Power Quality Control in a Wind Power Generating System Using SVPWM Controlled Unified Power Quality Conditioner with Genetic Algorithm

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Abstract--- This paper proposes a novel control design for power quality control in a wind turbine system using a Unified Power Quality Conditioner (UPQC). In UPQC, simultaneous compensation of voltage and current is possible. Current compensation is done by shunt active filter and voltage compensation is done by series active filter. UPQC provides unified solutions for various power quality problems such as harmonics in load current, sags/swell in the supply voltage, poor power factor at supply side etc. A seven-level cascaded multi-level inverter is used for high quality of the output quantities. The control algorithm used is Genetic Algorithm and modulation technique used is Space Vector Pulse Width Modulation (SVPWM) in the shunt active filter side. Simulation and experimental studies on a three phase power distribution system is used to verify the performance and real time implementation of this control design with UPQC.

Keywords--- Power Quality, UPQC, Cascaded Multilevel Inverter, SVPWM, Genetic Filter

I. INTRODUCTION

Wind is a free and unlimited source of energy that has attracts many people for its energy security and environmental benefit. With the limited resources of fossil fuels and recent environmental concerns, wind energy emerges as a clean renewable energy to substitute the traditional energy sources. With increasing construction of large wind power plant around the globe, maintaining control stability becomes important aspect of the wind power plant. One of the major technical challenges for wind power plant is power fluctuation at the output[1].

In order to solve this problems power conditioning devices are required. UPQC is such a power conditioning device. It is a hybrid combination of series and shunt active filter[1]. Current compensation is done by shunt active filter and voltage compensation is done by series active filter. Simultaneous compensation of current and voltage is done by the series and shunt active filters[6].

Compared to passive filters, active filters have been known for harmonic mitigation and reactive power compensation. Active filter circuits[4] will use active components like IGBT and MOSFET etc. Reduced resonance problems and fast response etc are some of the advantages of active filters. Significant attention must be given in the selection of control circuit for UPQC. The major objective must be reliability and fast response. UPQC must be capable of solving most of the power quality problems and at the same time replaces some power quality devices which consumes more power[10].

II. CONFIGURATION OF THE PROPOSED SYSTEM

The proposed system is mainly concerned for supply voltage compensation and harmonics elimination of load current. The supply voltage is generated by a wind power system. Active Power Filters are connected in series and parallel to the distribution system. The series APF is concerned for voltage compensation and shunt APF is concerned for current compensation[8]. Both filters use Synchronous Reference Frame theory for the production of reference signals. Genetic algorithm is used in the Shunt Active Filter control loop, to improve the harmonic quality. Unlike conventional VSI used in UPQC, a seven-level cascaded multilevel inverter is used. The modulation strategy used is Space Vector PWM.

Fig. 1: General Configuration of UPQC

A. Shunt Active Filter Control Strategy

One of the important parameters which determine the performance of an APF is its control strategy for reference signal generation[9]. In this paper, synchronous reference frame theory is being used for the generation of reference signal. In SRF theory, the 3phase load currents are transformed into instantaneous active(I_d) and reactive(I_q) components using a rotating frame synchronous with the positive sequence of the system voltage as given below.
The active and reactive components can be decomposed into their dc and ac values respectively as follows:

\[
\begin{bmatrix}
\frac{i_d}{i_q} \\
\frac{\text{sin} \omega t - 2\pi/3}{\text{cos} \omega t - 2\pi/3}
\end{bmatrix}
\]

The active and reactive components in the abc frame can be given by the equation as follows:

\[
\begin{bmatrix}
\frac{i_d}{i_q} \\
\frac{\text{sin} \omega t - 2\pi/3}{\text{cos} \omega t - 2\pi/3}
\end{bmatrix}
\]

This theory is applicable to both single phase and three phase circuits. It gives accurate results on both steady state and transient conditions.

Fig. 2: Simulation Diagram for Shunt Active Filter

B. Series Active Filter Control Strategy

Series active filter is concerned for voltage compensation. Depending upon the type of load used, so many control strategies are being proposed. In this paper, the proposed strategy is the minimisation of the injected active power for a given apparent power. Synchronous d-q frame theory is applied to extract the reference voltage for the series APF as shown in Fig. 2. For unbalanced Vs, the transformation to d-q axis is given by

\[
\begin{bmatrix}
\frac{V_{sd}}{V_{sq}} \\
\frac{V_{sb}}{V_{sq}}
\end{bmatrix}
\]

Where T is given as follows:

\[
T = \begin{bmatrix}
\text{cos} \omega t - 2\pi/3 \\
\text{sin} \omega t - 2\pi/3
\end{bmatrix}
\]

Cascaded multilevel inverters can be defined as power electronic devices that produces an output waveform of desired level by using input dc voltages. High quality of the output quantities, ability to operate at high power and high voltage and flexibility etc are some of the advantages of cascaded multilevel inverters. Smallest number of voltage level for a multilevel inverter using separate dc sources are three. For obtaining that, a single H bridge is required. A cascaded multilevel inverter is formed by connecting several H bridges in series. Each inverter will generate a square wave voltage waveform. Combining the waveform of each inverters, the output waveform of cascaded multilevel inverter will be formed.
There are mainly two types of cascaded multilevel inverters. They are

i. Symmetrical Type
ii. Asymmetrical Type

If the dc sources used in each inverter is equal, it is of symmetric type and if they are unequal, it is of asymmetric type a seven-level cascaded multi level inverter is used in this paper.

![Fig. 4: Three Phase Seven-Level Cascaded Multi Level Inverter](image)

### III. SVPWM

In multilevel inverters, several modulation techniques are used to reduce harmonics in sinusoidal signals. Space Vector Pulse Width Modulation can be defined as a vector approach to PWM technique in 3 phase inverters[2]. It is advantageous over the existing Sinusoidal PWM. The increasing trend of using SVPWM is due to its superior harmonic quality, ease of implementation and enhanced dc bus utilization.

In three phase inverters, there will be 8 switching states in total[7]. Out of which six are of active switching states and the other two are zero switching states. These vectors will form a hexagon in which six sectors will span 60 degree each. The reference voltage representing the three phase sinusoidal voltage in SVPWM can be constructed by switching between 2 nearest active vectors and zero vectors. The time of application of active vectors can also be found. The formulas used in SVPWM is given below.

**Line to line voltages:**

\[
V_{ab} = V_{aN} - V_{bN}
\]
\[
V_{bc} = V_{bN} - V_{cN}
\]
\[
V_{ca} = V_{cN} - V_{aN}
\]

**Phase voltages:**

\[
V_{an} = 2/3V_{aN} - 1/3V_{bN} - 1/3V_{cN}
\]
\[
V_{bn} = -1/3V_{aN} + 2/3V_{bN} - 1/3V_{cN}
\]
\[
V_{cn} = -1/3V_{aN} - 1/3V_{bN} + 2/3V_{cN}
\]

**Fundamental Frequency Component (V\_\text{ab}) _1**

\[
(V_{\text{ab}})_1^{(\text{rms})} = \sqrt{3} \frac{4}{\sqrt{2}} \frac{V_{d}}{\pi} - \frac{\sqrt{6}}{\pi} V_{s} = 0.78V_{d}
\]

**Harmonic Frequency Components (V\_\text{ab}) _h** is given by:

\[
(V_{\text{ab}})_h^{(\text{rms})} = \frac{0.78}{n} V_{d}
\]

where, \( h = \sin \pm 1 \) \( (n = 1, 2, 3, \ldots) \)

**Determine V\_d, V\_q, V\_\text{ref}, and angle (\( \alpha \)):**

\[
\begin{align*}
V_{d} &= V_{an} - V_{bn} \cdot \cos 60 - V_{cn} \cdot \cos 60 \\
V_{d} &= -V_{an} / 2 - V_{bn} / 2 - V_{cm} / 2 \\
V_{s} &= 0 - V_{an} \cdot \cos 30 - V_{bn} \cdot \cos 30 \\
V_{s} &= -V_{an} / 2 - V_{bn} / 2 - V_{cm} / 2
\end{align*}
\]

\[
\tan(\theta) = \frac{V_{d}}{V_{d}}
\]

(16) \( \alpha = \tan^{-1} (\frac{V_{d}}{V_{d}}) = \omega_c \cdot t = 2 \pi f_c \cdot t \)

(\text{where,} \, f_c \text{ = fundamental frequency})

**Calculation of Switching time duration at Sector 1:**

\[
\begin{align*}
\int_{0}^{T_2} \bar{V}_{\text{ref}} d\bar{t} &= \int_{0}^{T_1} \bar{V}_1 d\bar{t} + \int_{0}^{T_1} \bar{V}_2 d\bar{t} + \int_{0}^{T_2} \bar{V}_0 d\bar{t} \\
\therefore T_2 \bar{V}_{\text{ref}} &= (T_1 \bar{V}_1 + T_2 \bar{V}_2)
\end{align*}
\]

\[
T_2 \bar{V}_{\text{ref}} = \begin{bmatrix} \cos \alpha & \sin \alpha \end{bmatrix} = T_1 \bar{V}_1 + T_2 \bar{V}_2
\]

\[
\begin{bmatrix} \cos \frac{\pi}{3} \\
\sin \frac{\pi}{3} \end{bmatrix}
\]

Where \( 0 \leq \alpha \leq 60 \)

\[
\begin{align*}
\therefore T_1 &= T_c - \alpha \cdot \frac{\sin (\pi / 3 - \alpha)}{\sin (\pi / 3)} \\
\therefore T_2 &= T_c - \alpha \cdot \frac{\sin (\alpha)}{\sin (\pi / 3)} \\
\therefore T_0 &= T_c - (T_1 + T_2), \quad \left( \begin{array}{l}
\text{where,} \, T_c = \frac{1}{f_c} \text{ and } \alpha = \frac{\sqrt{3} V_{\text{ref}}}{3 V_{d}}
\end{array} \right)
\end{align*}
\]

### IV. GENETIC ALGORITHM

Genetic algorithm can be defined as a search algorithm based on natural selection and natural genetics. It can be used when no analytical formulation can be found for the mathematical description of the problem. The increasing tendency of using genetic algorithm in designing electronic circuits is due to the fact that it involves optimisation of a number of parameters[3]. When a vast range of possibilities are
there in a problem, we use genetic algorithm to choose the appropriate solution.

When a specific problem is given, the input to genetic algorithm will be a set of potential solutions to that problem. A set of genes corresponding to a chromosome in a natural gene is referred to as strings in genetic algorithm. In this paper genetic algorithm is used in the shunt filter side for current compensation. The shunt active filter will inject some reference compensating current into the distribution system for compensating load current. Here genetic algorithm will help to choose the optimum reference signal out of possible solutions. In the simulation, it is given a population of 20 samples. Each sample is delayed by 1 unit time. Out of this 20 samples, GA will choose the optimum solution by performing cross over and mutation. A metric called fitness function will quantitatively evaluate each candidate to find the optimum solution.

V. SIMULATION AND EXPERIMENTAL RESULTS

For the simulation of the proposed wind power system using UPQC, MATLAB/SIMULINK is used. The simulation results are given below. The shunt APF is used for current compensation. Compensation of load current is shown in Fig. 5. When sag/swell occurs in the supply system, the series active filter will inject compensating voltage into the supply system. SRF theory is used for reference signal generation. A series RLC load is used to produce sag/swell in the SIMULINK model. At t=0.2s, sag is produced and series APF injects compensation voltage into the circuit. Compensation of SAG/SWELL is shown in Fig. 6. Both the grid voltage and the compensated voltages are shown.

From FFT analysis, the THD of the load current is initially 26.5%. After doing current compensation by shunt active power filter, the THD is reduced to 2.29%. Thus a simultaneous compensation of current and voltage is obtained by the proposed system.

VI. CONCLUSION

A novel control strategy for a wind power generating system using UPQC is proposed in this paper. Both series and shunt APF are used for voltage and current compensation respectively. A cascaded multilevel inverter with SVPWM is used to improve harmonic quality. Genetic algorithm is used in the control circuit of shunt APF to choose an optimal solution and to reduce the THD. The proposed system is simulated using Matlab/simulink. Based on the simulation results, it is shown that the proposed UPQC provides solutions for many power quality problems in a wind power system such as sag/swell in the supply voltage, harmonics in the load current etc.

REFERENCES