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Overview of Shunt Active Filter used for Reduction of Harmonics in 3-Phase, 3-Wire System

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Abstract: ***Power quality is the major concern in today's electrical power system. Especially, power quality problems are continuously observed in distributed electrical power system. Mainly the voltage quality is the major aspect in distributed electrical power system. Voltage sags and voltage swells are the main parameters on which the improvement is needed. Voltage quality can be sufficiently improved in distributed electrical power systems by using some custom power devices. One of such active filter is dynamic voltage restorer. The Dynamic Voltage Restorer (DVR) is fast, flexible and efficient solution to voltage sag and voltage swell problems. The DVR is a power electronic based device that provides three-phase controllable voltage output, whose voltage vector -magnitude and angleadds to the supply voltage during sag event, to restore the load voltage to pre-sag conditions. And when voltage swell occurs DVR injects 180º out of phase voltage into the line. The DVR is designed for protecting the whole plant with loads in the range of some MVA. The DVR can restore the load voltage within few milliseconds.***

Index Terms— **custom power device, dynamic voltage restorer, voltage sag, voltage swell.**

I. Introduction

As an electrical energy plays a vital role in today's modern life, it is very important to handle this immense energy with utmost care. Especially, the thermal power plant, nuclear power plant and hydro power plant took the responsibility to supply this electrical energy. This electrical energy can be well utilized by industrial, customer, military, commercial etc. applications. And the demand of this energy is increasing day by day. Thus, the control and use of this energy must be limited by certain parameters.

Actually, the electrical devices are very sensitive and became less tolerant toward the power disturbances such as voltage sags, swells, harmonics etc. voltage sags or voltage dips are considered to be the most severe disturbances when industrial equipments are considered. Some of the industrial loads are very sensitive that these are unable to handle a very low deviation in voltage. Voltage sags can cause brutal damage in these loads. Now, the voltage support at the load end is very much required and it can be achieved by injecting the reactive power at the load point of common coupling.

Some of the useful conventional method is to utilize the mechanically switched capacitors which are connected in shunt. The reactive power can be injected by mechanical switching the capacitors as per the requirement of the system. But the disadvantage is that some of the high speed transients cannot be compensated by this method and also some voltage sags are not compensated because the limited time period of mechanical switching. And transformer tap changing can be used but tap changing under load is very complex and costly.

Here, power electronics technology had played an important role in power flow control and utilization of electrical energy. Also for the electrical power system, the FACTS devices are more often utilized because of its extraordinary performances and these devices have the ability to mitigate power quality problems such as voltage sag, swell,
harmonics etc.

The definitions of voltage sag and voltage swell can be highlighted in the following table [5].

TABLE I. Voltage Sags and Swell Criteria

Distrubance Type	Voltage	Duration
Voltage Sag	0.1 – 0.9 pu	0.5 cycles – 1 min
Voltage Swell	1.1 – 1.8 pu	0.5 cycles – 1 min

For example, the FACTS for transmission systems, the term custom power pertains to use of power electronics controllers especially in distribution systems in order to mitigate various power quality problems. FACTS devices can boost the power transfer capabilities and improve the stability, the custom power ensures that the customers get pre-specified power quality and reliability of the power supply. The pre-specified power quality may include the following specifications of the parameters: low phase unbalance, low flicker at load point, no power interruptions, low total harmonic distortions, overvoltage and undervoltage within specified limits etc.

There are many types of Custom Power devices. Such as : Active Power Filters (APF)[7], [11], Battery Energy Storage Systems (BESS), Distribution static synchronous compensators (DSTATCOM)[7], Distribution Series Capacitors (DSC), Dynamic Voltage Restorer (DVR)[7], Surge Arresters (SA), Super conducting Magnetic Energy storage(SMES), Static Electronic Tap Changers (SETC), Solid-State Transfer Switches (SSTS), Solid State Fault Current Limiter (SSFCL), Static VAR Compensator (SVC), Thyristor Switched Capacitors (TSC),and Uninterruptible Power Supplies (UPS) [1].

II. DVR Basic Configuration

DVR is a series connected custom power device. It adds the missing voltage to the line whenever required i.e. when power

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frequency disturbances are occurred in the system. DVR can well compensate for voltage sag and voltage swell. It has other features such as to compensate for fault current, harmonic reduction etc. Especially, for the distribution electrical networks voltage profile is so much important because most of the disturbances are occurred due to voltage disturbances and can improve the voltage profile mainly, in distribution networks. The DVR is an excellent in mitigating the voltage sags and swells in very precise manner.

A DVR consists of a two-level VSC, a dc energy storage device, controller and a coupling transformer connected in shunt to the distribution network. Figure 1 shows the schematic diagram of DVR

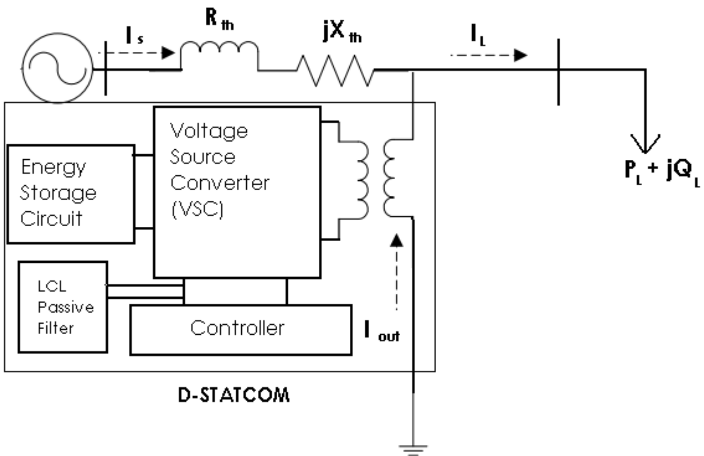

Figure: 1Schematic diagram of a DVR

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

$$I_{out} < \gamma = I_L < (-\theta) - (V_{th}/Z_{th}) < (\delta-\beta) + V_L/Z_{th} < (-\beta) \quad (2)$$

I_{out} =Output current
I_S = Source current
I_L = Load current
V_{th} = Thevenin voltage
V_L = Load voltage
Z_{th} = Impedance

Referring to the equation 2, output current, I_{out}will correct the voltage sags by adjusting the voltage drop across the system impedance, (Z_{th} ***=R+jX***). It may be mentioning that the effectiveness of D-STATCOM in correcting voltage sagsdepends on:

a) The value of Impedance, Z_{th} ***= R+jX***
b) The fault level of the load bus

A. Voltage Source Converter

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC 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. It also converts the DC voltage across storage devices into a set of three phase AC output voltages.

In addition, D-STATCOM is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages, D-STATCOM is said to be in capacitive mode. So, it will compensate the reactive power through AC system and regulates missing voltages. These voltages are in phase and coupled with the AC system through the reactance of coupling transformers.

Suitable adjustment of the phase and magnitude of the DSTATCOM output voltages allows effectives control of active and reactive power exchanges between D-STATCOM and AC system. In addition, the converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage.

B. Controller

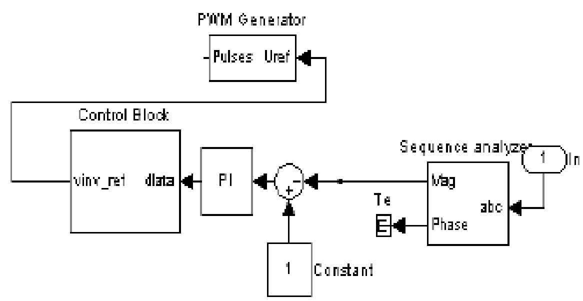

Figure:2 Block diagram of Controller System

Figure 2 shows the block diagram of Controller sytem.The controller system is partially part of distribution system.

Proportional-integral controller (PI Controller) is a feedback controller, which drives the system to be controlled with a weighted sum of the error signal (difference between the output and desired set point) and the integral of that value.

In this case, PI controller will process the error signal to zero. The load r.m.s voltage is brought back to the reference voltage by comparing the reference voltage with the r.m.s voltages that had been measured at the load point. It also is used to control the flow of reactive power from the DC capacitor storage circuit.

PWM generator is the device that generates the Sinusoidal PWM waveform or signal. To operate PWM generator, the angle is summed with the phase angle of the balance supply voltages equally at 120 degrees. Therefore, it can produce the desired synchronizing signal that required. PWM generator also received the error signal angle from PI controller. The modulated signal is compared against a triangle signal in order to generate the switching signals for VSC valves.

III. COMPENSATION METHODS

There are four different methods or techniques used for voltage sag/swell compensation are as follows:

a) Pre-sag compensation method
b) In-phase compensation method
c) Energy optimization compensation method
d) In-phase advanced compensation method

In the Pre-sag compensation method, the magnitude and the phase angle both are compensated as shown in figure 3 [3]

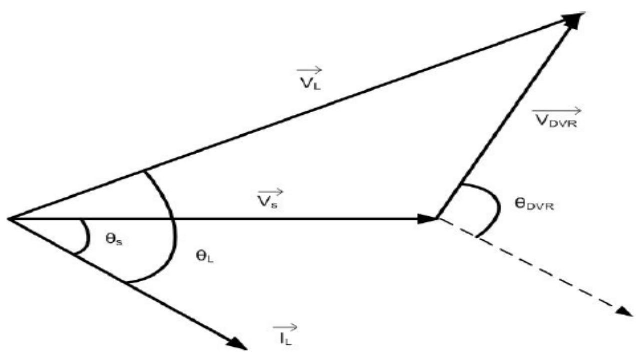

Fig.3 Pre sag compensation

The DVR injected voltage is the difference between the sagged voltage and pre-sag voltage/reference voltage and restores the voltage magnitude and the voltage phase angles to the nominal pre sag condition [3],[6],[20], [21]. The supply voltage is continuously tracked and the load voltage is compensated to the pre-sag condition. The method gives a nearly undisturbed load voltage, but can often exhaust rating of the DVR [10].

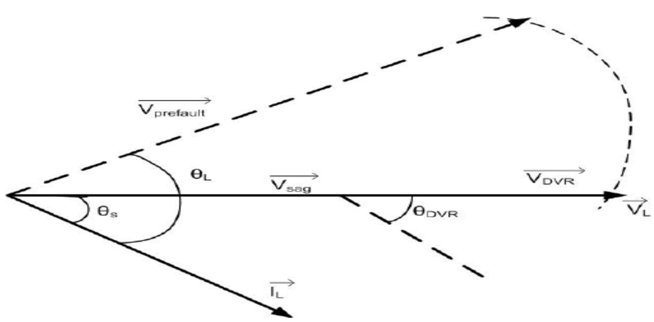

Fig.4 In phase compensation

In-phase compensation method [10], the generated DVR voltage is always in phase with the measured voltage supply irrespective of the load current and the pre voltage sag as shown in fig 4 [6].

One of the advantages of this method is that the DVR injected voltage magnitude/amplitude for certain types of voltage sags are minimum as compared to other methods Practical application of this methods is in non-sensitive loads.

In Energy optimization compensation method, the pre sag and in-phase compensation method injects the active power to loads. But to make the injected active power zero or to minimize the active power the injected voltages are at 90 degrees phase angle with respect to supply currents [10].

This method does not require any real power during compensation time and the injected energy is minimized.
This is its main advantage. The main drawback of this technique is that it increases the magnitude of injected voltage and therefore the total power of the compensator

In-phase advanced compensation method, real power spent by the DVR is decreased by minimizing the power angle between the sagged voltage and load current. The values of load current and voltage are normally fixed so only the phase of sagged voltage can be the changing parameter but all the voltage sags are not compensated without active power; this method is suitable for limited ranges. This method uses only reactive power for the compensation of voltage sags and voltage swells can perform well in most of the cases.

IV. CONTROL METHODS OF DVR

There are several techniques to implement and control methods of the DVR for power quality enhancements. The control of DVR is very important factor. Control methods for DVR involve the detection of any disturbance in voltage by using the suitable detection algorithms. The control system only measures the R.M.S voltage at the load point. It means there areno measurements of reactive powers. The performance of the DVR is directly affected by the control technique used for driving the inverter; because the inverter most valuable part of DVR [23], [24], [25]. The inverter control strategy employs following two types of controllers.

A. Linear Controller

The three main voltage controllers are Feed-forward (open loop), Feedback (closed loop) and Multi-loop controller [4], [6].

The feed-forward voltage controller can be the primary choice for the DVR, because of its simplicity and fastness. The supply voltage is continuously monitored and compared with a reference voltage value; if the difference exceeds a tolerable limit, the DVR injects the required amount voltage for compensation [6]. The drawback of the open loop controller is the high steady state error. Feed-forward controller canreact beforethe effect of thedisturbance shows up in theoutput [4].

In the feedback control, the load voltage is measured and compared with the reference value; the missing voltage is then supplied by the DVR at the supply bus in a feedback loop. This controller has the advantage of precise response, but it is complex controller and it introduces timedelayed. Feedback control is lesssensitive to modelling error. *Multi-loop control* is used with an outer voltage loop to control the DVR voltage and an inner loop to control the load current. This mode has the strengths of feed-forward and feedback control strategies, on the cost of complexity and time delay [4], [6].

B. Non Linear Controller

In the case of unstable system, the developed model may not work properly. So that all the linear control methods cannot work properly due to their limitations [4]. Then there are the need to use non-linear controllers such asthe artificial neural networks, fuzzy logic controllers and space vector pulse width modulation. Other non-linear controllers are also including in sliding mode control, hysteresis control and repetitive control.

ANN control method is usually presented as systems of interconnected "neurons" that can compute values from inputs by feeding information through the network. This method has developed with adaptive and self-organization capacity [6]. The ANN has inherent learning capability that can give superior precision by interpolation. Artificial neural networks can execute tasks that a linear program/network cannot perform. When an element of the ANN fails, it can continue without any problem by their parallel nature. A neural network does not need to be reprogrammed. It can be implemented in any application without

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any problem. The artificial neural network needs training to operate. This requires high processing time for large networks.

Fuzzy logic controllers are a smart choice when precise mathematical formulations are not possible. When Fuzzy logic controllers are used, the tracking error and transient overshoots of PWM inverter can be significantly reduced. It offers easy computation and widely available toolboxes and ICs. It is a flexible and spontaneous knowledge based design [4], [6].

The use of commercial packages introduces the use of non-standard file formats and initiates huge software overhead for simple applications. Many actual implementations are just like the equivalent to lookup table interpolation methods.

SVPWM control scheme is to adopt a space vector of the inverter voltage to get better performance. The better exchange is gained in low switching frequency conditions[4], [6].The lower order harmonic scan be well eliminated by the Space Vector PWM technique. Space Vector Modulation provides excellent output performance, optimized efficiency and high reliability than conventional PWM method and harmonics are reduced due to multi switching and output is approximately sine wave so filter design and cost reduced.

The block diagram which shows the various control methods is shown in fig 5[6].

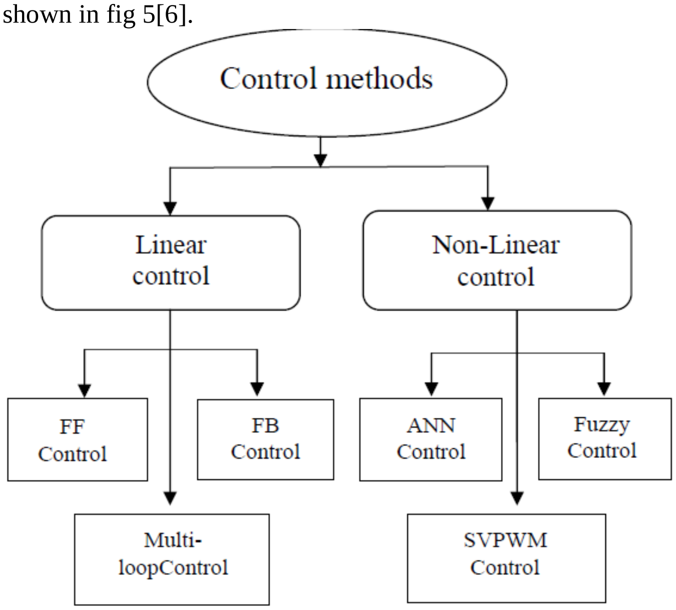

Fig: 5 Control Methods

V. Conclusion

In this paper, the overview of DVR is presented and also different control strategies are offered. The DVR can inject three phase controlled voltage to make the load voltage constant at its nominal value. Out of the various control methods, especially for inverter, the space vector PWM technique seems to be the most effective technique that can be implemented in DVR to mitigate the power quality problems. The SVPWM technique provides reduced power losses. It also provides less harmonic content which is very useful to avoid malfunctioning of sensitive apparatus by harmonic excess and also overcome the problems of transformers and wiring overheating. The only and main negative aspect of DVR is its incapability to alleviate interruptions.

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