

## CUSTOM POWER DEVICES

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### Introduction

Custom power is a technology driven product and service solution which embraces a family of devices which will provide power quality functions at distribution voltages. It has been made possible by the now spread availability of cost effective high power solid state switches such as GTO's and IGBT's. The rapid response of these devices enables them to operate in real time, providing continuous and dynamic control of the supply including: voltage and reactive power regulation, harmonic mitigation and elimination of voltage dips.

### The custom power concept

The term custom power pertains to the use power electronic controllers for power distribution systems. Just as the FACTS controllers improve the reliability and quality of power transmission systems, the custom power enhances the quality and reliability of power that is delivered to customers. All custom power devices are capable of providing a number of power quality functions which can be employed selectively or simultaneously. Basically the custom power devices are classified in to two types: those used for isolation and protection of the system and those used for compensation. Different types of custom power devices are given below.

#### • Network configuring type

- **Static current limiter:** limits a fault current by quickly inserting a series inductance in the fault path
- **Static circuit breaker:** breaks a faulted circuit much faster than a mechanical circuit breaker

- **Static transfer switch:** protects the sensitive load by quickly transferring it from the faulty feeder to the healthy feeder.

#### • Compensating type

- **Distribution STATCOM (DSTATCOM):** This is a shunt connected device that can operate either in current control mode or voltage control mode. In current control mode the DSTATCOM acts for load compensation like an active filter, power factor corrector, load balancer etc. In voltage control mode, it can regulate the bus voltage against any distortion, sag/swell, unbalance and even short duration interruptions
- **Dynamic Voltage Restorer (DVR):** it is a series compensating device used for protecting sensitive loads from sag/swell unbalance etc. It can also regulate bus voltage at load terminal
- **Unified power quality conditioner (UPQC):** This device consists of two voltage source inverters. It can simultaneously perform the task of both DVR and DSTATCOM

### 1.0 DSTATCOM

STATCOM is a power electronic shunt compensator to correct the current drawn from a utility to closely approximate balanced sinusoidal waveforms, without adversely affecting the voltage at the point of common coupling (PCC). STATCOMs are employed at distribution and transmission levels for different purposes. When a STATCOM is employed at the distribution level or at the load end for power factor improvement and voltage regulation alone, it is called Distribution level STATCOM (DSTATCOM). The DSTATCOM is a three-phase

device, which is able to provide a continuously variable level of shunt compensation (by current injection in to the distribution system). The injection waveform is created by high speed switching of the DC source, using pulse width modulation scheme. Because of this the DSTATCOM is capable of generating and injecting moderate level of harmonic waveforms to compensate for non-linear loads. It also appears as fully synchronous sources, which are capable of absorbing and injecting reactive power on an electricity system at distribution voltages. While operating, the DSTATCOM continuously monitors the line at the primary terminal and compares it with a reference signal. It then injects the necessary voltage and harmonic currents to compensate for the disturbance caused by a down stream load. Thus an ideal application of the D STATCOM is to prevent disturbing loads from polluting the rest of the distribution system and balance the bus voltages

### 1.1 Operating principle

The DSTATCOM is a three-phase PWM inverter, driven from the voltage available across a DC storage capacitor as shown in Fig1. It is connected in shunt to the distribution three-phase feeder circuit via a tie-reactance or a standard transformer. The three output voltages of the compensator are in phase with the AC system voltages. Whenever, the inverter output voltages are higher (or lower) than the AC system voltages, the current flow is caused to lead (or lag). The difference in voltage amplitudes determines the magnitude of current flow. Thus, controlling the PWM inverter voltage can control the reactive power and its polarity. When coupled with the Solid-State Breaker (installed on the line side of the DSTATCOM) and energy storage, the D-STATCOM can be used to provide full voltage support to a critical load during operation of the feeder breaker that protects the

distribution feeder on which the D-STATCOM is installed.

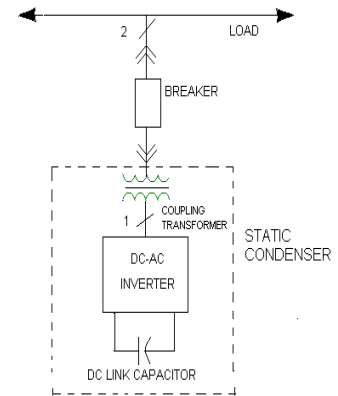


Fig.1 DSTATCOM Configuration

**Reactive power exchange:** Reactive power exchange is best done by varying the magnitude of three-phase output voltage  $V_i$  of the PWM inverter as per the following:

1. If  $V_i > V_t$  : The inverter generates Reactive Power and the net effect is Capacitive
2. If  $V_i < V_t$  : The inverter absorbs Reactive Power and the net effect is Inductive.
3. If  $V_i = V_t$  : No exchange of power between the inverter and line is done.

The exchange of reactive power is depicted in Fig.2. The above equations assume that the real input power provided by the DC source is zero. Further, the reactive power at zero frequency is also zero.

**Real power exchange:** The real power exchange between the inverter and the ac system can be controlled by phase shifting the inverter output voltage with respect to the ac system voltage. That is, the inverter from its energy storage supplies real power to the ac system, if the inverter output voltage is made to lead the corresponding ac system voltage. By the same token the inverter absorbs the real power from the ac system for dc energy storage, if the inverter output voltage is made to lag the ac system voltage.

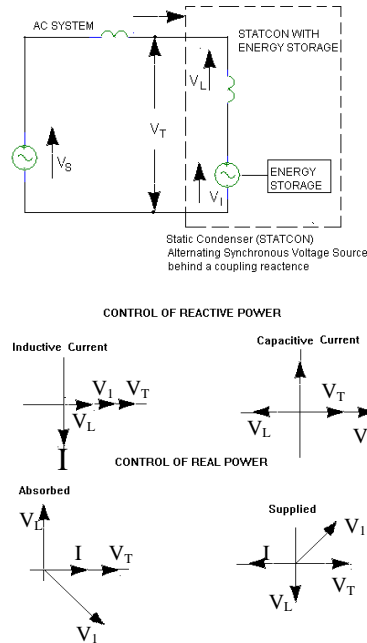


Fig.2 Real and reactive power exchange

## 2.0 DVR- Concept and Basic principle of operation

A dynamic voltage restorer (DVR) is a power-electronic-converter based device that has been designed to protect critical loads from all supply-side disturbances other than out-ages. It is connected in series with a distribution feeder and is capable of generating or absorbing real and reactive power at its ac terminals. The basic principle of a DVR is simple: by inserting a voltage of required magnitude and frequency, the DVR can restore the load-side voltage to the desired amplitude and waveform even when the source voltage is unbalanced or distorted.

The practical circuit of DVR installation along with bypass breaker and isolating switches, connected in series with the distribution line is depicted in Fig.3. The insertion transformer, bypass breaker and isolation switches are provided in the circuit for the purpose of ease of maintenance and safety of operation.

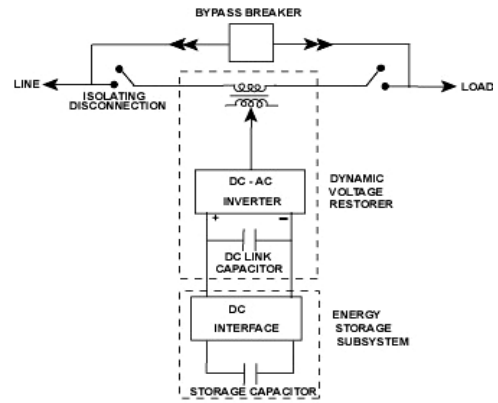


Fig.3. DVR Installation

Dynamic Voltage Restorer (DVR) is the most economic and effective means in improving the voltage related power quality problems. Fig.4 depicts how the DVR connected in series with the distribution feeder can compensate in real time for the voltage Sag by supplying compensating signal. The voltage sag in the system is mitigated by injecting the difference between the desired voltage and the actual voltage. This injection requires a power electronic converter, a high power source of energy in order to supply real power for compensation and a fast acting control system.

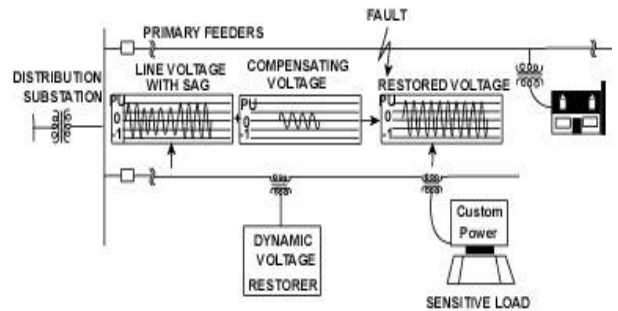


Fig.4 Elimination of Voltage Sag

The schematic and circle diagram as depicted Fig.5 (a) and 5(b), demonstrate how the DVR with energy storage can either supply or absorb the active and/or reactive power.

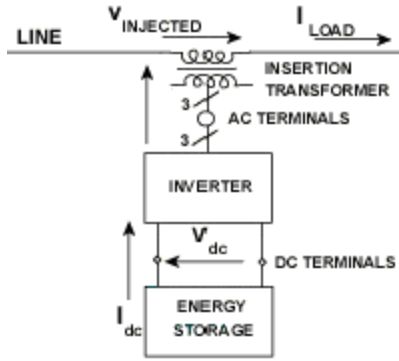


Fig.5 (a)

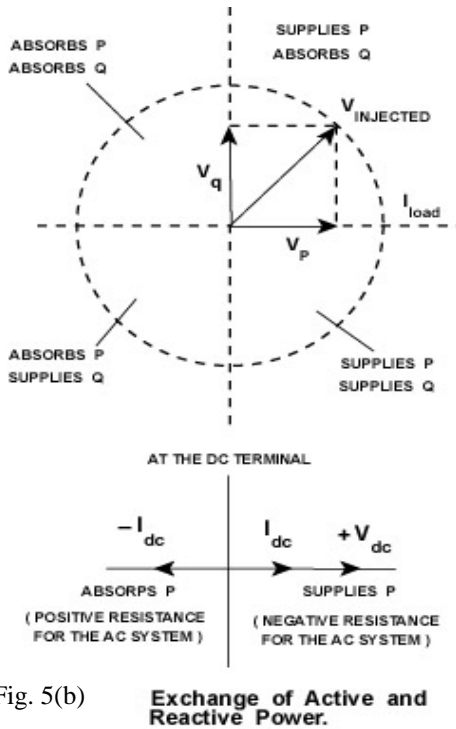


Fig. 5(b)

**Exchange of Active and Reactive Power.**

### 2.1 Voltage injection strategies

The DVR is capable of supplying and absorbing both real and reactive power. In many cases small disturbances can be restored through the exchange of reactive power only. For large disturbances it is necessary for the DVR to supply real power to the load. The reactive power exchanged is generated internally by the DVR without any energy storage device. The real power exchange requires energy storage. There are three distinguishing methods to inject

DVR compensating voltage- Pre-sag method, in-phase method and phase advance method.

#### A. Pre-sag method:

If the capacity of the energy storage unit and the voltage injection capability of the DVR are sufficiently large, it is the best way to make load voltage to be same as the pre-fault voltage. This method is suitable for loads, which are sensitive to magnitude and also phase angle shift. In this method, DVR compensates the load voltage by injecting the voltage difference between pre-sag voltage and sag voltage and make load voltage to be same as the pre-fault voltage (both magnitude and phase).

$$V_{DVR} = V_{pre-sag} - V_{sag} \quad (1)$$

#### B. In-phase injection method:

In consideration of the limitation of voltage injection capability in DVR, in-phase method can be used. In this method the DVR injection voltage is in phase with the sag voltage of the power source and may have a phase displacement with respect to the pre-sag voltages. In-phase voltage injection can result in maximum voltage boost with minimum injection voltage.

The pre sag method and in-phase method inject active power to loads during faults. The possible injecting active power is confined by the stored energy in the DC link. Due to the limit of energy storing capacity, The DVR restoration time and the performance are limited when these methods are used.

#### C. Phase advance method:

In order to overcome the limitation of energy storing capacity of DVR, phase advance method is proposed. This method minimizes the active power injection from DVR by making the vector of DVR compensating voltage current nearly perpendicular to each other.

### 3.0 NETWORK CONFIGURING TYPE CUSTOM POWER DEVICES

#### 3.1 TRANSFER SWITCH (TS)

Transfer switches (TS) have been used in the industry for many decades for protecting loads from interruptions. The basic configuration of TS containing two or more switches that allow transferring a load from a preferred feeder to an alternate feeder is shown in Fig.6.

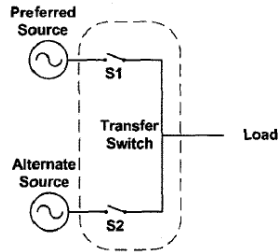


Fig 6. Basic configuration of a transfer switch

The mechanical transfer switch (MTS) has been used for many years to transfer industrial loads to a backup power source (e.g. alternate feeder, backup generator, etc.) as a countermeasure against interruptions on the preferred source or feeder. Due to the nature of the electromechanical switches used in the MTS, a “seamless” transfer is not obtainable. Typical transfer times can range from about 100 milliseconds up to approximately ten seconds.

##### 3.1.1 Static Transfer Switch (STS)

To protect sensitive loads against sags and interruptions, a similar system based on solid-state devices can be used. The STS system generally consists of three main components as shown in Fig. 7

- Static transfer switches: They are two three-phase AC thyristor switches. Under abnormal conditions, these switches allow the fast transfer of power from one source to another.
- Mechanical bypass switches: They are operated as standard mechanical transfer switches when the STS is overloaded or out of service for maintenance.
- Isolating switches: They allow STS system to be isolated from the distribution system.

There are two arrangements for the STS system as shown in Fig.7 (a) and (b). In the first configuration, one primary (preferred) source supplies all loads at a bus. Under normal operation, the bypass switches are open and the isolating switch is in the closed position. Once an interruption or a disturbance occurs, the primary source static switch is opened and the alternate source static switch is closed.

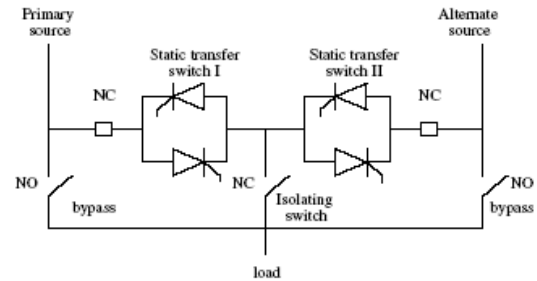


Fig.7 (a) The static transfer switch system (Type I)

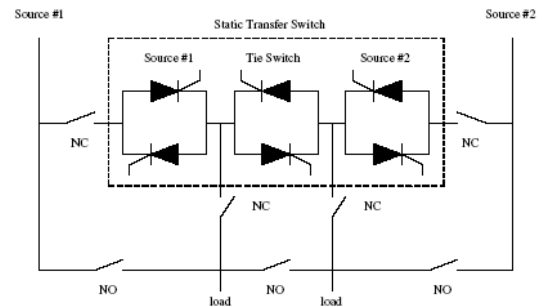


Fig.7 (b) The STS - split bus arrangement (Type II)

Fig.7(b) illustrates the other “split bus arrangement (Type II),” in which the bus load is equally split between two sources under normal condition. Once an interruption occurs, one of the source side switches is opened and the tie switch is closed.

Normally, the static switch on the primary source is fired regularly, while the other one is off. In the event of a voltage disturbance, the STS is used to transfer the load from the preferred source to an alternative healthy source. This results in a very effective way of mitigating the effects of both interruptions and voltage sags by limiting their

duration as seen by the load. The success of the STS is mainly due to its rather low cost compared with other solutions. A requirement is that a secondary in-feed, independent from the main source (e.g. a feeder to another substation), must be available. Therefore, this solution is particularly attractive for installations that already have an MTS, where upgrading to an STS does not require major changes in the layout of the distribution system. Formerly available only for low voltages, STS systems are now available for operating voltages up to 35 kV and load ratings, of 35 MVA, which makes them suitable for high-power industrial applications.

An STS can be operated to perform a ‘break-before-make’ transfer, which means that during the transfer the preferred and alternate sources are never paralleled. This type of transfer allows the current to go to zero in each phase of the preferred-side thyristors before the alternate side begins conducting. Depending upon how the STS is controlled, it is possible to gate the alternate-side thyristors before the zero-current crossing on the preferred side is reached, thus allowing the alternate side to “force” the preferred side to commutate (turn off). This transfer is known as a make-before-break transfer. Whether or not the two-thyristor pairs produce crosscurrents (e.g., back-feeding a fault) is dependent upon voltage levels and phase, load power factor, and the control algorithm being implemented. Depending upon the control algorithm, this method can result in either all three phases being switched at the same time or each phase being switched separately (sequential switching).

### 3.1.2 Hybrid static switch

Another approach that has been used involves a static switch in parallel with a vacuum switch (hybrid static switch). [10]. During normal operation, the preferred-side vacuum switch conducts, thus supplying power to the load. When the need for a transfer arises,

the vacuum switch opens and the appropriate thyristor is gated. The opening of the vacuum switch produces an arc voltage, which in turn forward biases one of the preferred-side thyristors. Once this occurs, the load current begins to conduct through the preferred-side static switch. The load is then transferred to the alternate source similar to the standard static STS. Once the alternate side static switch picks up the load, it is then transferred to the alternate side vacuum switch. This method increases efficiency and eliminates the need for cooling devices but the transfer rate is comparatively longer compared to the thyristor-controlled switch.

### 3.2 STATIC CIRCUIT BREAKERS (SCB)

Advanced current interruption technology, utilizing high power Solid-State breakers also called Static Circuit Breakers (SCB), offers a viable solution to many of the distribution system problems that results in voltage sags, swells, and power outages. Solid-state fast-acting (sub-cycle) breakers can instantaneously operate to prevent the spreading of a disturbance by breaking a faulted circuit much faster than a mechanical circuit breaker, thereby improving power quality performance to other customers. When combined with a current limiting reactor or resistor, the SSB can rapidly insert the current limiting device in to the distribution line to prevent excessive fault current from developing from sources of high short circuit capacity. SSB is shown in fig.8.

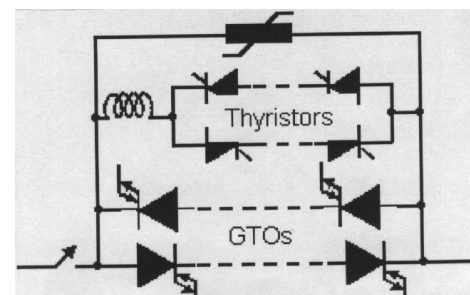


Fig.8 Static circuit breakers

Here GTO's are the normal current carrying elements. For a persistent fault, the GTO's are turned off and the thyristors are tuned on. The fault current now starts flowing through the current limiting reactor and it can be eventually cut off by blocking the thyristors.

### 3.3 STATIC CURRENT LIMITER (SCL)

An SCL shown in fig.9 consists of a parallel connection of an anti-parallel gate turn off thyristor (GTO) switch with snubbers, a current limiting inductor and a zinc oxide (ZnO) arrester.

A GTO can be switched off at any time by applying a negative gate pulse, thus can interrupt the current instantaneously. A thyristor switches off only when the current through it changes its polarity. An anti-parallel thyristor switch in a current limiter will keep on conducting till the next zero crossing irrespective of the instant of the occurrence of the fault. This will defeat the purpose for which the current limiter is installed.

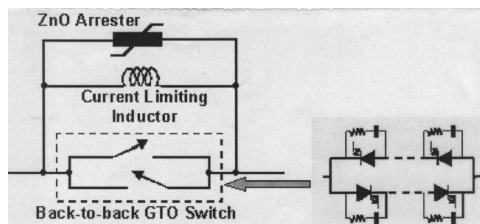


Fig.9 static current limiters

Under the normal operating condition, the GTOs are gated for full conduction. Once a fault occurs the GTOs are turned off as soon as the fault is detected and the fault current is diverted to the snubber capacitor that limits the rate rise of voltage across GTOs. The voltage across the GTO rises until it reaches the clamping level established by the ZnO arrester. The same voltage comes across the current limiting inductor also. Once the clamping level is reached, the current through the reactor increases linearly and will continue till it becomes the instantaneous current flowing

through the line. Thus the current will be limited by the total effective impedance offered by the current limiting reactor and the faulted feeder.

### References

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