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Application of multilevel shunt active filter to power quality issues in renewable energy sources

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ABSTRACT

The need to generate pollution free energy has triggered the effect towards the usage of wind energy interconnection with the grid. Thus, the wind power plants l interfaced with the grid causes the power quality problems such as a harmonics, voltage sag etc., Active power filters are the powerful tool for mitigation of harmonics. This proposed work describes the methodology for improving power quality of the grid system interfaced with renewable energy. The inverter used this methodology can also be used as a power converter for injecting power from RES to grid along with harmonic compensation. This concept is validated through dynamic simulation using MATLAB/Simulink Power system toolbox.

Introduction

Increase in demand for power and depletion of conventional energy sources have made it necessary to move towards the Renewable Energy Sources (RES) for power generation. Among the renewable energy sources, wind energy is available in abundance and the electric power can be directly generated from the wind energy. The incursion of wind power plant with the distribution grid may cause thread to the power quality issues. For the improvement of power quality issues, Traditional controllers such as passive filters such as synchronous capacitors and phase advances can eliminate harmonics [1]. But they possess bulkiness, fixed compensation, electromagnetic interface and reasonable problems.

Apart from traditional controller, hybrid, shunt and series active power filters have been developed for the power quality problem [2]. The series APF are used to compensate voltage disturbances such as sag, harmonic voltages etc., The shunt APF are used to compensate reactive power, harmonic current. [3-5] So Efforts have been made to combine shunt active filter with the gird interfaced to renewable energy source.

Many researches have a made research on control strategies of grid interfaced renewable energy. Khazaie et al., [6], proposed a Shunt hybrid active power filter to alleviate the harmonics of VSC-HVDC in off-shore wind farms. In this, p-q theory is used for reference current generation. Mukhtiar Singh et al., [7] formulated a control strategy based p-q theory for Grid Interconnection of Renewable Energy Sources at the Distribution Level. N.Mohana Priya et al., [8], an assent controlled voltage source inverter is proposed for Mitigation of Power Quality Features with the Renewable Energy Sources at the Distribution Level. In [9], wavelet transform is used as a controller for shunt active filter. Hassan Abniki [10] proposed a wavelet based technique for DFIA harmonic reduction of power system using active filter.

On the other hand, the researchers have focused the harmonic reduction in renewable energy sources using conventional converters. This work focused on an improvement of power quality for the wind panel interfaced with the grid using multilevel inverter topology [11].

This work proposes and validates an enhanced control Strategy of multilevel shunt active filter for wind system interfaced with the grid. In this proposed technique, the grid interfaced inverter can be effectively utilized to transfer the active power from the renewable resource along with the compensation of reactive power and load current harmonics.

System Description

Shunt active power filter should compensate current harmonics by injecting equal but opposite compensating current. If I_s is the AC source current and I_L is the Load current, then the compensated current I_C from APF should be

$$I_c = I_L - I_s$$

The proposed system consists of wind plant connected to dc link of a grid interfacing inverter is a shown in fig. 1.

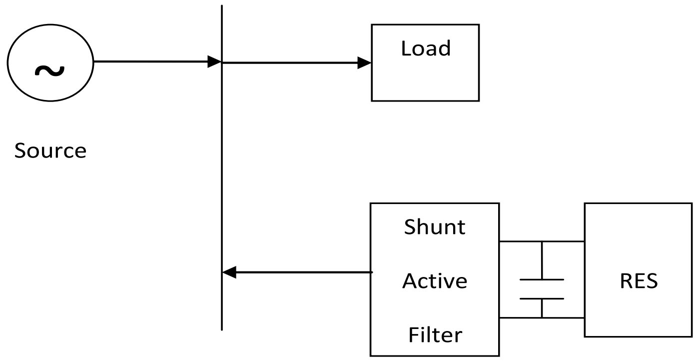

Fig. 1. Configuration of a RES interactive shunt active power filters system.

As the variable speed wind turbines generate power at variable ac voltage, the generated power needs power conditioning before connected to dc-link.

A. Wind energy conversion

The wind turbine captures the wind's kinetic energy a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to

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enhance the energy capture. Numerous wind turbines are installed at one site to build a wind farm transferred into electrical energy by a generator before being fed into the grid.

B. Inverter Deign

The inverter is a key element of system as it interfaces a wind power plant to the grid and delivers power. Cascaded multilevel inverters [12] are increasingly used in high power applications due its direct high voltage output without the need of transformers. The cascaded multilevel inverter is shown in Fig.2. In this configuration, if s=no of full bridge then the output level will be 2s+1. Each H-bridge can generate three different voltages, +Vdc, 0 and -Vdc

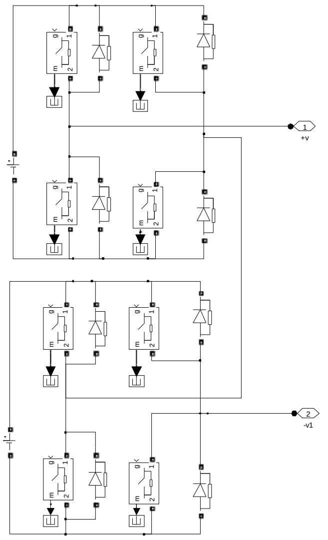

Fig. 2. Topology of a cascaded multilevel inverter in one phase

In the operation of APF, APF should correctly trace the reference so that the source current will be free from harmonic. This APF will draw small power from the source to compensate the switching loss and capacitor losses, so the DC voltage of each converter should be balanced [13]. Studies have been conducted on fuzzy logic controller for shunt active filter [14,15]. Thus dynamic characteristics of the PI fuzzy controller being fast and robust over fuzzy controller, this work proposes Fuzzy PI based controller for dc voltage control in APF.

C. Fuzzy PI based DC voltage control

The design of fuzzy PI controller shown in fig.3. Variable which represents the dynamic performance of the system to be controlled is chosen as input to the controller. Generally error and the change in error controller input.

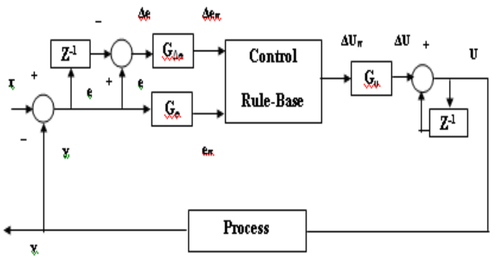

Fig. 3 Block diagram of Fuzzy PI Controller

In this, the capacitor voltage and its derivative are considered as the input of fuzzy PI and the load power requirement for voltage regulation is taken as the output of the controller.

The proposed controller implements mandani's fuzzy inference method and centroid defuzzification for fuzzification and defuzzification process. The fuzzy values are presented by triangular membership function having linguistic variable of NL(Negative Large), NM (Negative Medium), NS(negative Small), ZE (Zero),PS (Positive Small), PM (Positive Medium) and (Positive Large), are shown in fig.4.

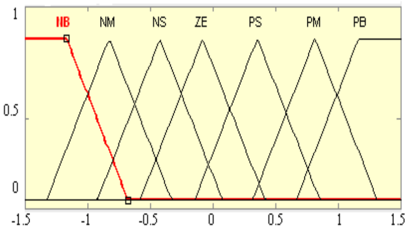

Fig. 4a. Membership Functions for *e*.

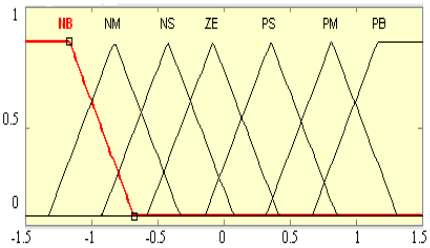

Fig. 4b. Membership Functions for Δ*e*.

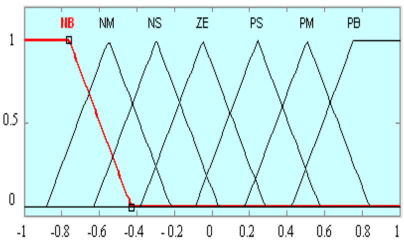

Fig. 4c. Membership Functions for Δu.

As both the inputs have seven subsets a rule base formulated for this application is given in table.1

Table I. Rule base of fuzzy PI controller

Δe/e	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	ZE
NM	NB	NB	NM	NS	NS	ZE	PS
NS	NB	N	NS	NS	ZE	PS	PM
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PS	PM	PB	PB
PB	ZE	PS	PM	PM	PB	PB	PB

D. Reference Current Generation

Most APFs have been designed on the basis of instantaneous reactive power theory to calculate the desired compensation current. It is valid for both steady-state and transient operation. It involves an algebraic transformation (Clarke transformation) of three phase voltages and currents in the a-b-c coordinate to α-β-0 coordinate. The main advantage of using Clarke transformation is separation of zero sequence components. The calculation of the instantaneous power p-q theory components is given by

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (2)$$

The instantaneous zero sequence power is given by

$$P_o = v_0 * i_0 \qquad (3)$$

The instantaneous real power and, the instantaneous imaginary power is given by

$$p = v_\alpha i_\alpha + v_\beta i_\beta$$
$$q = v_\alpha i_\beta + v_\beta i_\alpha \qquad (4)$$

Thus, the power components p and q are represented as

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (5)$$

In order to calculate the reference compensation currents needed to compensate the harmonics, the α-β-0 coordinates is inverted as in the equation

$$\begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} = \frac{1}{v_{s\alpha}^2 + v_{s\beta}^2} \begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix} \begin{bmatrix} \tilde{p}_l \\ \tilde{q}_l \end{bmatrix} \qquad (6)$$

Thus, the reference compensation currents in a-b-c coordinate is given by

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c0}^* \\ i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \qquad (7)$$

Thus, the p-q theory calculations are carried out in the shunt active power filter block shown in Figure 5.

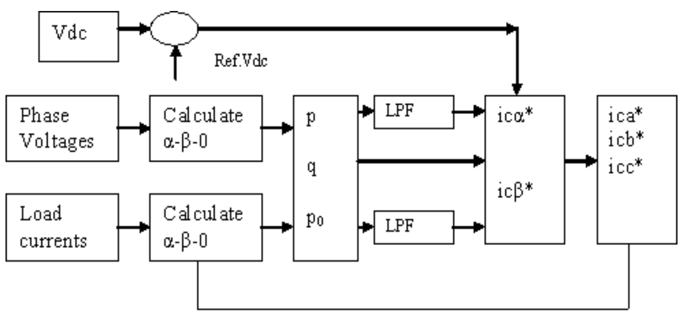

Fig 5. Calculation of p-q theory components

The inverter uses these reference currents to produce the compensation currents which are injected in power system by the inverter.

E. Carrier phase shifted PWM (CPS-PWM)

In this PWM method the equivalent switching frequency of the whole converter is (*m*-1) times as the each power device switching frequency. This means CPS-PWM can achieve a high equivalent switching frequency effect at very low real device switching frequency which is most useful in high power applications. The advantage of CPS-PWM that the semiconductor device can be used at comparatively low switching frequency so that switching loss is reduced greatly.

The carriers C1 and C2 are used to generate gating for the upper switches in left legs of power cells respectively. The inverted signals are used for upper switches in the right legs. The gate signals for the lower switches operate in a complementary manner with respect to their corresponding upper switches. Figure 6 gives the block diagram of the controller to generate the gating signals, where C1 andC2 are two triangular carrier waves shifted by 90º from each other.

C1 is used to generate gating signal for upper switch in left leg and inverted triangular wave is used for upper switch in right leg of power cell. C2 is used for lower power cell.

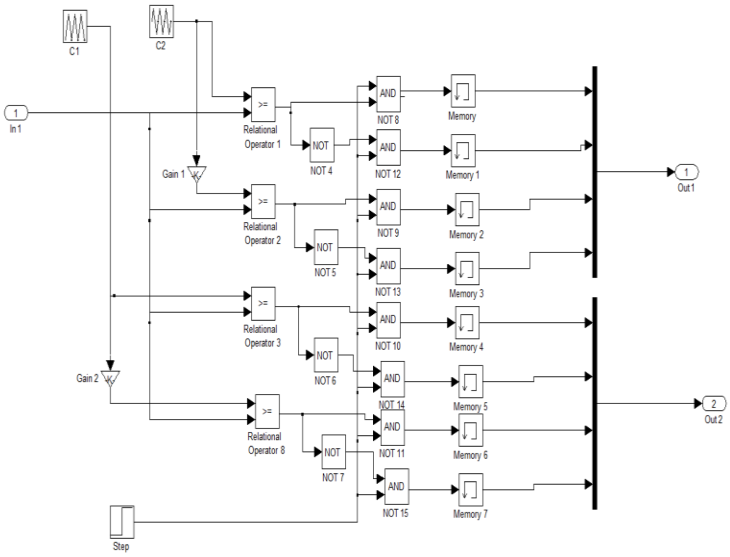

Fig 6. Gating Signal Generation by CPS-PWM

Simulation Result and Analysis

The SIMULINK model of the test system with proposed system is depicted in fig 7.

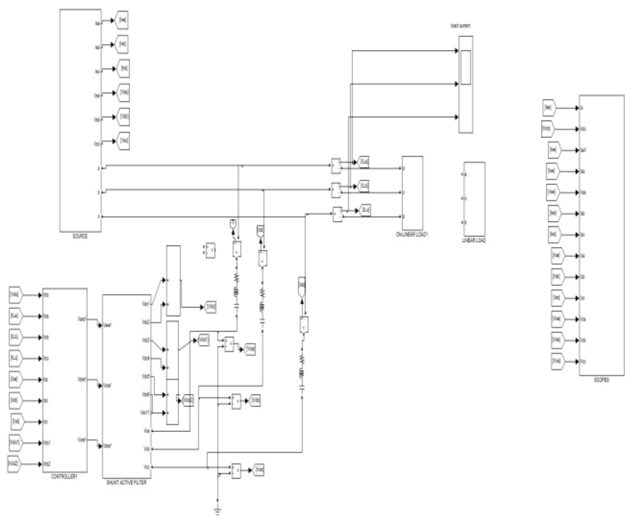

Fig 7. SIMULINK model of proposed System

The test consists of a three phase AC source of voltage 4500 v (peak) and 50 Hz frequency to a nonlinear diode rectifier load through a source and line combined reactance of 15mH/Phase. The R-L Load on the DC side of diode rectifier is about 20 ohm and 0.1 mH.

The simulation results of the proposed multilevel inverter based SAPF compensation.

The Fig. 8 shows the single phase voltage and current waveforms after compensation. The three phase compensating currents of multilevel inverter based SAPF shown in Fig. 9(a) which compensated the load current harmonics and the source current approached sinusoidal as shown in Fig. 9(b). The THD in source current is reduced to 2.66% as shown in Fig.9(c). Thus, the multilevel inverter based SAPF successfully injected the power from wind panel into the grid along with harmonic compensation.

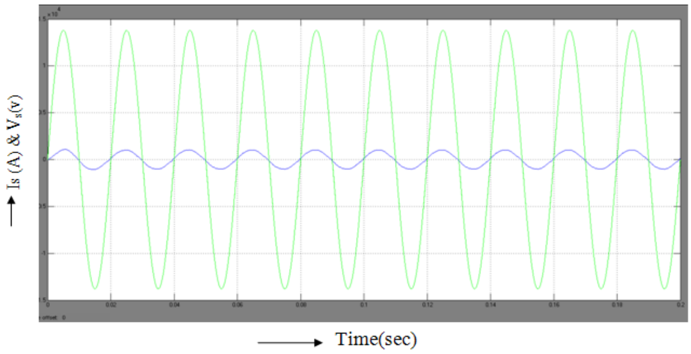

Fig 8. Voltage and current waveforms after compensation

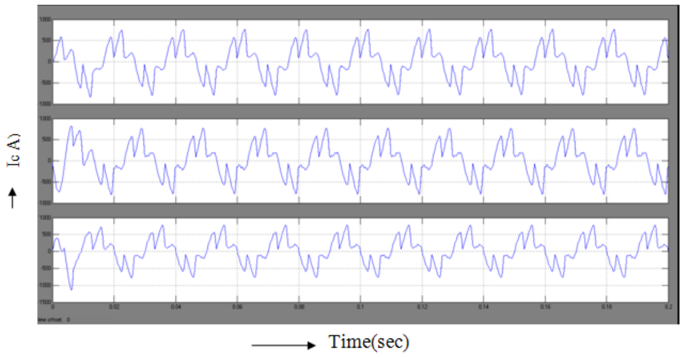

Fig 9. (a) Three phase compensating currents

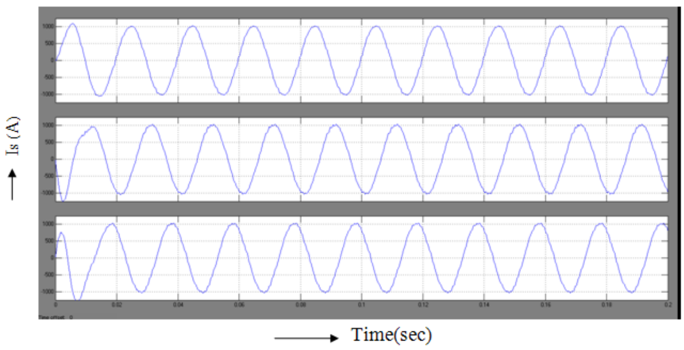

Fig 9. (b) Three phase source current after compensation

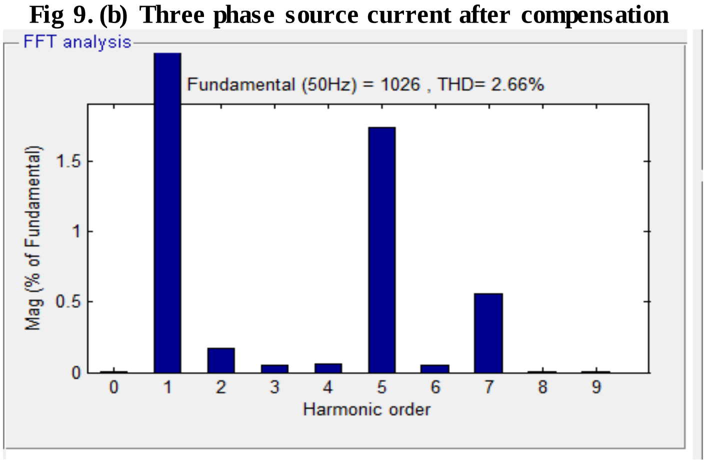

Fig 9. (c) Harmonic Spectrum of Source Current of SAF with controller

Conclusion

It has been shown that the grid-interfacing inverter can be effectively utilized for power conditioning without affecting its normal operation of real power transfer. From the results obtained, it is proven that the proposed system, injects surplus power into the mains with harmonic mitigation capability. Thus, the proposed system is an effective tool for bringing green energy for future generations.

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