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Power Quality Improvement of Grid Using Distributed Generation with ANN DC-link controller

G. Swathi
M.Tech Scholar
Department of EEE
QISCET, Ongole, (AP), India

Ms. T. Sai lakshmi
Assistant Professor
Department of EEE
QISCET, Ongole, (AP), India

Mrs. A. Pradeepthi Pavani
Assistant Professor
Department of EEE
St. ANN'S Engineering College, Chirala

Abstract: *In order to improve the power quality and reliability of grid at point of common coupling (PCC) we use distributed generation. This system should transfer the energy from the dc link to the 3-phase AC system with controlled active and reactive power and without injecting harmonic currents by using Voltage source Inverter which is to be connected between the DC Source and the AC grid. This voltage source inverter is used to perform multi functions such as i)To inject power generated from the renewable energy source to the grid. ii) Load reactive power demand support. iii) Current harmonic compensation at PCC. iv) Current unbalance and neutral current compensation in case of 3-phase 4-wire system. Any changes in the load affect the DC link voltage of the inverter, In this paper artificial neural network controller is used for controlling the DC capacitor voltage in the inverter. Simulation using MATLAB/SIMULINK is carried out to verify the importance of proposed controller.*

Index terms:*Distributed generation (DG), Voltage source inverter, power quality, artificial neural network and Phase locked loop.*

1. Introduction

The increased power demand and the depletion of fossil fuels resources and the growth of environmental pollution have led the world to think seriously of other alternative sources of energy such as solar, wind, fuel cell, hydrogen energy etc…. as a future energy solution. Since the past decades there has been enormous interest in many countries on renewable energy sources (RES) for power generation. There are some drawbacks if we use RES directly to the commercials, residential and industrial applications. Moreover, the grid is also suffering from severe power quality problems due to continuous increment of non-linear type of loads. In order to overcome these problems, the distributed generation (DG) can now be actively controlled to enhance the system operation with improved power quality at PCC. However the extensive use of power electronic based equipment and non-linear loads at PCC generate harmonic currents, which may decreases the quality of power [1], [2]. Normally active power filter (APF) is extensively used to compensate the load current harmonics and load unbalance at distribution level. This results in an additional hardware cost, so we use inverter as an active power filter in distribution network is proposed in [4] but in this work, to improve the power quality at PCC a control strategy for renewable interfacing inverter based on single phase p-q theory is proposed [5],here inverter acts as an APF without any additional hardware cost. Here the main idea is the maximum utilization of inverter, in this the grid interfacing inverter can effectively be utilized to perform the following functions: 1) transfer of active power harvested from RES; 2) load reactive power demand support; 3) current harmonic compensation at PCC; and 4) current unbalance and neutral current compensation. The PQ constraints at PCC can therefore be strictly maintained within the utility standards without any additional hardware cost. Therefore, DG integration may need some control devices to be applied in the network which will facilitate the integration process and assure the required power quality. The basic objective of the distribution generation system connected with grid is to control the power that the inverter injects into the grid. According to the grid demands, injected power does not only include the control of the reactive power, but also to control the injected active power. Fig.1 shows a general purpose block diagram of DG-grid with power electronics system for injectingDG power into the grid while improving the system power quality.

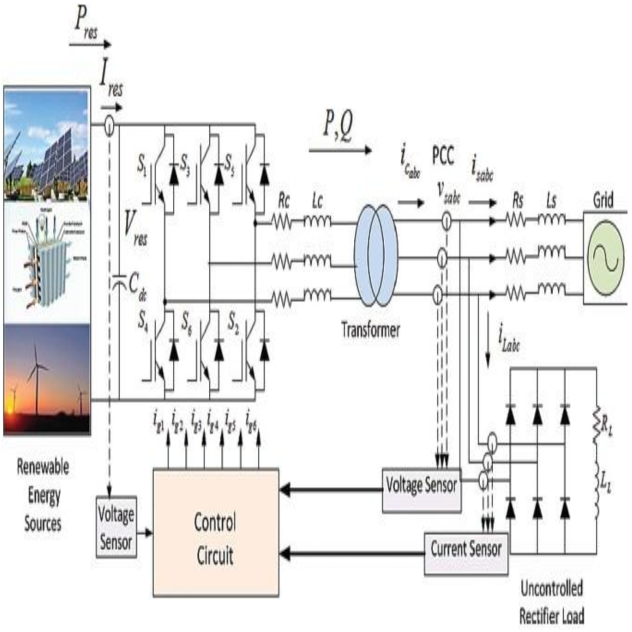

Fig 1: Proposed Renewable Based Distributed Generation System

2. System description:

The grid interfacing inverter and its interconnection with the grid is represented in Fig.1. It consists of a four-leg four-wire voltage source inverter. The voltage source inverter is a key element of a distributed generation system as it interfaces the renewable energy source to the grid and delivers the generated power. In this type of applications, the inverter operates as a current controlled voltage source inverter. Fourth leg is used for neutral connection. The renewable energy source may be a DC source or an AC source with rectifier coupled to dc-link. Here we use photo voltaic cells is used as a renewable energy source. The power which is generated from RES is given to the grid by connecting the grid-interfacing inverter not only fulfills the total load active and reactive power demand but also delivers the excess generated sinusoidal active power to the grid at unity power factor.

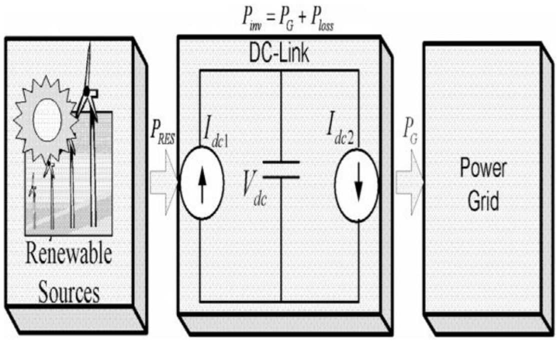

Fig 2: DC-Link Equivalent Diagram

3. Dc-link voltage controllers

As mentioned before, the source supplies an unbalanced nonlinear ac load directly. The transient response of the DSTATCOM is very important while compensating rapidly varying unbalanced and non-linear loads. Any change in the load affects the DC-link voltage directly. The proper operation of DSTATCOM requires variation of the DC link voltage within the prescribed limits. Toregulate this dc link voltage, closed-loop controllers are used, in this paper ANN controller is used to maintain constant DC link voltage To maintain the dc link voltage at the reference value, the dc link capacitor needs a certain amount of real power, which is proportional to the difference between actual and reference voltages. The amount of real power is calculated by using ANN controller

An artificial neural network (ANN), often just called a "neural network" (NN), is a mathematical model or computational model based on biological neural networks. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. In more practical terms neural networks are non-linear statistical data modeling tools.

They can be used to model complex relationships between inputs and outputs or to find patterns in data. NN is an artificial intelligence technique that is used for generating training data set and testing the applied input data. A feed forward type NN is used for theproposed method. Normally, the NN consist of three layers: input layer, hidden layer and output layer.Here, the error,change of error, and the regulated output voltage are denoted as V_e,$V_{\Delta e}$, V_{DC}^{NN}respectively. The structure of the NN is shown in fig3.

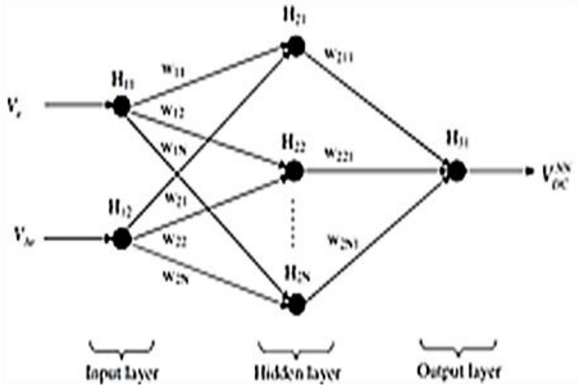

Fig3: Structure of the NN for Capacitor Voltage Regulation

In the above figure, the input layer, hidden layer and output layer of the network are (H11, H12), (H21, H22…..H2N), and H31 respectively. The weight of the input layer to hidden layer is denoted as*w11, w 12, w1N, w21, w22, and w2N.* Theweight of the hidden layer to output layer is denoted as *w 211, w221, w2N1.* Here, the Back Propagation (BP) trainingalgorithm is used for training the network

4. Proposed control algorithm

The control algorithm to use the inverter as an APF is discussed in this section. Based on the load on the 3P4W system, the current drawn from the utility can be unbalanced. In this paper a new control strategy is proposed to compensate the current unbalance present in the load currents by using the concept of single phase p—q theory. According to this theory, a signal phase system can be defined as a pseudo two-phase system giving π/2 lead or π/2 lag, that is each phase voltage and current of the original three-phase system can be considered as three independent two phase systems. These resultant two phase systems can be represented in α—β coordinates, and thus, the p—q theory applied for balanced three phase system can also be used for each phase of unbalanced system independently. The actual load voltages and load currents are considered as α—axis quantities whereas the π/2 lead load or π/2 lag voltages and π/2 lead or π/2 lag load currents are considered as β—axis quantities. In this paper π/2 lead is considered to achieve a two phase system for each phase. The major disadvantage of p-q theory is that it gives poor results under distorted or unbalanced inputand utility voltages. In order to eliminate these limitations, the reference load voltage signal extracted from PLL is used instead of actual load voltages.

4(a). Extraction of reference load voltages

The control strategy uses a PLL based unit vector template for extraction of reference signal from the distorted input supply. The schematic diagram of unit vector template generation is as shown in fig4.

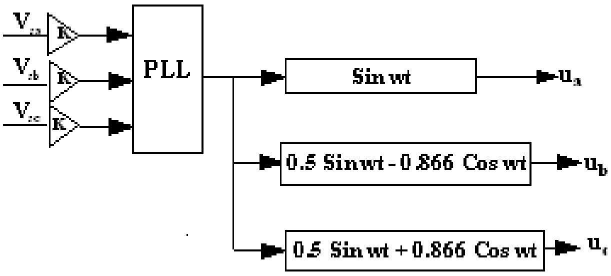

Fig4: Extraction of Unit Vector Template

The input source voltage at the point of common coupling contains fundamental and distorted component. To get unit vector templates of voltage, the input voltage is sensed, and multiplied by a constant. These vector templates are then passed through a PLL for synchronization. The unit vector templates for different phases are thus obtained as follows:

$$u_a = \sin(\omega t) \tag{1}$$

$$u_b = \sin(\omega t - 120^0) \tag{2}$$

$$u_c = \sin(\omega t + 120^0) \tag{3}$$

To get the positive sequence amplitude of source voltage the reference load voltages are obtained by multiplying the peak amplitude of fundamental input voltage with unit vector. In order to have distortion less load voltage, the load voltage must be equal to these reference signals. In this case, the αβ coordinate representation of the source voltage is

$$\begin{bmatrix} V_{g\alpha}(\omega t) \\ V_{g\beta}(\omega t) \end{bmatrix} = \begin{bmatrix} V_g(\omega t) \\ V_g(\omega t - \frac{\pi}{2}) \end{bmatrix} = \begin{bmatrix} VCos(\omega t + \phi) \\ VSin(\omega t + \phi) \end{bmatrix} \tag{4}$$

Where V and ɸare the source voltage amplitude obtained from PLL frequency and phase angle respectively. Similarly, the αβ-coordinate representation of the load current is

$$\begin{bmatrix} i_{L\alpha}(\omega t) \\ i_{L\beta}(\omega t) \end{bmatrix} = \begin{bmatrix} i_l(\omega t) \\ i_l(\omega t - \frac{\pi}{2}) \end{bmatrix} \tag{5}$$

Once the αβ-axis quantities are obtained, the instantaneous active and reactive powers drawn by the nonlinear load canbe expressed as

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} \overline{p} + \tilde{p} \\ \overline{q} + \tilde{q} \end{bmatrix} = \begin{bmatrix} V_{g\alpha} & V_{g\beta} \\ -V_{g\beta} & V_{g\alpha} \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \tag{6}$$

Where, p and q are the instantaneous active and reactive powers, respectively. The components $\overline{p}$ and $\overline{q}$ represent the DC components that are responsible for fundamental load active and reactive powers, respectively, whereas $\tilde{p}$ and $\tilde{q}$ represents the AC components that are responsible for harmonic powers. The fundamental active and reactive power components can be extracted from p and q respectively by using low pass filter.

The fundamental active current drawn by the nonlinear load can be obtained by taking the inverse of (6) as

$$\begin{bmatrix} i'_{L\alpha p} \\ i'_{L\beta p} \end{bmatrix} = \begin{bmatrix} V_{g\alpha} & V_{g\beta} \\ -V_{g\beta} & V_{g\alpha} \end{bmatrix}^{-1} \begin{bmatrix} \overline{p} \\ 0 \end{bmatrix} = \frac{1}{(V_{g\alpha}{}^2 + V_{g\beta}{}^2)} \begin{bmatrix} V_{g\alpha} \\ V_{g\beta} \end{bmatrix} \overline{p} \tag{7}$$

Since, only the α-axis quantities are belong to the original single-phase system, therefore

$$i'L, p = i'L\alpha p = \frac{\overline{p}}{(V_{g\alpha}{}^2 + V_{g\beta}{}^2)} V_{g\alpha} \tag{8}$$

Where $\overline{p} = p_s/ph + p_{dc}/ph$, $p_s/ph = (p_{l,total})/3$, $p_{l,total} = (p_{La} + p_{Lb} + p_{Lc})$ and p_{dc}/ph is the precise amount of per-phase active power that should be taken from the source in order to maintain the dc-link voltage at a constant level and to overcome the losses. Therefore the reference currents for each phase is represented as

For phase 'a' $$I_a^* = \frac{(P_{s/ph} + P_{dc/ph})}{(V_{ga\alpha}{}^2 + V_{ga\beta}{}^2)} V_{ga\alpha} \tag{9a}$$

For phase 'b' $$I_b^* = \frac{(P_{s/ph} + P_{dc/ph})}{(V_{gb\alpha}{}^2 + V_{gb\beta}{}^2)} V_{gb\alpha} \tag{9b}$$

For phase 'c' $$I_c^* = \frac{(P_{s/ph} + P_{dc/ph})}{(V_{gc\alpha}{}^2 + V_{gc\beta}{}^2)} V_{gc\alpha} \tag{9c}$$

The reference neutral current signal can be extracted by simply adding all the sensed load currents without actual neutral current that is

$$i_{Ln} = i_{La} + i_{Lb} + i_{Lc}$$

The neutral current, present if any, due to the loads connected to the neutral conductor should be compensated by forth leg of grid-interfacing inverter and thus should not be drawn from the grid. In other words, the reference current for the grid neutral current is considered as zero and can be expressed as

$$I_n^* = 0 \tag{10}$$

The reference grid currents (Ia* , Ib* ,Ic* and In*)are compared with actual grid currents (Ia , Ib ,Ic and In) to compute the current errors as

$$I_{aerr} = I_a^* - I_a \tag{11a}$$

$$I_{berr} = I_b^* - I_b \tag{11b}$$

$$I_{cerr} = I_c^* - I_c \tag{11c}$$

$$I_{nerr} = I_n^* - I_n \tag{11d}$$

These current errors are given to hysteresis current controller. The hysteresis controller then generates the switching pulses (P1 *to* P8) for the gate drives of grid-interfacing inverter. The average model of 4-leg inverter can be obtained by the following state space equations

$$\frac{dI_{Inva}}{dt} = \frac{(V_{Inva} - V_a)}{L_{sh}} \qquad (12a)$$

$$\frac{dI_{Invb}}{dt} = \frac{(V_{Invb} - V_b)}{L_{sh}} \qquad (12b)$$

$$\frac{dI_{Invc}}{dt} = \frac{(V_{Invc} - V_c)}{L_{sh}} \qquad (12c)$$

$$\frac{dI_{Invn}}{dt} = \frac{(V_{Invn} - V_n)}{L_{sh}} \qquad (12d)$$

$$\frac{dV_{dc}}{dt} = \frac{(I_{Invad} + I_{Invbd} + I_{Invcd} + I_{Invnd})}{C_{dc}} \qquad (12e)$$

Where V_{Inva}, V_{Invb}, V_{Invc} and $V_{Invn}$are the three-phase ac switching voltages generated on the output terminal of inverter. These inverter output voltages can be modeled in terms of instantaneous dc bus voltage and switching pulses of the inverter as

$$V_{inva} = \frac{(P_1 - P_4)}{2} V_{dc} \qquad (13a)$$

$$V_{invb} = \frac{(P_3 - P_6)}{2} V_{dc} \qquad (13b)$$

$$V_{invc} = \frac{(P_5 - P_2)}{2} V_{dc} \qquad (13c)$$

$$V_{invn} = \frac{(P_7 - P_8)}{2} V_{dc} \qquad (13d)$$

Similarly the charging currents I_{Invad}, I_{Invbd}, I_{Invcd} and I_{Invnd} on dc bus due to the each leg of inverter can be expressed as

$$I_{Invad} = I_{Inva}(P_1 - P_4) \qquad (14a)$$

$$I_{Invbd} = I_{Invb}(P_3 - P_6) \qquad (14b)$$

$$I_{Invcd} = I_{Invc}(P_5 - P_2) \qquad (14c)$$

$$I_{Invnd} = I_{Invn}(P_7 - P_8) \qquad (14d)$$

The switching pattern of each IGBT inside inverter can be formulated On the basis of error between actual and reference current of inverter, which can be explained as: If $I_{Inva} < (I^*_{Inva} - h_b)$ then upper switch S1will be OFF (P_1=0) and lower switch will be ON (P_4=0) in the phase "a" leg of inverter. If, $I_{Inva} < (I^*_{Inva} - h_b)$ then upper switch will be ON (P_1=1) and lower switch S4 will be OFF (P_4=0) in the phase "a" leg of inverter. Where h_b is the width of hysteresis band. On the same principle, the switching pulses for the other remaining three legs can be derived.The proposed balanced per phase fundamental active power estimation, dc link voltage control based on PI regulator, and the reference neutral current generations are shown in figure5.

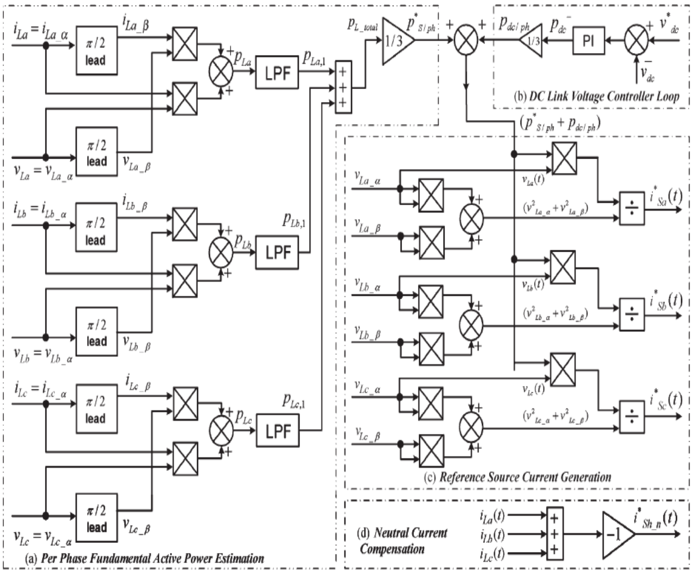

Fig 5: Shunt active filter control block diagram. (a) Proposed balanced per-phase fundamental active powerEstimation. (b) DC-link voltage control loop. (c) Reference source current generation. (d) Neutral currentCompensation

5. Simulation results

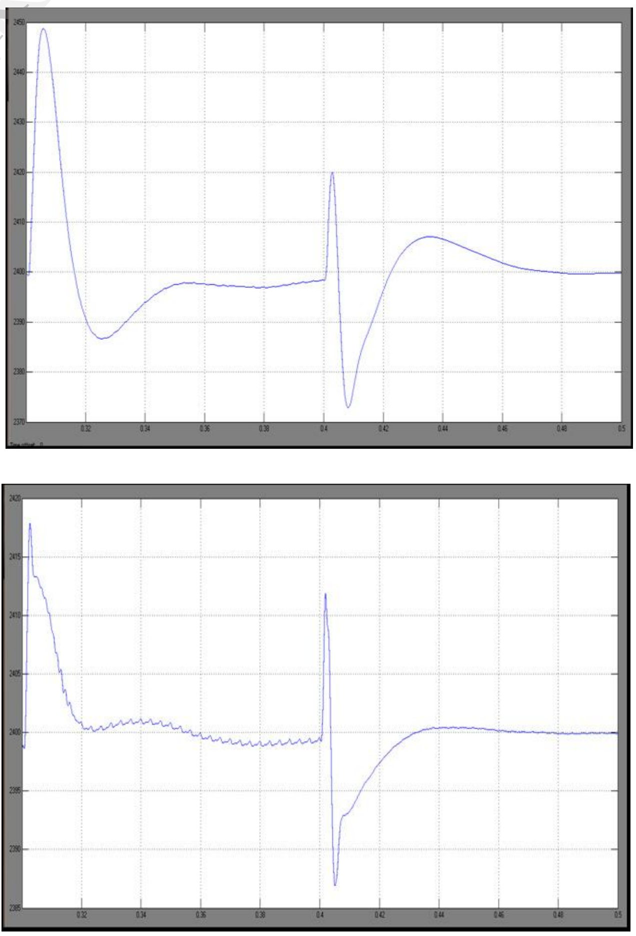

Fig 6: Comparison of DC link voltage of DSTATCOM without and with neural network.

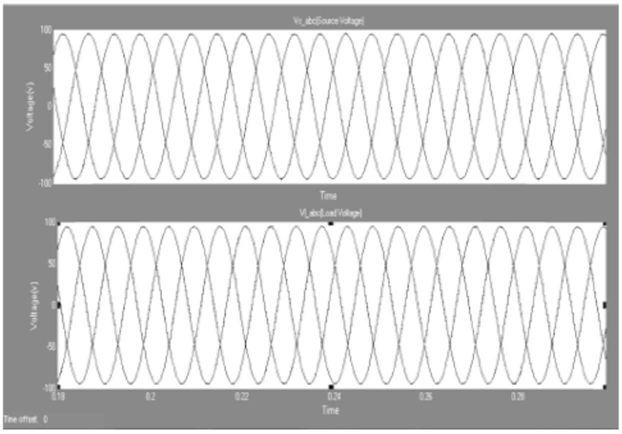

Fig 7: Voltage waveforms of source and load

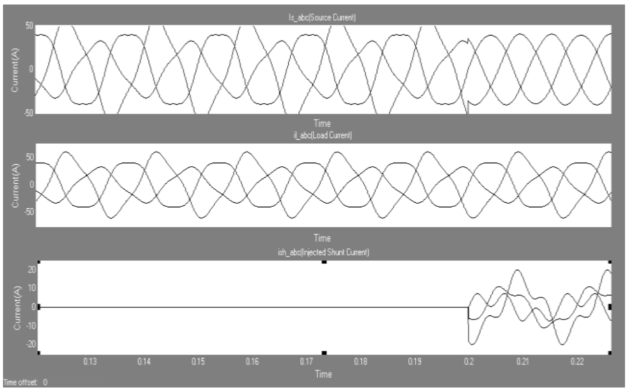

Fig 8: Current waveforms of source, load & inverter

6. Conclusion

The performance of interfacing inverter mainly depends on how accurately and quickly reference signals are generated. It has been observed that the power conditioner should have a stable DC link current for the better compensation of load harmonics and voltage sags, however, its performance using the conventional PI controller was not satisfactory. In order to improve its performances ANN controller is proposed in this paper because ANN controller is more effectively stabilizing the DC link than PI controller.

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