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DSTATCOM with LCL Filter to improve the voltage sags and current harmonic distortion in power distribution 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. There has been increase in the demand for reliable and high quality power distribution systems. In power distribution systems quality in distribution of power is desired. The problems that occur frequently in such systems include low power factor, harmonic distortion and voltage sags. In order to achieve this Distributed Static Compensator (D-STATCOM) is used. This device along with LCL passive filter when used with power distribution systems the quality of power gets improved. By injecting current into the distribution system, the D-STATCOM improves the quality in power distribution. The extensive simulations made in MATLAB's SIMULINK revealed that the proposed approach is effective.***

Keywords: Quality Power, STATCOM, LCL, Voltage source converter, Hysteresis current controller, Voltage sag, Interruption, Voltage swell.

Introduction:

In India, Power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage. Sensitive power electronic equipment and non-linear loads are widely used in industrial, commercial and domestic applications leading to distortion in voltage and current waveforms. With ongoing regulatory, policy and structural changes in the Indian electricity industry, following the Electricity Act 2003, the issue of PQ is poised to become a figure-of-merit amongst the competing distribution utilities. Improvement of PQ has a positive impact on sustained profitability of the distribution utility on the one hand and customer satisfaction on the other.

STATCOM:

The advantage of a statcom is that the reactive power provision is independent from the actual voltage on the connection point. This can be seen in the diagram for the maximum currents being independent of the voltage in comparison to the svc. This means, that even during most severe contingencies, the statcom keeps its full capability.

In the distributed energy sector the usage of voltage source converters for grid interconnection is common practice today. The next step in statcom development is the combination with energy storages on the dc-side. The performance for power quality and balanced network operation can be improved much more with the combination of active and reactive power.

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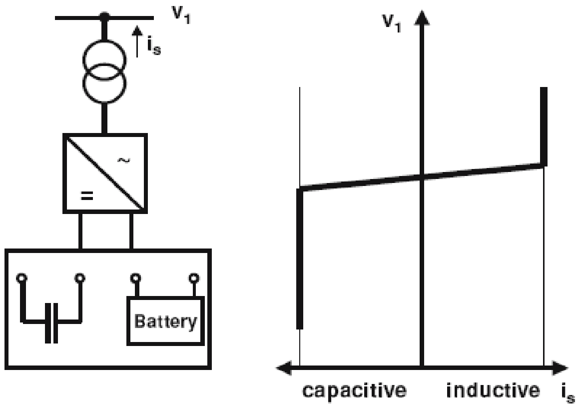


Statcom structure and voltage / current characteristic

Statcoms are based on voltage sourced converter (VSX) topology and utilize either gate-turn-off thyristors (GTO) or isolated gate bipolar transistors (IGBT) devices. The statcom is a very fast acting, electronic equivalent of a synchronous condenser. If the statcom voltage, vs, (which is proportional to the dc bus voltage vc) is larger than bus voltage, ES, then leading or capacitive vars are produced. If vs is smaller than ES then lagging or inductive vars are produced.

Unified Power Flow Controller:

The upfc is a combination of a static compensator and static series compensation. It acts as a shunt compensating and a phase shifting device simultaneously.

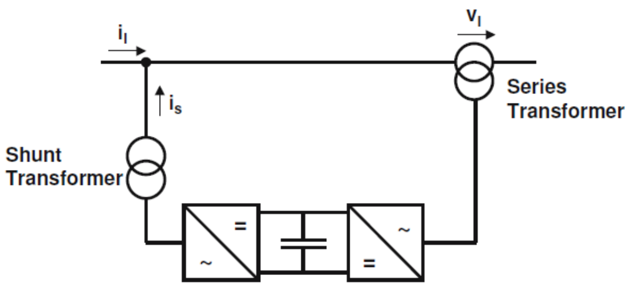


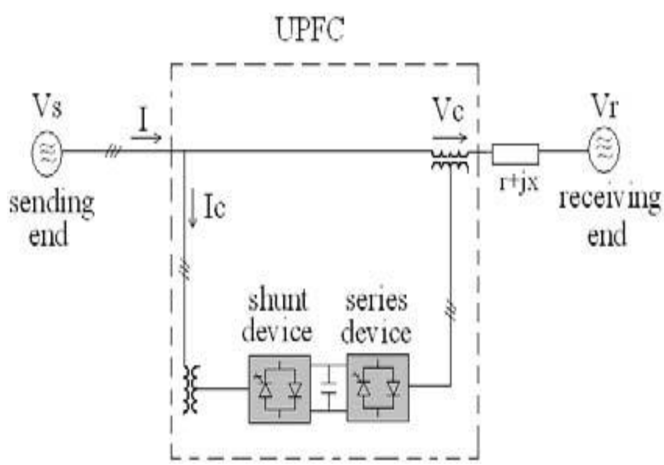
Fig. Principle configuration of an upfc

The upfc consists of a shunt and a series transformer, which are connected via two voltage source converters with a common dc-capacitor. The dc-circuit allows the active power exchange between shunt and series transformer to control the phase shift of the series voltage. This setup, as shown in figure 1.21, provides the full controllability for voltage and power flow. The series converter needs to be protected with a thyristor bridge. Due to the high efforts for the voltage source converters and the protection, an upfc is getting quite expensive, which limits the practical applications where the voltage and power flow control is required simultaneously.

Operating Principle Of Upfc

The basic components of the upfc are two voltage source inverters (vsis) sharing a common dc storage capacitor, and connected to the power system through coupling transformers. One vsi is connected to in shunt to the transmission system via a shunt transformer, while the other one is connected in series through a series transformer.

A basic upfc functional scheme is shown in fig.below.



The series inverter is controlled to inject a symmetrical three phase voltage system (VSC), of controllable magnitude and phase angle in series with the line to control active and reactive power flows on the transmission line. So, this inverter will exchange active and reactive power with the line. The reactive power is electronically provided by the series inverter, and the active power is transmitted to the dc terminals. The shunt inverter is operated in such a way as to demand this dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor

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vdc constant. So, the net real power absorbed from the line by the upfc is equal only to the losses of the inverters and their transformers. The remaining capacity of the shunt inverter can be used to exchange reactive power with the line so to provide a voltage regulation at the connection point.

The two vsi's can work independently of each other by separating the dc side. So in that case, the shunt inverter is operating as a statcom that generates or absorbs reactive power to regulate the voltage magnitude at the connection point. Instead, the series inverter is operating as sssc that generates or absorbs reactive power to regulate the current flow, and hence the power low on the transmission line.

Distribution Static Compensator (DSTATCOM)

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Figure, 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.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter.

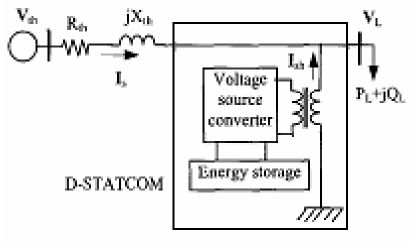

Figure- the shunt injected current I_{sh} corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{th}. The value of I_{sh} can be controlled by adjusting the output voltage of the converter.

The shunt injected current I_{sh} can be written as,

$$I_{sh} = I_L - I_s = I_L - \frac{V_{Th} - V_L}{Z_{Th}}$$

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

The complex power injection of the D-STATCOM can be expressed as,

$$S_{sh} = V_L I_{sh}^*$$

It may be mentioned that the effectiveness of the D-STATCOM in correcting voltage sag depends on the value of Z_{th} or fault level of the load bus. When the shunt injected current I_{sh} is kept in quadrature with V_L, the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of I_{sh} is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system. The control scheme for the D-STATCOM follows the same principle as for DVR. The switching frequency is set at 475 Hz.

Voltage Sag

Voltage sags and momentary power interruptions are probably the most important PQ problem affecting industrial and large commercial customers.

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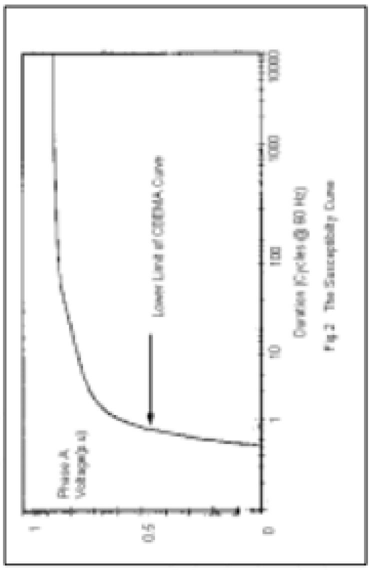
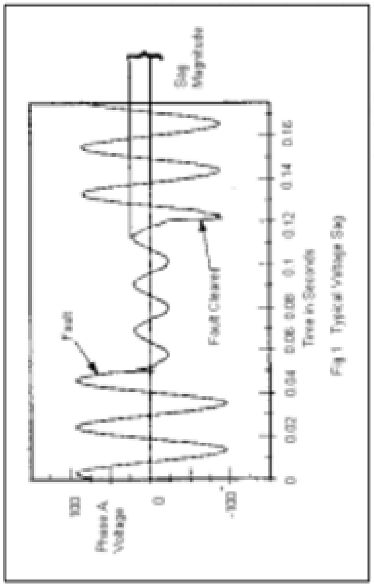
These events are usually associated with a fault at some location in the supplying power system. Interruptions occur when the fault is on the circuit supplying the customer. But voltage sags occur even if the faults happen to be far away from the customer's site. Voltage sags lasting only 4-5 cycles can cause a wide range of sensitive customer equipment to drop out. To industrial customers, voltage sag and a momentary interruption are equivalent if both shut their process down. A typical example of voltage sag is shown in fig below. The susceptibility of utilization equipment to voltage sag is dependent upon duration and magnitude of voltage sags and can be defined.





Characteristics of Voltage Sags:

Voltage sags which can cause equipment impacts are caused by faults on the power system.

Motor starting also results in voltage sags but the magnitudes are usually not severe enough to cause equipment mis operation

Methodology

To enhance the performance of distribution system, DSTATCOM was connected to the distribution system. DSTATCOM was designed using MATLAB simulink version R2007b. Figure below shows the flowchart for the methodology:

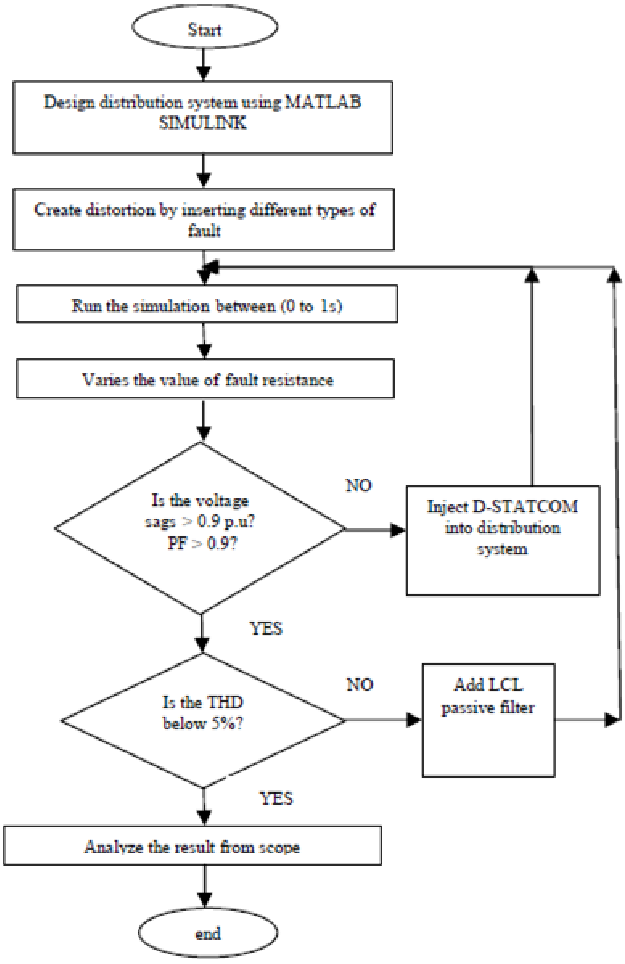


Fig: Flowchart of Methodology

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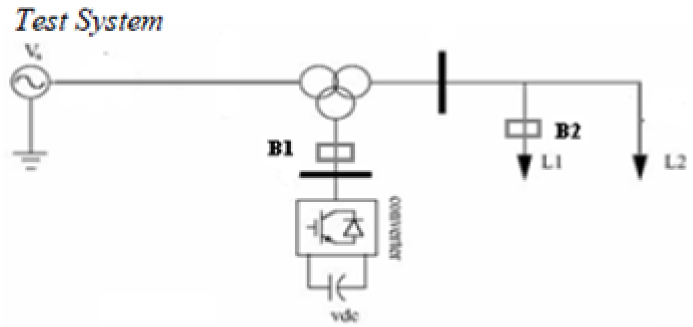
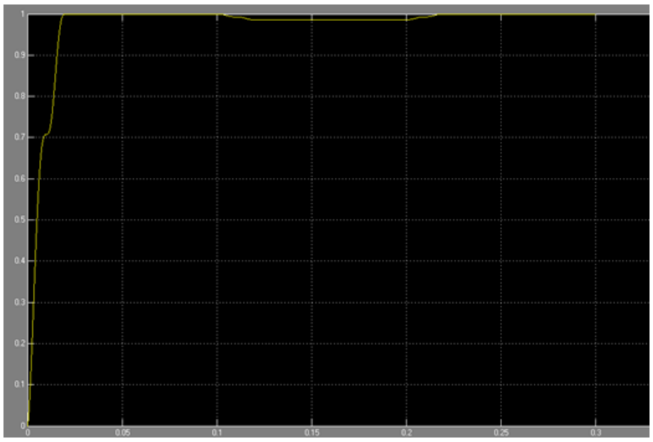
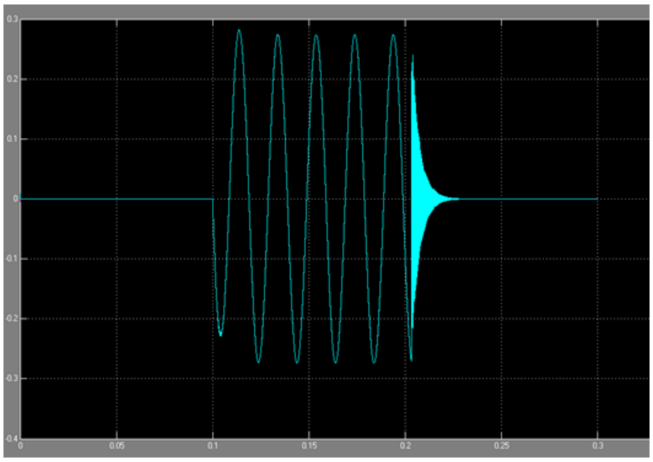


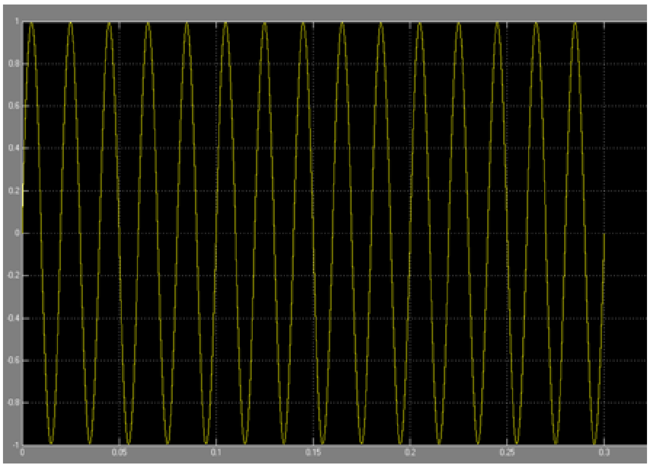
Fig: Single Line Diagram of Test System

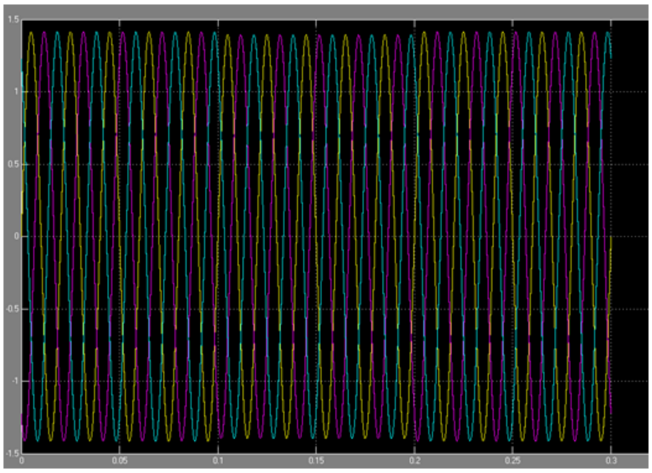
The test system shown in figure 3 comprises a 230kV, 50Hz transmission system, represented by a Thevenin equivalent, feeding into the primary side of a 3-winding transformer connected in Y/Y/Y, 230/11/11 kV. A varying load is connected to the 11 kV, secondary side of the transformer. A two-level D-STATCOM 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 D-STATCOM energy storage capabilities. Breaker 1 is used to control the period of operation of the D-STATCOM and breaker 2 is used to control the connection of load 1 to the system.





Results:





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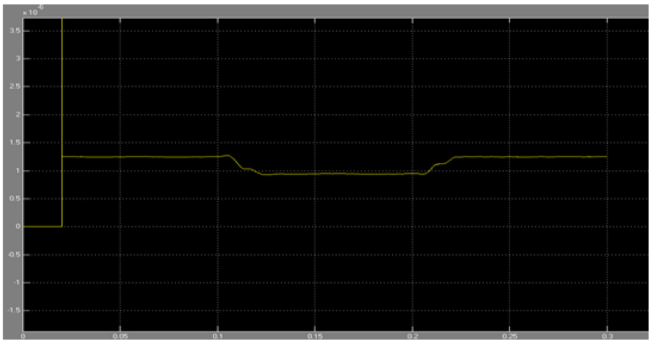

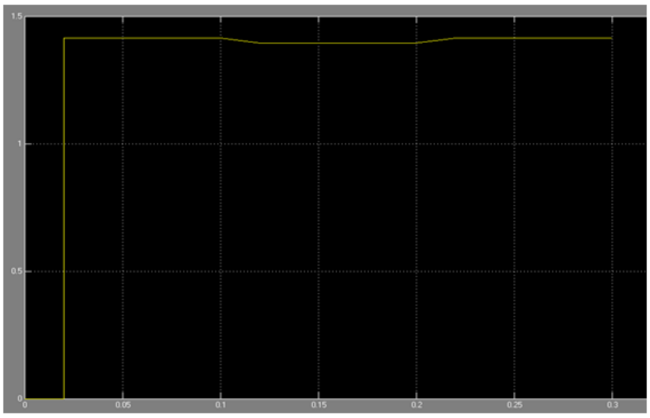

Conclusion

The simulation results show that the voltage sags can be mitigate by inserting D-STATCOM to the distribution system. By adding LCL Passive filter to D-STATCOM, the THD reduced within the IEEE STD 519-1992. The power factors also increase close to unity. Thus, it can be concluded that by adding D-STATCOM with LCL filter the power quality is improved.

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