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Power Quality and the Need for Compensation

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***Abstract*— A Power quality problem refers to the problems that are caused by the rise of a non standard voltage or current or frequency. Because of this it results into the failure of the equipments in use. The problems which are faced due to poor power quality are voltage sag, swell, interruptions harmonics and transients. These problems create a lot of disturbance in the whole system and thus it is required to resolve the problems for the lossless and efficient working of the system. The process which mitigates such problems is known as compensation. Various compensation devices are being used now a days. Some of them are DSTATCOM and the Dynamic Voltage Restorer (DVR). Such devices are fast, flexible and efficient solution to power quality problems. These devices are power electronic based devices that provides three-phase controllable voltage source, whose voltage vector magnitude and angle adds or subtracts to the source voltage during sag or swell event, to restore the load voltage during fault conditions. These devices can restore the load voltage within few milliseconds. This paper is an overview of the power quality problems the need for compensation and effective measures. The functions, configurations, components, compensating strategies and control methods along with the device capabilities and limitations.**

***Keywords*—DVR, Compensation, DSTATCOM, sag, swell.**

I. Introduction

By Power Quality we mean something that tells about the quality of power. Power quality is actually the quality of the voltage rather than power. If we talk about the power distribution system a good distribution system should be such that which provides an uninterrupted flow of energy and a lossless voltage to its customers. But in practice the distribution systems, have number of nonlinear loads, which affects the quality of power supplied significantly. As a result of the nonlinear loads, the result obtained is distorted this in turns produces many power quality problems. Power quality disturbance can be defined as the deviation of the voltage and the current from its ideal voltage or current. Faults occur at either the transmission or distribution levels that may cause voltage sag or swell in the entire system or a large part of it. Under heavy load conditions, a significant voltage drop may occur in the system whereas in the light load conditions the voltage raises significantly. Power Quality problems have a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions.

Voltage sags/swells can occurs more frequently than any other Power quality phenomenon. These sags/swells are the most important power quality problems in the power distribution system. Of all the power quality problems, 92% of the interruptions in industrial installations are due to voltage sags and swells. According to IEEE Std. 1159-1995, sag is defined as a decrease in rms voltage or current between 0.1pu and 0.9 pu at the power frequency for durations from 0.5 cycles to 1 min. In order to resolve the problems various compensating devices are used to regulate the voltage. Two of such devices are DSTACOM and DVR. DSTACOM is a shunt device whereas DVR is a series device. These devices helps in mitigating the major power quality problems like sag and swell and the other power quality problems like the flickers, harmonics, and transients etc. under steady state to obtain a better quality output under continuous operation. A variety of control strategies are proposed for load voltage control using the two devices. In DSTATCOM, this includes reactive power compensation and voltage-control mode operation of DSTATCOM. In DVR, it includes open-loop and closed-loop load voltage-control methods. The closed-loop voltage-control mode operation of the two devices is considered best, most precise and fast control against sudden variations in the supply voltage and the load. Both of these compensators are used under closed-loop voltage-control mode. In this paper various power quality problems the devices used to cure these problems and their effects have been studied.

II. Power Quality Problems, Causes And Effects

The various power quality problems are as followed:

1. Voltage sags- A voltage sag or dip is a phenomenon where the voltage drop occurs for a short period of time due to heavy load conditions. Here the voltage drop is from 0.1pu to 0.9 pu for 1 minute.

2. Transients- When a sudden change in state occurs the voltage on the line get disturbed and the voltage gets distorted for a short period of time. Such disturbances are called transients.

3. Voltage interruption- There are two types of interruption short duration and long duration. Interruption is a phenomenon where the voltage drops to zero or almost zero for a certain period of time.

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4. Voltage swells- Voltage swell, is a momentary increase in voltage that occurs during the light load conditions in the system.

5. Harmonics- Harmonics is the integral multiple of frequencies voltages and currents in an electric power system due to non linear loads. Harmonic frequencies in the power grid are a frequent cause of power quality problems.

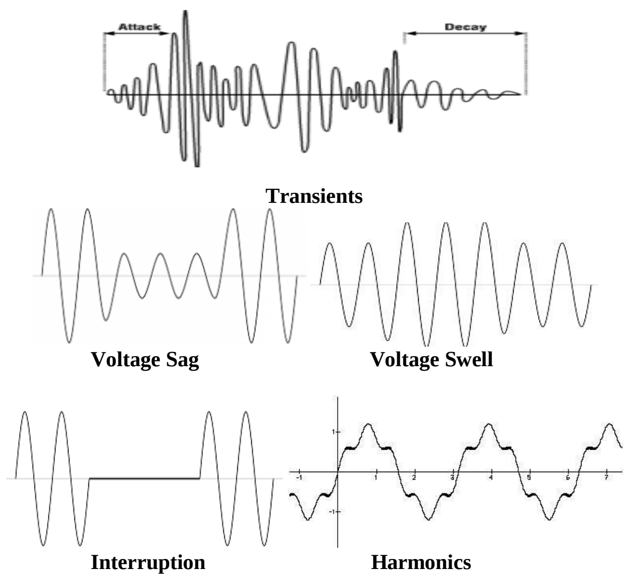

Fig. 1.1 Power Quality Problems

Causes and effects of Power Quality Problems:

1. *Voltage Sags* – during heavy loads which results into Dim lights, Equipment shutdown, Data error, shrinking display screens, Memory loss.

2. *Transient* – lightning surges, switching surges, turning heavy equipment on and off, back to back capacitor energization which results into Tripping, Processing error, loss of data, hardware reboot required, failure of components.

3. *Interruption* – during Short circuits, Equipment failures, during attempting to isolate electrical problem which results into Faults, Equipment failures, Control malfunctions.

4. *Voltage Swells* – during light loads which results into Bright lights, Data error, shrinking display screens.

5. *Harmonics* – IT equipment, Variable frequency drives, Electro Magnetic Interference from appliances, fluorescent lighting, during any non linear load which results into Line current increases, Losses increase, transformer and neutral conductor heating leading to reduced equipment life span.

III. NEED FOR COMPENSATION

Electrical energy is generated, transmitted, distributed, and utilized as alternating current (AC). But the alternating current has several disadvantages. One of these is the need of reactive power that is required to be supplied along with active power. Reactive power can be leading or lagging. The total power comprises of active and reactive power and there is no other need of the reactive power in the transmission and distribution.

Reactive power is generated or consumed in almost every component of the system, generation, transmission, and distribution and eventually by the loads. The Reactance contributes to reactive power in the circuit and it can be either inductive or capacitive. Majority of the loads are inductive, and must be supplied with lagging reactive power.

The main reason for reactive power compensation in a system is:

1) The voltage regulation
2) Increased system stability
3) Better utilization of machines connected to the system
4) Reduction in losses associated with the system
5) To prevent voltage swell as well as voltage sag.

The impedance of transmission lines and the need for lagging reactive power by most machines in generating system results in the consumption of reactive power, thus disturbing the stability limits of the system as well as transmission lines. Unnecessary voltage drops lead to bigger losses which need to be supplied by the source and in turn leading to faults in the line due to increased stress on the system. Thus we can conclude that the compensation of reactive power not only removes all these effects but also helps in better transient response to faults and disturbances. Now days, there has been a better focus on the techniques that are being used for the compensation and with better devices included, the compensation is made more effective. It is very much required that the lines be relieved of the debt to carry the reactive power, which is better provided near the generators or the loads. Shunt compensation can be installed near the load, in a distribution substation or transmission substation.

3.1 Reactive Power Requirement

- Since the HVDC converters absorb large amount of reactive power almost 50-60% of the active power thus reactive power need to be supplied to the transmission line.

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- With the transmitted active power and the need for filtering of harmonics is also increased which in turn increases the reactive power absorption of a converter.
- The need for reactive power grows slowly at low power, and more at high power.
- The reactive power compensation scheme has to take care of the unbalances for the AC system requirement, by switching of filters.
- For filtering the AC current and for generation of reactive power harmonic filters are installed on the AC side.

3.2 Purpose of the Reactive Power Control

- The reactive power control is required in order to control the working of the AC system that is converted in the converter stations.
- The Reactive Power Compensation will prevent the excess harmonics from entering into the system by employing filters.
- Such compensation is done by installing the filter circuits in the systems.

3.3Reactive Power Control

- The reactive power controllers have been employed on the two sides of the HVDC transmission systems.
- Each Reactive Power Compensator is located in the pole control level and operates independently from the other end of the HVDC transmission.
- Protection is provided by switching of the filter banks or sub-banks.
- According to the limits in the reactive power compensation study for the different control modes switching priority restrictions are determined.

IV. Types Of Compensation

There are two types of compensation techniques one is the series compensation the other is the shunt compensation:

4.1 Shunt compensation

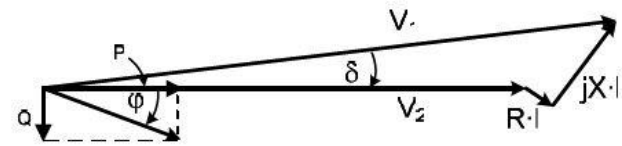
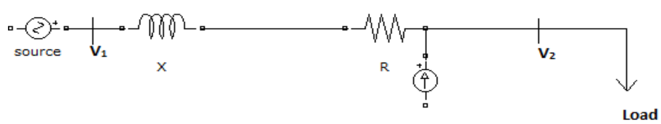


Fig 1.2

In figure 1.2 a source V1, a power line and an inductive load is there. This system is not compensated. The phasor diagram of these is shown above. The current Ip is in phase with the load voltage V2. Because the load is inductive it requires reactive power for its proper operation and this has to be supplied by the source, thus increasing the current from the generator and through the power lines. Instead of the lines, if the reactive power can be supplied near the load, the line current can be minimized which reduces the power losses and improves the voltage regulation at the load terminals. This can be done by employing a voltage source, a current source or a capacitor.



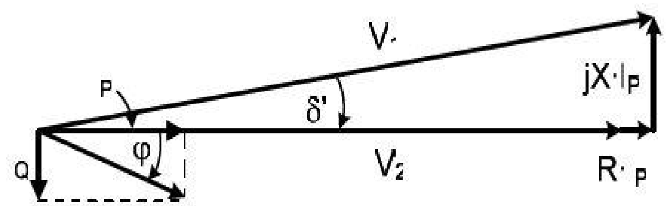


Fig 1.3

In fig 1.3 here a current source device is used to compensate Iq, which is the reactive component of the load current. This results in the improved voltage regulation of the system and the elimination of the reactive current component. This is lagging compensation. For leading compensation, we use an inductor.

4.2 Series compensation

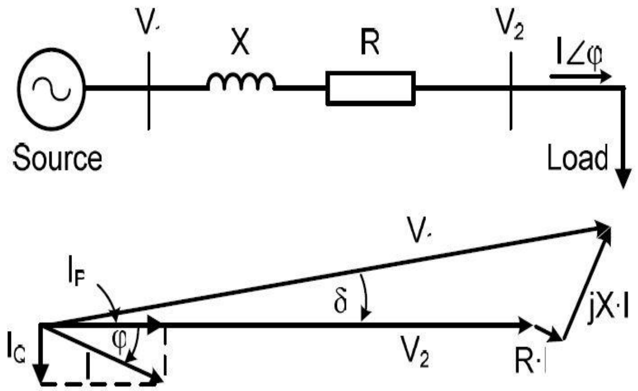


Fig 1.4

Series compensation can be implemented like shunt compensation, i.e. with a current or a voltage source as shown in figure 1.5. We can see the results which are obtained by series compensation through a voltage source and it is adjusted to have unity power factor at V2. However series compensation techniques are different from shunt compensation techniques, as capacitors are used mostly for series compensation techniques. In this case, the voltage V_{comp} has been added between the line and the load to change the angle V_2. Now, this is the voltage at the load side. With proper adjustment of the magnitude of V_{comp}, unity power factor can be reached at V_2.

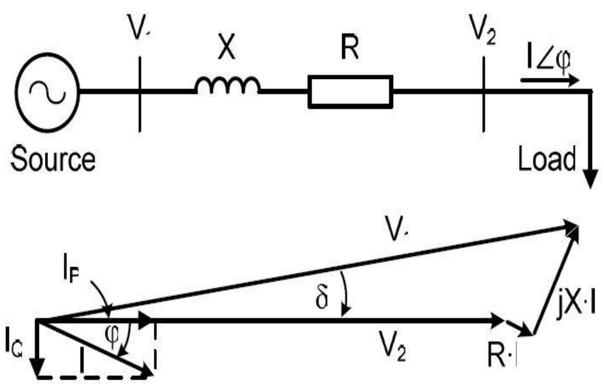


Fig 1.5

V. Devices Used For Compensation

Flexible AC transmission system or FACTS devices used are:

1) *Reactive power generators.*

   a) Fixed or mechanically switched capacitors
   b) Synchronous condensers.
   c) Thyristorized VAR compensators.
      i) Thyristors switched capacitors (TSCs).
      ii) Thyristor controlled reactor (TCRs).
      iii) Combined TSC and TCR.
      iv) Thyristor controlled series capacitor (TCSC).

2) *Reactive power compensators*

   a) Static synchronous compensators (STATCOMs).
   b) Static synchronous series compensators (SSSCs).
   c) Unified power flow controllers (UPFCs).
   d) Dynamic voltage restorers (DVRs).

VI. DVR

DVR is a power electronic device which is used to protect the system against the faults or abnormal conditions. It is connected in series to the system. The DVR consists of two types of circuits, the power circuit and the control circuit. Control circuit is used to generate the parameters as like magnitude, frequency, phase shift, etc. Due to control signal, the injected voltage is generated using switching power circuit.

The power circuit of DVR consists of

a) An injection transformer,
b) AC harmonic filter,
c) High speed switching pulse width modulation (PWM) inverter and
d) DC energy storage unit
e) Control unit

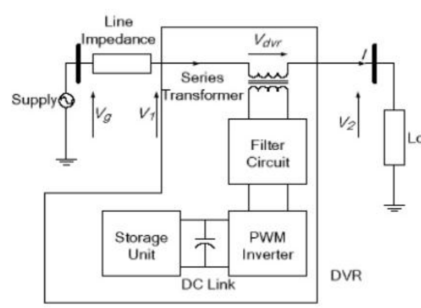


Fig 1.6

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6.1 Principle of DVR

Whenever the source voltage is unbalanced or distorted the DVR restores the load-side voltage to the desired amplitude by injecting a voltage of required magnitude- this is the principle of DVR. Thus, the main function of DVR is to regulate the load voltage waveform constantly and if any sag or swell occurs, the required voltage will be injected to the load point. In short, the principle of DVR can be explained with the help of the following equation which has to be satisfied for all the time.

Source Voltage + DVR Voltage = Load Voltage

The DVR has to work only when there is a sag/swell in the source voltage. Depending on that there are actually three modes of operation for a DVR. They are

i. Protection Mode
ii. Standby Mode
iii. Injection Mode

Whenever there is a fault on the line, very high fault currents will be flowing through the line. Since the DVR is series connected, the fault currents will be flowing through the DVR also which is not desired. The DVR should be protected from these over currents or large inrush currents. The bypass switches remove the DVR from system by supplying another path through switch for current.

In standby mode (normal steady state conditions), the DVR may either go into short circuit operation or inject small voltage to compensate the voltage drop for transformer reactance or losses. Short circuit operation of DVR is the general preferred solution in steady state. (Because the small voltage drops due to transformer reactance do not disturb the load requirements).

The DVR goes into injection mode as soon as the sag is detected. Three single-phase ac voltages are injected in series with required magnitude, phase and wave shape for compensation. The types of voltage sags, load conditions and power rating of DVR will determine the possibility of compensating voltage sag.

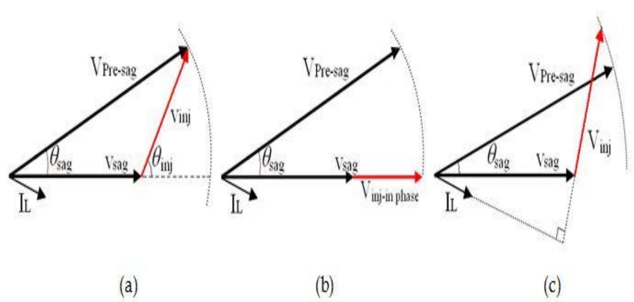

Fig 1.7

VII. STATCOM

6.1 Static Shunt Compensator: STATCOM

One of the many devices under the FACTS family, a STATCOM is a regulating device which can be used to regulate the flow of reactive power in the system independent of other system parameters. STATCOM has no long term energy support on the dc side and it cannot exchange real power with the ac system. In the transmission systems, STATCOMs primarily handle only fundamental reactive power exchange and provide voltage support to buses by modulating bus voltages during dynamic disturbances in order to provide better transient characteristics, improve the transient stability margins and to damp out the system oscillations due to these disturbances.

A STATCOM consists of a three phase inverter (generally a PWM inverter) using SCRs, MOSFETs or IGBTs, a D.C capacitor which provides the D.C voltage for the inverter, a link reactor which links the inverter output to the a.c supply side, filter components to filter out the high frequency components due to the PWM inverter. From the D.C. side capacitor, a three phase voltage is generated by the inverter. This is synchronized with the a.c supply. The link inductor links this voltage to the a.c supply side. This is the basic principle of operation of STATCOM.

For two AC sources which have the same frequency and are connected through a series inductance, the active power flows from the leading source to the lagging source and the reactive power flows from the higher voltage magnitude source to the lower voltage magnitude source. The phase angle difference between the sources determines the active power flow and the voltage magnitude difference between the sources determines the reactive power flow. Thus, a STATCOM can be used to regulate the reactive power flow by changing the magnitude of the VSC voltage with respect to source bus voltage.

6.2 Phase angle control

In this case the quantity controlled is the phase angle δ. The modulation index "m" is kept constant and the fundamental voltage component of the STATCOM is controlled by changing the DC link voltage. By further charging of the DC link capacitor, the DC voltage will be increased, which in turn increases the reactive power delivered or the reactive power absorbed by the STATCOM. On the other hand, by discharging the DC link capacitor, the reactive power delivered is decreased in capacitive operation mode or the reactive power absorbed by the STATCOM in an inductive power mode increases.

For both capacitive and inductive operations in steady-state, the STATCOM voltage lags behind AC line voltage ($\delta > 0$).

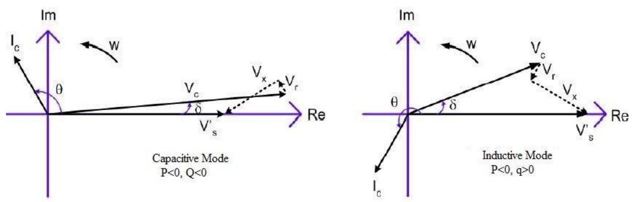

Fig.1.8

By making phase angle δ negative, power can be extracted from DC link. If the STATCOM becomes lesser than the extracted power, Pc in becomes negative and STATCOM starts to deliver active power to the source. During this transient state operation, Vd gradually decreases.

The phasor diagrams which illustrating power flow between the DC link in transient state and the ac supply is shown in above Fig. 1.8

For a phase angle control system, the open loop response time is determined by the DC link capacitor and the input filter inductance. The inductance is applied to filter out converter harmonics and by using higher values of inductance; the STATCOM current harmonics is minimized. The reference reactive power (Qref) is compared with the measured reactive power (Q). The reactive power error is sent as the input to the PI controller and the output of the PI controller determines the phase angle of the STATCOM fundamental voltage with respect to the source voltage.

REFERENCES

[1] O. Anaya-Lara, E. Acha, "Modeling and analysis of custom power systems by PSCAD/EMTDC," IEEE Trans. Power Delivery, vol. 17, no. 1, pp. 266-272, January 2002.

[2] S. Ravi Kumar, S. Sivanagaraju, "Simualgion of D-Statcom and DVR in power system," ARPN jornal of engineering and applied science, vol. 2, no. 3, pp. 7-13, June 2007.

[3] N. Hingorani, "FACTS-Flexible ac transmission systems," in Proc. IEE 5th In!. Conf. AC DC Transmission, London, U. K. , 1991, Conf. Pub 345, pp. 1-7.

[4] S. S. Choi, B. H. Li, and D. D. Vilathgamuwa, "Dynamic voltage restora- tion with minimum energy injection," IEEE Trans. Power Syst., vol. 15, pp. 51-57, Feb. 2000.

[5] Saripalli Ragesh, Mahesh K Mishra, and Sridhar K, "Design and simulation of dynamic volatge restorer using sinusoidal pulse width modulation," 16th National Power System Conf. Andhra Pradesh, India. pp. 317-322, Dec. 2010.

[6] W. Freitas, A. Morelato, "Comparitive study between power system bolckset and PSCAD/EMTDC for transient analysis of custom power devices based on voltage source converter," IPST, New Orleans, USA, 2003, pp. 1-6.

[7] Ravilla Madhusudanl, G. Ramamohan Rao IEEE- International Conference On Advances In Engineering, Science And Management (ICAESM -2012) March 30, 31,2012 442Modeling and Simulation of a Dynamic VoltageRestorer (DVR) for Power Quality ProblemsVoltage Sags and Swells.

[8] Rakeshwri Pal, Dr. Sushma Gupta, "State of the Art: Dynamic Voltage Restorer for Power Quality Improvement," Electrical and Computer Engineering: An International Journal (ECIJ), vol. 4, no. 2, June 2015.