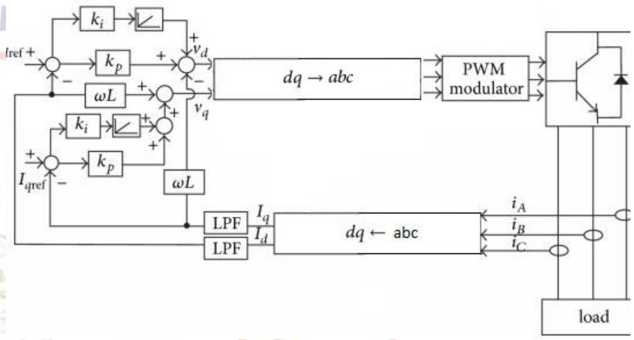


Fig-1: Synchronous PI Controller

(c) PR Controller:

It is the advance version of PI controller. It does not require any steady state magnitude or phase error to calculate the sinusoidal reference current. Advantages of PR controller is that a large gain around the resonance frequency can be achieved with the integral controller. The gain of the PR controller can be described as follows.

$$G_{PR}^{(\alpha\beta)} = \begin{bmatrix} k_p + \frac{k_{is}}{s^2 + w^2} & 0 \\ 0 & k_p + \frac{k_{is}}{s^2 + w^2} \end{bmatrix} \quad \ldots\ldots\ldots (2)$$

Width of resonance frequency bond can be adjusted through $K_i$, like smaller $K_i$ results in narrow bond whereas larger $K_i$ results for large bond.

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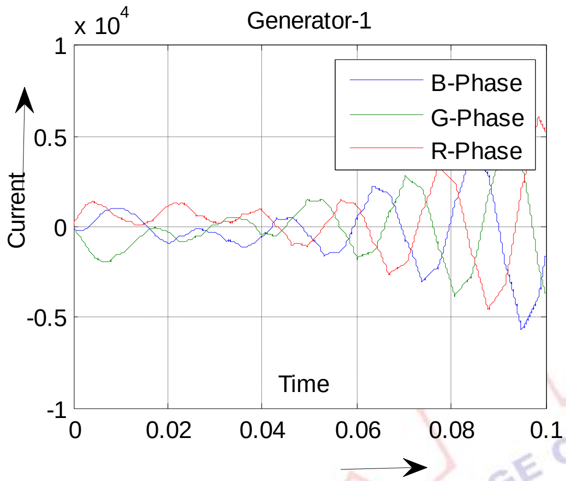


Fig-2: Current Wave Form at Renewable Generator

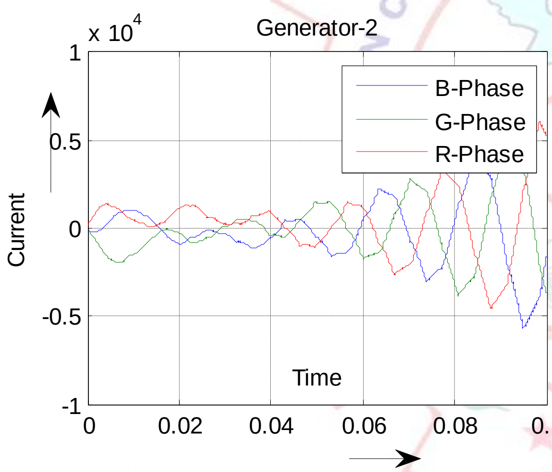


Fig-3: Current Wave Form at Renewable Generator

(d) Predictive and Deadbeat Controller:

This controller forecast the error at the beginning of each sampling period. The error is being forecasted based on the current error vector and AC load side parameters. Thus the voltage vector to be generated by PWM controller is generated to minimize the forecasted error. When the voltage vector is so assumed to nullify the error at the end of the sample period the predictive controller is often called a deadbeat controller. Here in fig-4 PLL used because it supply the information of the grid voltage to grid current.

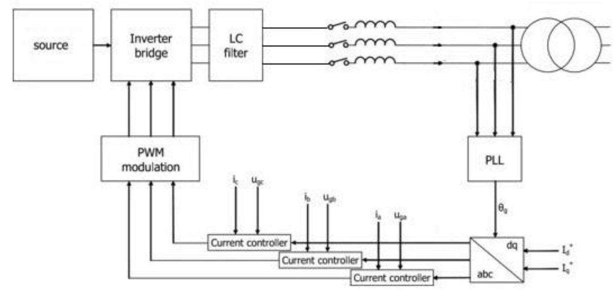


Fig-4: Dead Beat Controller with PLL Tracking

## 3. NON LINEAR CONTROLLER

Non-linear controller has many advantages over the linear controller in the form of robustness, independent in the load parameter variation, good dynamics and dynamic property in tracking the error. Non-linear controllers are of many types such as Hysteresis controller, Optimized controller, Neural Network fuzzy controller and DM controller.

(a) Hysteresis Controller:

It compares the reference current and instantaneous grid current to produce the gating signal for the inverter. The band of Hysteresis controller defined by minimum and maximum error. This further allows the current to be kept under the lower and upper limit. Instead of many advantages of the converter, it suffers from variation in the load parameter changes and AC voltages. Inherent randomness present in the controller limit cycle requires some precise protection system. The hysteresis controller is shown in fig-6 is contain PLL for the reference frame generation.

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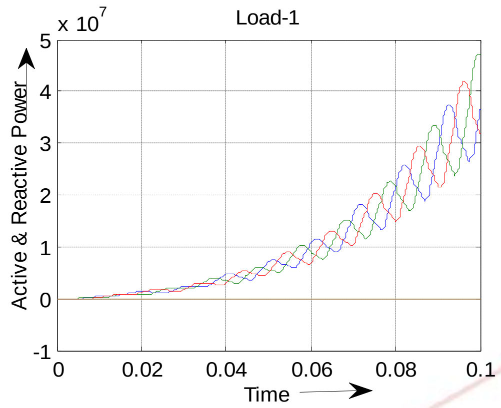


Fig-5: Real & Reactive Power Exchange

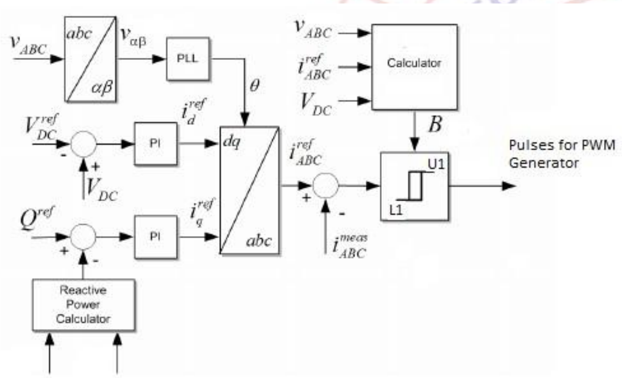


Fig-6: Hysteresis Controller

(b) Optimised Controller:

It is based on the space vector analysis of Hysteresis Controller. The boundary of the current error area in the case of independent controller with equal tolerance band in each of three phases makes a regular hexagon. Based on the area of hexagon, optimisation is applies to minimise the voltage vector.

(c) Neural Networks:

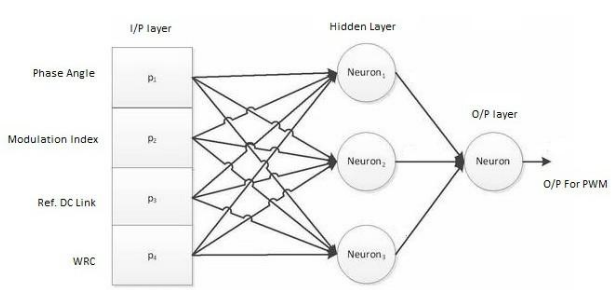


Fig-7 Neural Network based CC

Neural Network controller is the most advance version of non-linear controllers. Parallel processing, robustness and learning ability present in the controller makes it suitable for high speed operation, calculation of error signal and online optimisation are neutralised through parallel processing. Training each layer of the controller was carried out through back propagation algorithm. No further training of the layer is allowed during the controller operation and how exactly neural network exactly work that is shown in fig-7. Hence the performance of the controller largely depends upon the quality of training data and the amount of data. Online training of neural data is allowed where it is required to compensate the large variation in load parameter. However for fast operation of online training random with change must be applied.

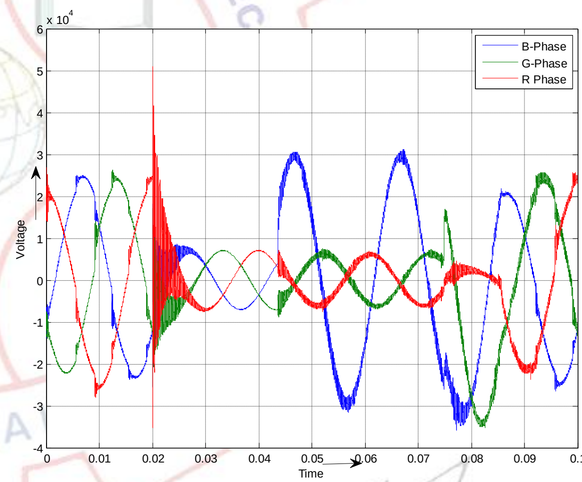


Fig:- 8 Grid level voltage during single phase fault through ANN

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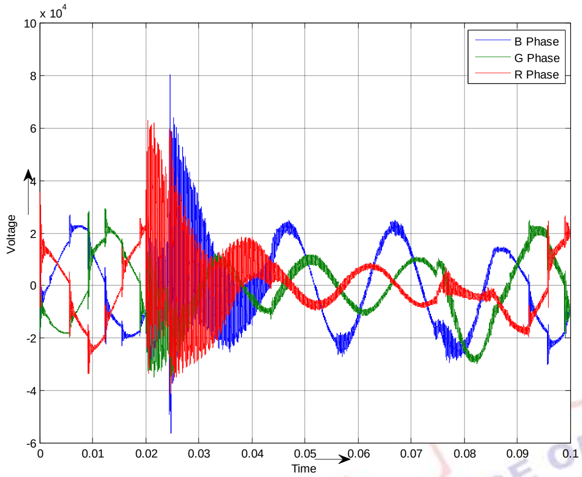


Fig:-9 Grid level voltage during three phase fault through ANN

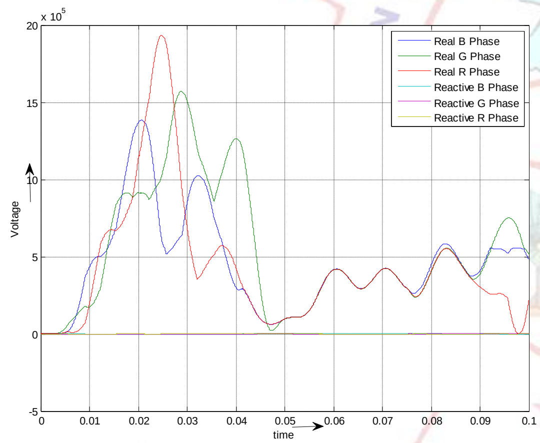


Fig:-10 Real & Reactive Power Flow

## 4. CONCLUSION

A comprehensive review of different types of current control techniques has been presented in this paper. Grid interconnection issues of renewable sources were also addressed in this paper. A fair discussion among the different types of controller were also discussed with their results. From the literature and result it may be concluded that, PI controller typically uses d-q reference frame of operation and PR controller uses αβ reference frame of control action. PR controller has very high dynamic performance with flexibility for selective harmonic compensation. All the controllers were tested under different grid fault condition. However, Deadbeat converter shows good performance under single phase too ground fault condition which is more common among the distribution lines. However, from overall performance view PR controller shows high dynamic characteristics and harmonic compensation capacity, especially lower order harmonics as compared to others.

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