Grid Voltage Synchronization for Distribution Systems under Grid fault conditions with multilevel STATCOM

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ABSTRACT: Grid connection of distributed generation systems, mainly wind and photovoltaic (PV) systems, are becoming very demanding. The transmission system operators (TSOs) are especially concerned about the low-voltage-ride-through requirements. Solutions based on the installation of STATCOMs.This paper propose study on two, three & five-level STATCOM. The device uses neutral-point clamping method to divide the inverter circuit into positive, negative and zero three level, so that each component subject to the maximum voltage reduced to half of the traditional inverter circuit. STATCOM (Static Synchronous Compensator)is an important member of Flexible AC Transmission System, comparing with traditional reactive power compensation device, it not only decreases the volume and cost of the device, but also has faster response speed and more smooth regulating property.

KEY WORDS: photo voltaic, STATCOM, five level converter, Flexible AC Transmission system.

I. INTRODUCTION

Distributed generation, also called on-site generation, dispersed generation, embedded generation, decentralized generation, decentralized energy or distributed energygenerates electricity from many small energy sources. Currently, industrial countries generate most of their electricity in large centralized facilities, such as fossil fuel (coal, gas powered) nuclear or hydropower plants. These plants have excellent economies of scale, but usually transmit electricity long distances and negatively affect the environment.

Most plants are built this way due to a number of economic, health & safety, logistical, environmental, geographical and geological factors. For example, coal power plants are built away from cities to prevent their heavy air pollution from affecting the populace. In addition, such plants are often built near collieries to minimize the cost of transporting coal. Hydroelectric plants are by their nature limited to operating at sites with sufficient water flow. Most power plants are often considered to be too far away for their waste heat to be used for heating purposes.Low pollution is a crucial advantage of combined cycle plants that burn natural gas. The low pollution permits the plants to be near enough to a city to be used for district heating and cooling.

Distributed generation is another approach. It reduces the amount of energy lost in transmitting electricity because the electricity is generated very near where it is used, perhaps even in the same building. This also reduces the size and number of power lines that must be constructed. Typical distributed power sources in a Feed-in Tariff (FIT) scheme have low maintenance, low pollution and high efficiencies. In the past, these traits required dedicated operating engineers and large complex plants to reduce pollution. However, modern embedded systems can provide these traits with automated operation and renewable, such as sunlight, wind and geothermal. This reduces the size of power plant that can show a profit.

II. BASIC PRINCIPLE OF STATCOM

A STATCOM is a controlled reactive source, which includes a Voltage Source Converter (VSC) and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles of a STATCOM are based on the exact equivalence of the conventional rotating synchronous compensator. The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which could be a filter inductance or the leakage inductance of the coupling transformer, as shown

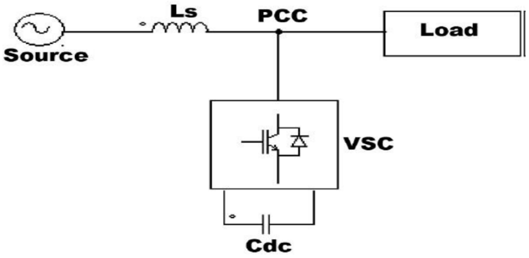

Fig.1 line diagram of STATCOM

The DC side of the converter is connected to a DC capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element. This capacitor could be charged by a battery source or could be pre-charged by the converter itself. If the output voltage of the VSC [5] is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the STATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages. It is to be noted that voltage regulation at PCC and power factor correction cannot be achieved simultaneously. For a STATCOM used for voltage regulation at the PCC, the compensation should be such that the supply currents should lead the supply voltages; whereas, for power factor correction, [6] the supply current should be in phase with the supply voltages. The control strategies studied in this paper are applied with a view to studying the performance of a STATCOM for power factor correction and harmonic mitigation.

III. MULTILEVEL CONVERTER

An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Static inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries.

A single-phase structure of an m-level cascaded inverter is illustrated in Figure 31.1. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, +Vdc, 0, and –Vdc by connecting the dc source to the ac output by different combinations of the four switches, S1, S2, S3, and S4. To obtain +Vdc, switches S1 and S4 are turned on, whereas –Vdc can be obtained by turning on switches S2 and S3. By turning on S1 and S2 or S3 and S4, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by m = 2s+1, where s is the number of separate dc sources. An example phase voltage waveform for an 11-level cascaded H-bridge inverter with 5 SDCSs and 5 full bridges is shown in Figure 31.2. The phase voltage van = va1 + va2 + va3 + va4 + va5.

For a stepped waveform such as the one depicted in Figure 31.2 with s steps, the Fourier Transform for this waveform follows

$$V(\omega t)=\frac{4V_{dc}}{\pi}\sum_{n}\left[\cos(n\theta_1)+\cos(n\theta_2)+\ldots+\cos(n\theta_s)\right]\frac{\sin(n\omega t)}{n},\quad \text{where } n=1,3,5,7,\ldots$$

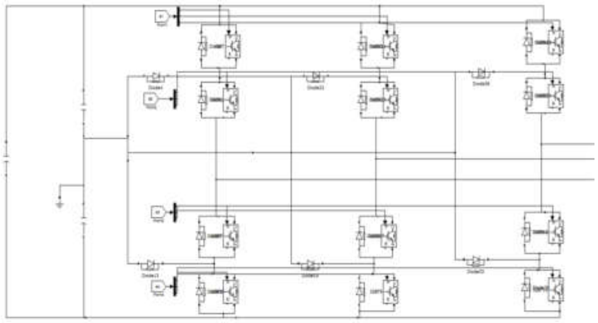

Fig.2 three levels STATCOM

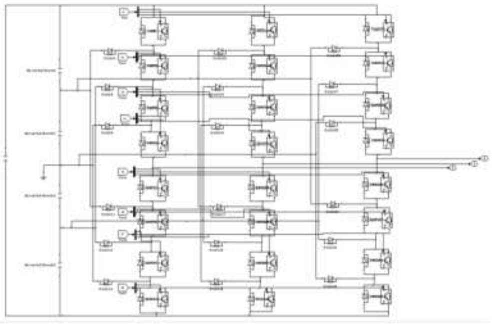

Fig.3 five level STATCOM

The magnitudes of the Fourier coefficients when normalized with respect to Vdc are as follows

$$H(n)=\frac{4}{\pi n}\left[\cos(n\theta_1)+\cos(n\theta_2)+\ldots+\cos(n\theta_s)\right],\quad \text{where } n=1,3,5,7,\ldots$$

The conducting angles, θ1, θ2... θs, can be chosen such that the voltage total harmonic distortion is a minimum. Generally, these angles are chosen so that predominant lower frequency harmonics, 5th, 7th, 11th, and 13th, harmonics are eliminated. [7] More detail on harmonic elimination techniques will be presented in the next section.

Multilevel cascaded inverters have been proposed for such applications as static var generation, an interface with renewable energy sources, and for battery-based applications. Three-phase cascaded inverters can be connected in wye, as shown in Figure, or in delta. Peng has demonstrated a prototype multilevel cascaded static var generator connected in parallel with the electrical system that could supply or draw reactive current from an electrical system.

IV. CONTROL STRATEGIES

Satisfactory performance, fast response, flexible and easy implementation are the main objectives of any compensation strategy. The control strategies of a STATCOM are mainly implemented in the following steps:

- Measurements of system variables and signal conditioning
- Extraction of reference compensating signals
- Generation of firing angles for switching devices

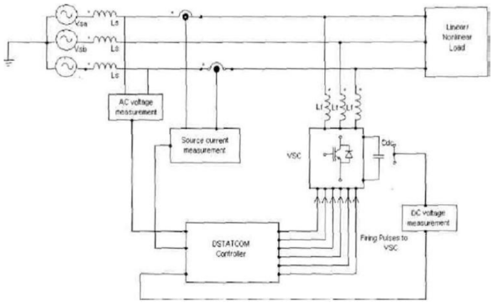

Figure.4 schematic diagram of STATCOM

Figure.3 shows the schematic diagram of STATCOM control taking into consideration the above steps. The generation of proper pulse width modulation (PWM) firing is the most important part of STATCOM control and it has a great impact on its compensation objectives, transient as well as steady state performance. Since a STATCOM shares many concepts with that of a STATCOM at the transmission level, a few control techniques [8] have been directly implemented to a STATCOM, incorporating PWM switching, rather than fundamental frequency switching (FFS) methods. A PWM based distribution static compensator offers faster response and capability for harmonic elimination. This paper is an attempt to compare the following schemes of a STATCOM for power factor correction and harmonic mitigation based on:

1. Phase shift control

2. Indirect decoupled current control

3. Regulation of AC bus and DC link voltage

The performance of STATCOM with different control schemes have been studied through digital simulations for common system parameters, as given in the Appendix.

• Phase Shift Control:

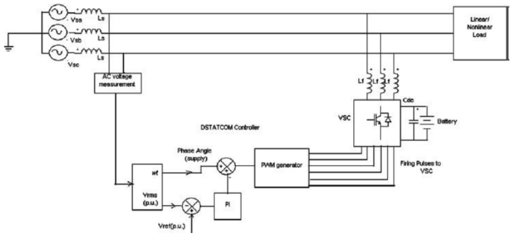

Figure.5 control diagram of STATCOM

The schematic diagram of phase shift control is shown in figure. In this method, the compensation is achieved by the measuring of the rms voltage at the load point, whereas no reactive power measurements are required. Sinusoidal PWM technique is used with constant switching frequency. The error signal obtained by comparing the measured system rms voltage and the reference voltage is fed to a proportional integral (PI) controller, [9] which generates the angle for deciding the necessary phase shift between the output voltage of the VSC and the AC terminal voltage. This angle is summed with the phase angle of the balanced supply voltages, assumed to be equally spaced at [14] 120 degrees, to produce the desired synchronizing signal required to operate the PWM generator. In this scheme, the DC voltage is maintained constant, using a separate battery source.

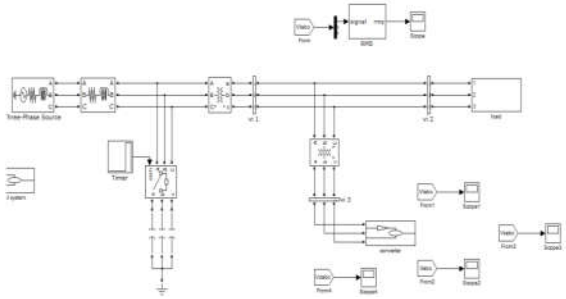

Fig.6 simulation model of three levels STATCOM

Figure a and figure b show the simulation results obtained using phase shift control for reactive power compensation and harmonic mitigation for a balanced varying linear load and for a non linear load respectively.

It is observed that the source current and the source voltage are in phase, correcting the power factor of the system in case of a linearly varying load; [15] whereas, complete compensation is not achieved in case of nonlinear load (source current THD 24.34%). The frequency spectrum of the source current for a nonlinear load, before and after compensation, is shown in Figure a and Figure b. Though this strategy is easy to implement, is robust and can provide partial reactive power compensation without harmonic suppression, [11] it has the following major disadvantages:

- The controller does not use a self supporting DC bus and thus requires a very large DC source to pre charge the capacitor. [12]
- Balanced source supply as rms voltage is assumed and the supply phase angle are calculated over the fundamental only.
- No harmonic suppression and partial compensation is achieved in case of nonlinear loads

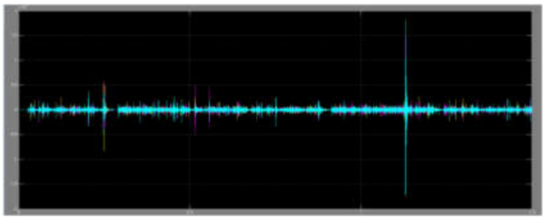

Fig.7 five level STATCOM source current

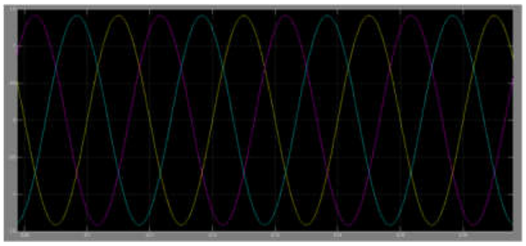

Fig: 8 five level STATCOM load current

- **Indirect Decoupled Current Control:**

This scheme is based on the governing equations of advanced static var compensator. [10] It requires the measurement of instantaneous values of three phase line voltages and current. Figure shows the block diagram representation of the control scheme. The control scheme is based on the transformation of the three phase system to a synchronously rotating frame, using Park's transformation. [13]

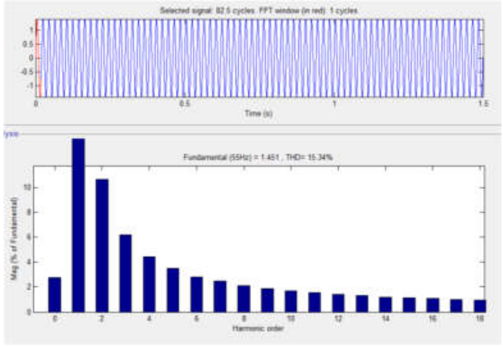

Fig. 10 THD of three level STATCOM

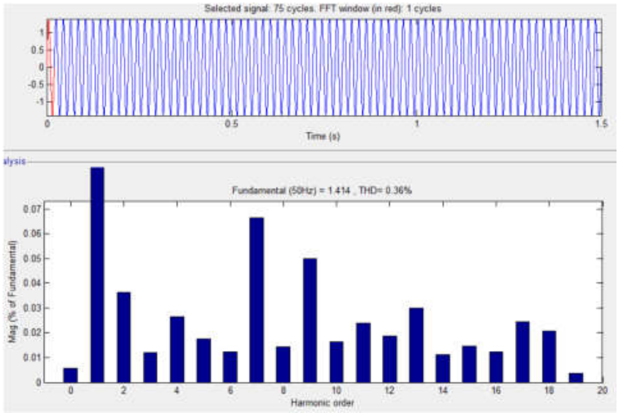

Fig. 10 THD of five level STATCOM

V. CONCLUSION

The behaviour of grid synchronisation systems during fault conditions can be achieved by multilevel STATCOM and performance of THD observed for five-level STATCOM.Compared to dynamic regulators, static compensators are of less cost and flexible control.

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