International Journal of Electrical and Electronics Research ISSN 2348-6988 (online)
Vol. 2, Issue 2, pp: (11-17), Month: April - June 2014, Available at: www.researchpublish.com

D-STATCOM APPLICATION TO MITIGATE VOLTAGE FLUCTUATION AND OVERCOME POWER BLACKOUT RISKS

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***Abstract*: For efficient and reliable operation of power system it is important to control voltage and reactive power. In power distribution network, reactive power is the main cause of increasing distribution system loss and various power quality problems. Power quality issues are gaining significant attention due to the increase in the number of sensitive loads. Distribution Static Compensator is an important device in improving power factor, maintaining constant distribution voltage, and mitigating harmonics in a distribution network. Distributed Static Compensator is a fast-acting reactive power source that can reduce voltage variations and voltage instability in the power system, and can aid in faster system voltage recovery after contingency events. When D-STATCOM is associated with a particular load, it can inject compensating current so that total demand meets the specification for utility connection. This paper shows the control techniques and application of D-STATCOM in Distributed Generation System to mitigate voltage fluctuation and overcome the risks of power blackouts.**

***Keywords:* D-STATCOM, Distributed Generation System, Voltage Source Converter, Voltage Fluctuation, Power Blackout, Micro-Grid.**

1. INTRODUCTION

Nowadays, most industrialised countries have 10 to 20 years experience with privatisation and liberalisation of electricity systems. Electricity is the backbone of each industrialised society and economy. Modern countries are not used to having even short power blackouts. The increased dependency on continuous power supply related to industrial production and daily life makes today's life much more vulnerable power supply interruption. Power quality issues are gaining significant attention due to the increase in the number of sensitive loads. Many of these loads use equipment that is sensitive to distortions or dips in supply voltages. In power distribution network, reactive power is the main cause of increasing distribution system loss and various power quality problems.

Reactive power supports the voltages that must be controlled for system reliability. Voltage control (keeping voltage within defined limits) in an electric power system is important for proper operation of electric power equipment to prevent damage such as overheating of generators and motors, to reduce transmission losses and to maintain the ability of the system to withstand disturbances and prevent voltage collapse. A voltage collapse occurs when the system is trying to serve much more load than the voltage can support which leads to power blackout risks.

To overcome the problem related to the power quality custom power device is introduced. Distributed Static Compensator is a fast-acting reactive power source that can reduce voltage variations and voltage instability in the power system, and can aid in faster system voltage recovery after contingency events. A D-STATCOM basically VSC based FACTS controller sharing many similar concept with that of STATCOM used at transmission level. D-STATCOM is employed at distribution level or at load side also behaves as shunt active filter. The main application of STATCOM is D-STATCOM exhibit high speed control of reactive power to provide voltage stabilization in power system. The D-STATCOM protect the distribution system from voltage sags, flicker caused by reactive current demand.

2. VOLTAGE SOURCE CONVERTER

Prior to the type of control algorithm incorporated, the choice of converter configuration is an important criterion. The two converter configurations are voltage source converter or current source converter, in addition to passive storage elements, either a capacitor or an inductor respectively. Normally, voltage source converters are preferred due to their smaller size, less heat dissipation and less cost of the capacitor, as compared to an inductor for the same rating. A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate voltage dips. The VSC is used to either completely replace the voltage or to inject the missing voltage. The missing voltage is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. The solid-state electronics in the converter is then switched to get the desired output voltage. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, e.g. flicker and harmonics.

3. VOLTAGE FLUCTUATION AND POWER BLACKOUT

Inadequate reactive power supply lowers voltage; as voltage drops, current must increase to maintain the power supplied, causing the lines to consume more reactive power and the voltage to drop further. If current increases too much, transmission lines trip, or go off-line, overloading other lines and potentially causing cascading failures. If voltage drops too low, some generators will automatically disconnect to protect themselves. Voltage collapse occurs when an increase in load or loss of generation or transmission facilities causes dropping voltage, which causes a further reduction in reactive power from capacitors and line charging, and still further voltage reductions. If the declines continue, these voltage reductions cause additional elements to trip, leading to further reduction in voltage and loss of load. The result is a progressive and uncontrollable decline in voltage, all because the power system is unable to provide the reactive power required to supply the reactive power demand. There are several cases in which inadequate reactive power leading to voltage collapse has been a causal factor in major power outages worldwide. Voltage collapse occurred in the United States in the blackouts of July 2, 1996, and August 10, 1996, on the West Coast. Voltage collapse also factored in the blackouts of December 19, 1978, in France; July 23, 1987, in Tokyo; March 13, 1989, in Québec; August 28, 2003, in London; September 23, 2003, in Sweden and Denmark; and September 28, 2003, in Italy.

4. D-STATCOM

A D-STATCOM is basically a converter based distribution flexible AC transmission controller, that shares many similar concepts with Static Compensator (STATCOM) used at transmission level. D-STATCOM is employed at the distribution level or at load end for dynamic compensation. A D-STATCOM is a controlled reactive source, which include a Voltage Source Converter (VSC) and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operational principles of a D-STATCOM are based on the exact equivalence of the conventional rotating synchronous compensator. The AC terminal 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.

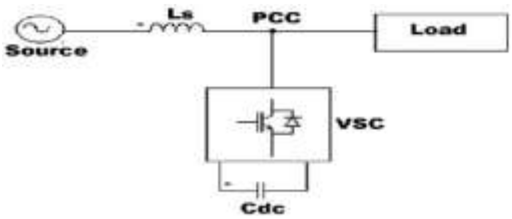

Fig.1 Schematic diagram of a D-STATCOM

The DC side of 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 input voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than AC terminal voltage, the D-STATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to difference in the two voltages.

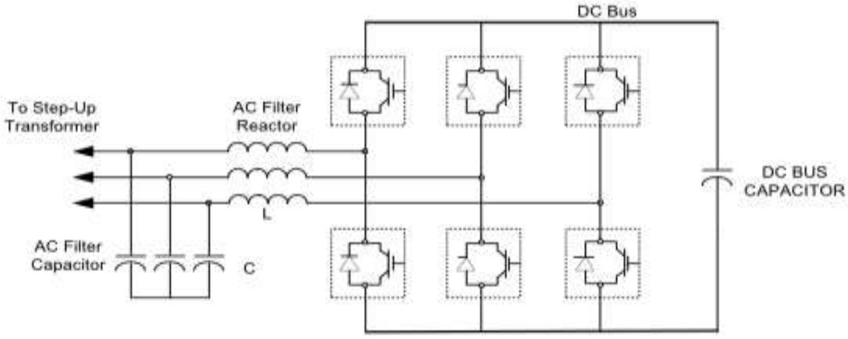

Fig.2 Single line diagram of a D-STATCOM

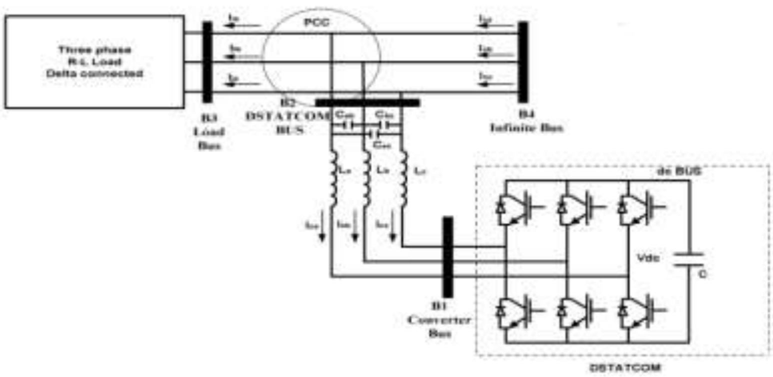

Fig.3 Schematic of a typical Distribution System compensated by DSTATCOM.

The D-STATCOM system master control provides flexible voltage and reactive control strategies that can be applied to support many power system applications including reactive support and voltage control, fast voltage recovery support, enhancing system voltage stability, improving system transient stability, improving system reliability, improving line capacity utilization, minimizing system losses.

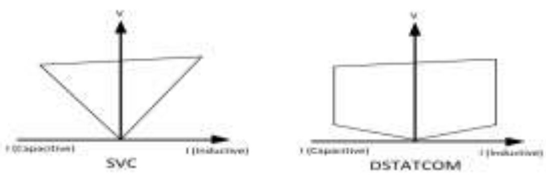

Fig.4 Voltage- Current (V-I) Characteristics of SVC vs D-STATCOM

A. Operating Principles of the D-STATCOM

STATCOM is the solid-state-based power converter version of the SVC. Operating as a shunt-connected SVC, its capacitive or inductive output currents can be controlled independently from its connected AC bus voltage. Because of the fast-switching characteristic of power converters, the STATCOM provides much faster response as compared to the SVC. In addition, in the event of a rapid change in system voltage, the capacitor voltage does not change instantaneously; therefore, the STATCOM effectively reacts for the desired responses. For example, if the system voltage drops for any reason, there is a tendency for the STATCOM to inject capacitive power to support the dipped voltages .Theoretically, the power converter employed in the STATCOM can be either a VSC or a current-source converter (CSC).

In practice, however, the VSC is preferred because of the bi directional voltage-blocking capability required by the power semiconductor devices used in CSCs. In general, a CSC derives its terminal power from a current source, i.e., a reactor. In comparison, a charged reactor is much lossier than a charged capacitor. Moreover, the VSC requires a current-source filter at its AC terminals, which is naturally provided by the coupling transformer leakage inductance, while additional capacitor banks are needed at the AC terminals of the CSC. In conclusion, the VSCs can operate with higher efficiency than the CSCs do in high-power applications. A suitable VSC is selected based on the following considerations: the voltage rating of the power network, the current harmonic requirement, the control system complexity, etc. Basically, the STATCOM system is comprised of three main parts: a VSC, a set of coupling reactors or a step-up transformer, and a controller. In a very-high-voltage system, the leakage inductances of the step-up power transformers can function as coupling reactors. The main purpose of the coupling inductors is to filter out the current harmonic components that are generated mainly by the pulsating output voltage of the power converters. The STATCOM is connected to the power networks at a PCC, where the voltage-quality problem is a concern. All required voltages and currents are measured and are fed into the controller to be compared with the commands. The controller then performs feedback control and outputs a set of switching signals to drive the main semiconductor switches of the power converter accordingly.

B. Control Strategies

Satisfactory performance, fast response, flexible and easy implementation are the main objectives of any compensation strategy. The control strategies of a DSTATCOM 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

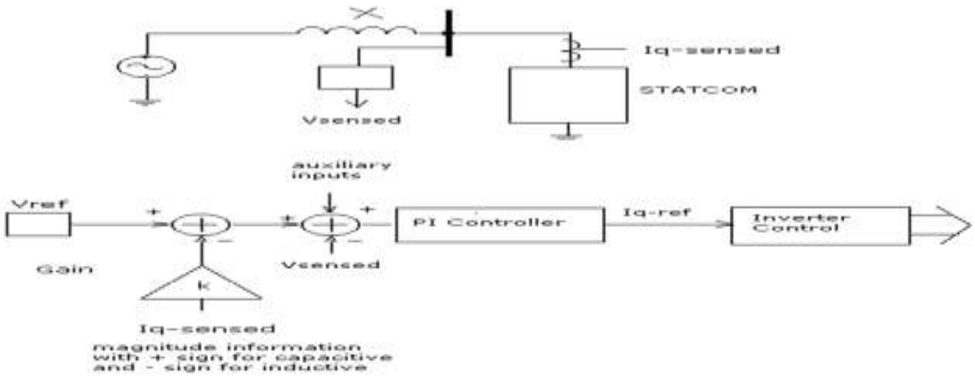

Fig.5 Schematic diagram of DSTATCOM control

The schematic diagram of DSTATCOM control, taking into consideration the above steps. The generation of proper pulse width modulation (PWM) firing is the most important part of DSTATCOM control and it has a great impact on its compensation objectives, transient as well as steady state performance. Since a DSTATCOM shares many concepts with that of a STATCOM at the transmission level, a few control techniques have been directly implemented to a DSTATCOM, 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 DSTATCOM 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

C. Hysteresis Current Control

An alternative method to reduce the low-order harmonic content of the DSTATCOM output current is to use hysteresis current control. Under hysteresis control, rapid switching of each switch according to the continuous measurement of the difference between the STATCOM supply current and reference sinusoidal current. The basic principle of current hysteresis control technique is that the switching signals are derived from the comparison of the current error signal with a fixed width hysteresis band. With simple, extreme robustness, good stability, fast dynamic, this current control technique exhibits some unsatisfactory features. For hysteresis control the phase output current is fed back to compared with the reference current I_{ref}. An upper tolerance band and a lower tolerance band, taken as ±2% of I_{ref}, are also assigned in order to define an acceptable current ripple level. Whenever the phase current exceeds the upper band, the upper switch of that leg will be turned ON while the lower switch will be turned OFF. If phase current falls below the lower band, the upper switch will be turned OFF whereas the lower switch will be turned ON.

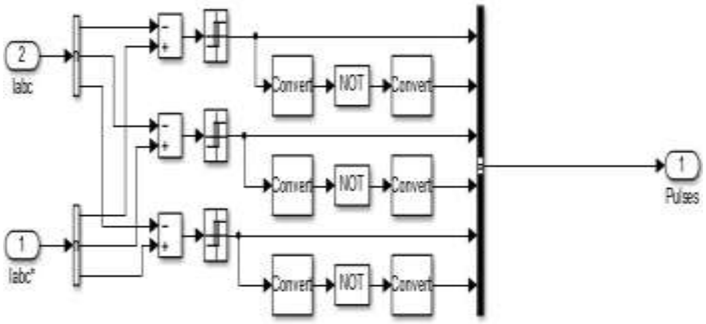

Fig. 6 shows the subsystem of generating switching signal by hysteresis current control technique.

5. Simulation Model of Test System with D-STATCOM

In this test system we have a radial line of 23KV and 100MVA at 50 Hz. The test system employed to carry out simulation consisting the D-STATCOM actuation. The compensation of fluctuation in voltage and current at the buses are shown in the waveform when D-STATCOM operates in fig 8 (a) and (b). Effect on the active and reactive power when D-STATCOM works is shown in fig 9(a) and (b). Parameters of this system are:-

(1) In case of compensation in voltage fluctuation.
Three phase programmable voltage source configuration is 23kv, 50Hz.
Positive sequence:- amplitude (V_{rms} phase to phase)= 20e3*1.0491, Phase (degree)=9.2, Frequency(Hz)=50
Amplitude values(pu)= [1 0.955 1.045 1], Time values= [0, 0.1, 0.2, 0.3]
Three phase RLC load:- configuration- Y grounded
Nominal phase to phase voltage V_n (V_{rms})= 500e3
Nominal frequency (Hz)= 50
Active power P(W)= 200e6

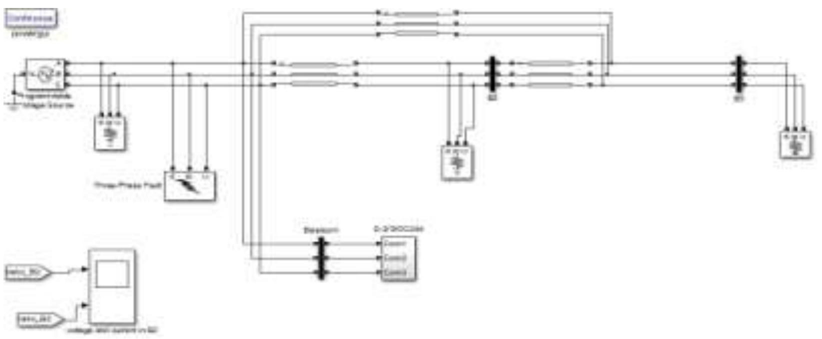

Fig. 7 MATLAB simulation diagram of Three phase Distributed Generation System

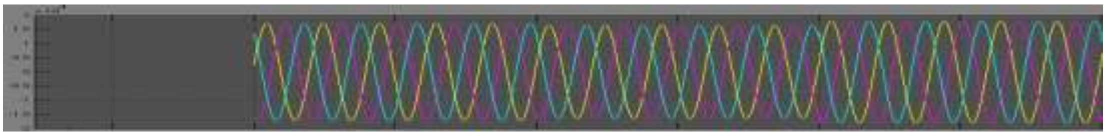

Fig. 8(a)

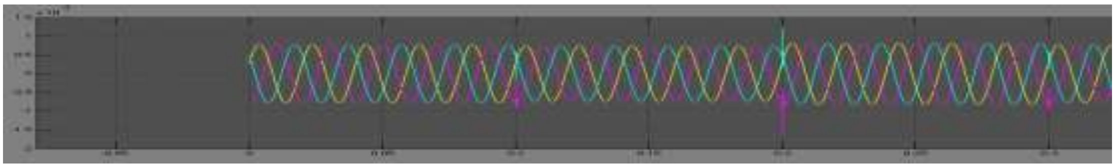

Fig. 8(b)

Fig 8(a) shows the normal and compensated voltage waveform when D-STATCOM work. Fig 8(b) shows the normal and compensated current waveform when D-STATCOM work.

(2) In case of without D-STATCOM
Positive sequence:- amplitude(V_{rms} phase to phase)=11e3*1.0491, Phase (degree)= 9.2, Frequency (Hz)= 50
Amplitude values (pu)= [1 0.955 1.045 1], Time values= 0, 0.1, 0.2, 0.3
Three phase parallel RLC load:- configuration= Y grounded
Nominal phase to phase voltage V_n (V_{rms})= 500e3
Nominal frequency (Hz)= 50
Active power P(W)= 300e6
Inductive reactive power QL (positive var)= 15
Three phase fault parameter:- Fault resistance (ohms)= 0.001, Ground fault= 0.001

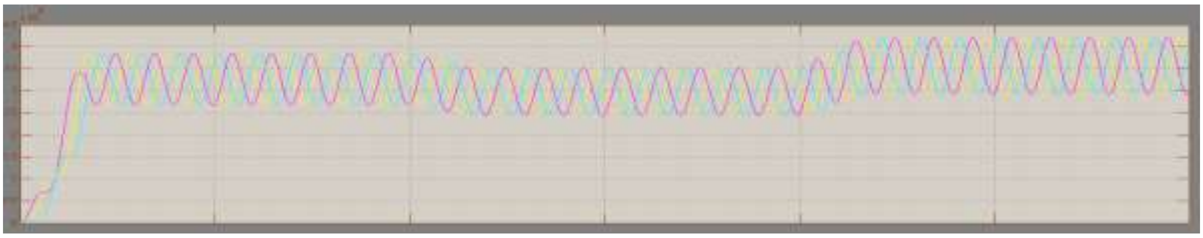

Fig. 9(a) Active and Reactive power waveform with D-STATCOM

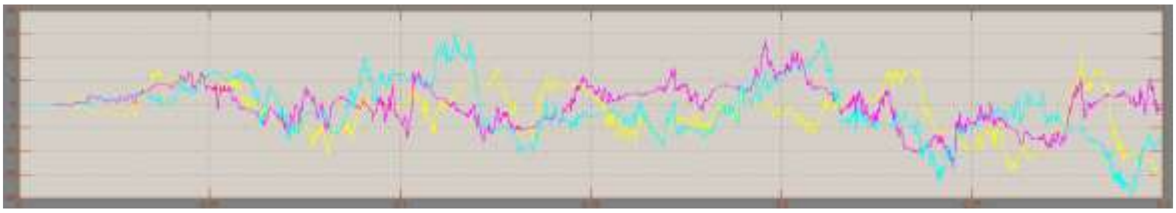

Fig. 9(b) Active and Reactive power waveform without D-STATCOM

6. CONCLUSION

The paper presents the comparative study of the control strategies used for the control of DSTATCOM, with their relative merits and demerits. The control schemes are described with the help of simulation results, under linear and nonlinear loads. Simulation results show the suitability of AC/DC bus voltage regulation for harmonic suppression and reactive power compensation to achieve improved power quality levels at the distribution end.

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