D-STATCOM AND DVR IMPROVE POWER QUALITY IN TRANSMISSION SYSTEM

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ABSTRACT

In developing countries like India, where the variation of power frequency and many such other determinants of power quality are themselves a serious question, it is very vital to take positive steps in this direction. This paper presents the enhancement of voltage sags/swell; harmonic distortion and low power factor using Distribution Static Compensator (D-STATCOM). A DVR injects a voltage in series with the system voltage and D-STATCOM injects a current into the system to correct the voltage sag, swell and interruption. the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. Its appeal includes lower cost, smaller size, and its fast dynamic response to the disturbance.

Keywords: *D-Statcom, DVR, voltage dips, swells, interruption, power quality, Total harmonics Distortion (THD), Voltage Sag/swell.*

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I. INTRODUCTION

Electric problems always occur regardless of time and place. This may cause an impact to the electric supply thus may affect the manufacturing industry and impede the economic development in a country. The major electric problems that always occur in power systems are the power quality problems that have been discussed by the electrical engineers around the world, since problems have become a major issue due to the rapid development of sophisticated and sensitive equipment in the manufacturing and production industries. The increased concern for power quality has resulted in measuring power quality variations, studying the characteristics of power disturbances and providing solutions to the power quality problems.

In distribution systems, the power quality problems can reduce the power supplied to the customers from its nominal value. Voltage sag, harmonic, transient, over voltage and under voltage are major impacts to a distribution system. The utility and the users are responsible in polluting the supply network due to operating of large loads. The best equipment to solve this problem at distribution systems at minimum cost is by using Custom Power family of D-STATCOM. Voltage dips are one of the most occurring power quality problems. Off course, for an industry an outage is worse, than a voltage dip, but voltage dips occur more often and cause severe problems and economical losses.

Utilities often focus on disturbances from end-user equipment as the main power quality problems. This is correct for many disturbances, flicker, harmonics, etc., but voltage dips mainly have their origin in the higher voltage levels. Faults due to lightning, is one of the most common causes to voltage dips on overhead lines. If the economical losses due to voltage dips are significant, mitigation actions can be profitable for the customer and even in solution which will work for every site, each mitigation action must be carefully planned and evaluated. There are different ways to mitigate voltage dips, swell and interruptions in transmission and distribution systems. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Among these, the distribution static compensator and the dynamic voltage restorer are most effective devices, both of them based on the VSC principle.

Modern society relies heavily upon electricity. With deregulation, electricity has become a commodity as well as a means for competition. Power quality, as a consequence, is coming into focus to an extent hitherto unseen. Industry as well as commercial and domestic groups of users simply demand power quality. Flickering lamps and TV sets are no longer accepted, nor are deratings or interruptions of industrial processes due to unsufficient power quality. In fact, the interruption of an industrial process for instance due to a voltage sag can result in very substantial costs to the operation. These costs include lost productivity, labour costs for cleaning and restart, damaged product, reduced product quality, delays in delivery, and reduced customer satisfaction. Thus, costs previously hidden in poor power quality are brought forward to their face value and may become an issue of dispute involving consumers as well as suppliers.

Disturbances emanating from any particular load will travel far, and, unless properly remedied, spread over the grid to neighboring facilities. Thus, for instance, voltage flicker and harmonics may turn up far away from their source and disturb other consumers, urban as well as industrial, and become a nuisance to many. At the end of the day, the disturbing equipment will therefore become an issue to many and not just to the owner of the particular equipment. We are then talking about lack of power quality.

Fortunately, there are means to deal with the problem of poor or insufficient power quality in grids. One obvious way is to reinforce the power grid by building of new lines, installing new and bigger transformers, or moving the point of common coupling to a higher voltage level.

Such measures, however, are expensive and time-consuming, if they are at all permitted. As a matter of fact, there is a tendency in the opposite direction at present in some places, with Points of Common Connection in some cases being moved to lower voltage levels in the grid.

A simple, straightforward and cost-effective way of power quality improvement in such cases as well as similar is to install equipment especially developed for the purpose in immediate vicinity of the source(s) of disturbance.

Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency [1] however, in practice, power systems, especially the distribution systems, have numerous nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producing many power quality problems. Apart from nonlinear loads, some system events, both usual (e.g. capacitor switching, motor starling) and unusual (e.g. faults) could also inflict power quality problems [2]. Power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage.

Sensitive equipment and non-linear loads are now more common place in both the industrial sectors and the domestic environment. Because of this a heightened awareness of power quality is developing amongst electricity users.

Faults at either the transmission or distribution level may cause transient voltage sag or swell in the entire system or a large part of it. Also, under heavy load conditions, a significant voltage drop may occur in the system. Voltage sags can occur at any instant of time, with amplitudes ranging from 10–90% and a duration lasting for half a cycle to one minute [3]. Further, they could be either balanced or unbalanced, depending on the type of fault and they could have unpredictable magnitudes, depending on factors such as distance from the fault and the transformer connections. Voltage swell, on the other hand, is defined as a sudden increasing of supply voltage up 110% to 180% in RMS voltage at the network fundamental frequency with duration from 10 ms to 1 minute [4]. Voltage swells are not as important as voltage sags because they are less common in distribution systems. Voltage sag and swell can cause sensitive equipment (such as found in semiconductor or chemical plants) to fail, or shutdown, as well as create a large current unbalance that could blow fuses or trip breakers.

These effects can be very expensive for the customer, ranging from minor quality variations to production downtime and equipment damage [5].

II. PROPOSED TECHNIQUE

A. Dynamic Voltage Restorer (DVR)

A Dynamic Voltage Restorer (DVR) is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. The DVR was first installed in 1996 [8]. It is normally installed in a distribution system between the supply and the critical load feeder [9]. Its primary function is to rapidly boost up the load-side voltage in the event of a disturbance in order to avoid any power disruption to that load [7, 10]. There are various circuit topologies and control schemes that can be used to implement a DVR. In addition to voltage sags and swells compensation, DVR can also added other features such as: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

The general configuration of the DVR consists of an Injection / Booster transformer, a Harmonic filter, a Voltage Source Converter (VSC), DC charging circuit and a Control and Protection system as shown in Figure 1.

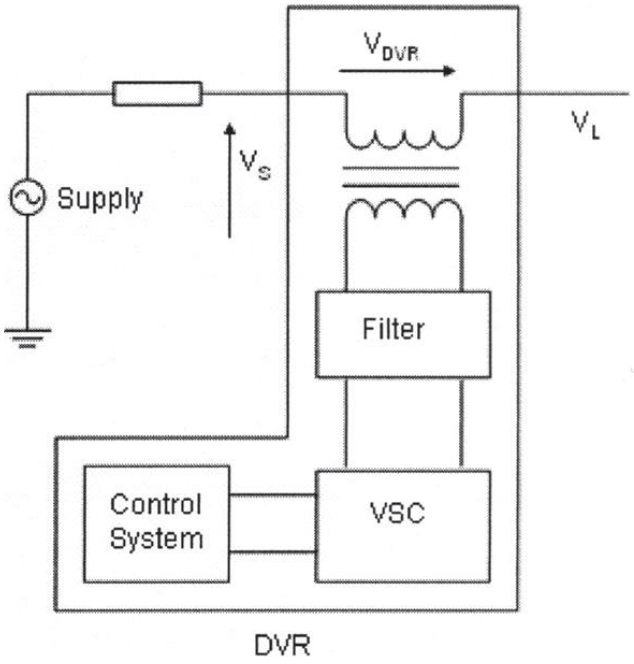

Figure 1. Dynamic Voltage Restorer (DVR) is a recently proposed series connected solid state device

B. VOLTAGE SOURCE CONVERTERS (VSC)

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.

C. Harmonic Filter

The main task of harmonic filter is to keep the harmonic voltage content generated by the voltage source converters to the permissible level. It has a small rating approximately 2% of the load MVA connected to delta-connected tertiary winding of the injection transformer [11].

D. Distribution Static Compensator (DSTATCOM)

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Figure-2, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer.

The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation and compensation of reactive power.
2. Correction of power factor and
3. Elimination of current harmonics.

The value of Ish can be controlled by adjusting the output voltage of the converter. The shunt injected current Ish can be written as,

$$I_{sh} = I_L - I_S = I_L - \frac{V_{th} - V_L}{Z_{th}} \quad (1)$$

$$I_{sh}\angle\eta = I_L\angle-\theta - \frac{V_{th}}{Z_{th}}\angle(\delta-\beta) + \frac{V_L}{Z_{th}}\angle-\beta \quad (2)$$

I out = output current

I L = load current

I S = source current

V th = thevenin voltage

V L = load voltage

Z th = impedence

Referring to the equation 2, output current, will correct the voltage sags by adjusting the voltage drop across the system impedance, (Z th = R + jX)

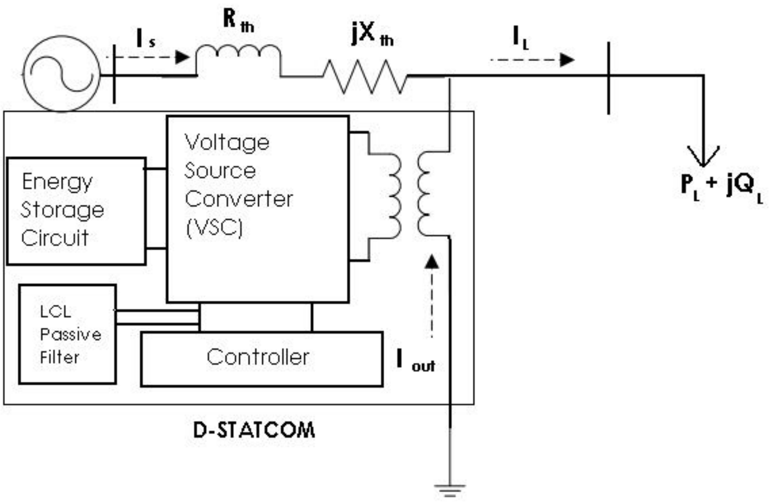

Figure 2. Schematic Diagram of D-STATCOM

III. TEST RESULTS AND ANALYSIS

Single line diagram of the test system for DVR is shown in Figure-3 and the test system employed to carried out the simulations for DVR. Such system is composed by a 13 kV, 50 Hz generation system, feeding two transmission lines through a 3-winding transformer connected in Y/Δ/Δ, 13/115/15 kV. Such transmission lines feed two distribution networks through two transformers connected in Δ/Y, 15/11 kV.

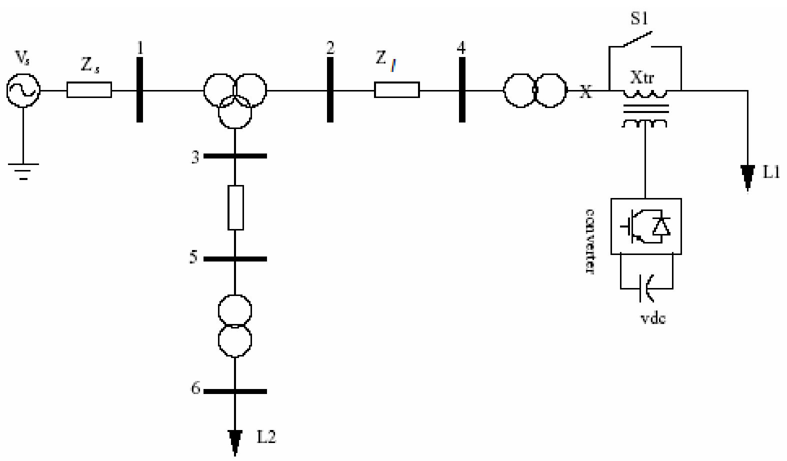

Figure-3. Single line diagram of the test system for DVR

To verify the working of a DVR employed to avoid voltage sags during short-circuit, a fault is applied at point X via a resistance of 0.4 Ω. Such fault is applied for 100msec. The capacity of the dc storage device is 5 kV.

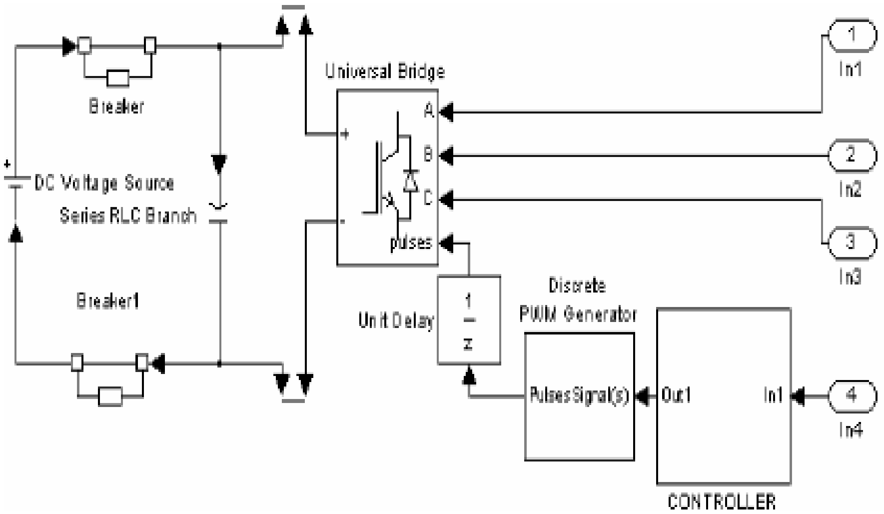

Figure-4. Simulink model of DVR

Using the facilities available in MATLAB SIMULINK, the DVR is simulated to be in operation only for the duration of the fault, as it is expected to be the case in a practical situation. Power System Block set for use with Matlab/ Simulink is based on state-variable analysis and employs either variable or fixed integration-step algorithms. Figure-4 shows the simulink model of DVR.

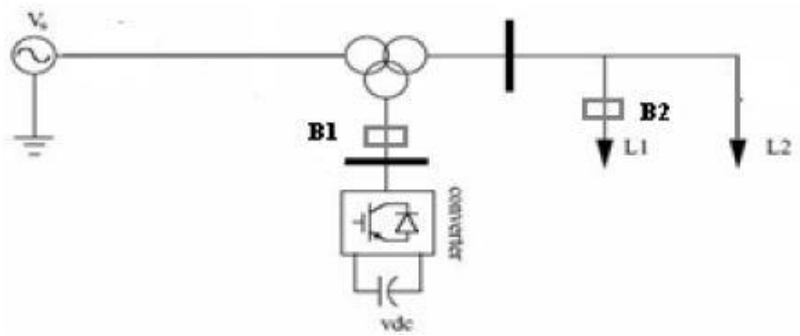

Figure 5. Single line diagram of the test system for D-STATCOM.

The test system shown in figure 5 comprises a 230kV, 50Hz transmission system, represented by a Thevenin equivalent, feeding into the primary side of a 3-winding transformer connected in Y/Y/Y, 230/11/11 kV. A varying load is connected to the 11 kV, secondary side of the transformer. A two-level D-STATCOM is connected to the 11 kV tertiary winding to provide instantaneous voltage support at the load point. A 750 μF capacitor on the dc side provides the DSTATCOM energy storage capabilities. Circuit Breaker is used to control the period of operation of the D-STATCOM.

CONCLUSION

The first simulation contain no DVR and a single line to ground fault is applied at point A in Figure-6, via a fault resistance of 0.2 Ω, during the period 500–900 ms. The voltage sag at the load point is 30% with respect to the reference voltage. The second simulation is carried out using the same scenario as above but now with the DVR in operation. The total simulation period is 1400 ms.

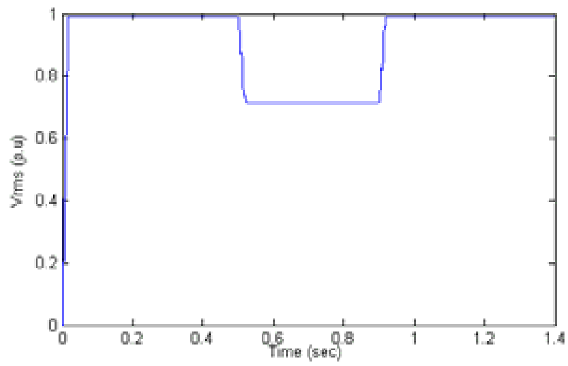

Figure-6. Voltage Vrms at load point: without DVR

When the DVR is in operation the voltage sag is mitigated almost completely, and the rms voltage at the sensitive load point is maintained at 98%, as shown in Figure-7

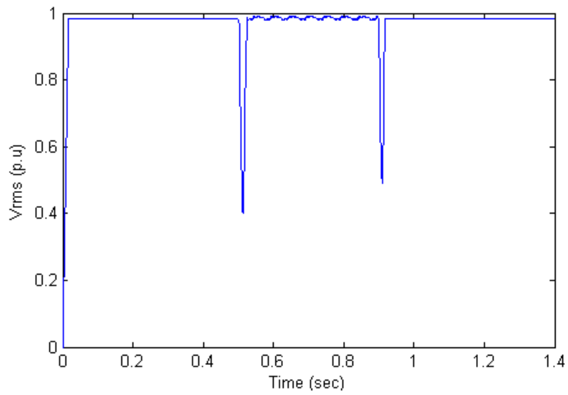

Figure-7. Voltage Vrms at load point: with DVR

In this case, D-STATCOM is not connected and a single line to ground fault is applied at a point ‘A’ with a fault resistance of 1.06 Ω. The voltage sag is shown in fig.8. with a time period of 500ms- 900ms.

From the fig.9 the voltage sag is mitigated with an energy storage of 18.2 kv, when the DSTATCOM is connected to the system.

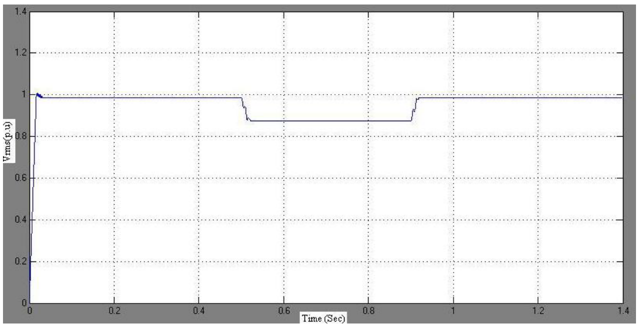

Fig.8.Voltage Vrms at the load point without DSTATCOM

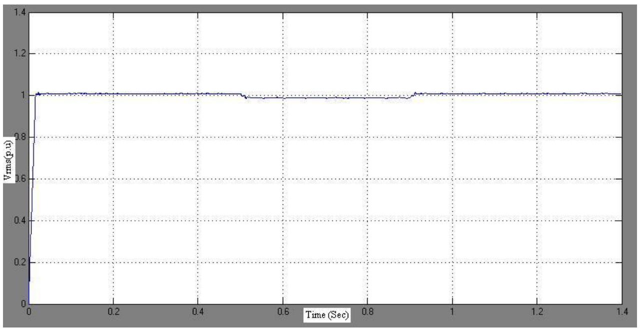

Fig.9.Voltage Vrms at the load point with DSTATCOM: with energy storage of 18.2 kv.

IV. CONCLUSIONS

This paper has presented the power quality problems such as voltage dips, swells and interruptions, consequences, and mitigation techniques of custom power electronic devices DVR, and D-STATCOM. The design and applications of DVR, and D-STATCOM for voltage sags, interruptions ands swells, and comprehensive results are presented.

As opposed to fundamental frequency switching schemes already available in the MATLAB/ SIMULINK, This characteristic makes it ideally suitable for low-voltage custom power applications. The simulations carried out showed that the DVR provides relatively better voltage regulation capabilities. It was also observed that the capacity for power compensation and voltage regulation of DVR and D-STATCOM depends on the rating of the dc storage device.

A single-phase to ground fault, and voltage swell are occurred in a time period of 500ms-900ms at different inductive and capacitive loads. So by using D-STATCOM sag of 10%, interruption of 22% and swell of 9% conditions are mitigated.

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