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Custom Power Devices for Power Quality Improvement: A Review

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***Abstract*- During Last decade power quality problems has become more complex at all level of power system. Recently, the Power electronics controllers are gaining concern to provide the quality of power for both power suppliers and consumers. Various power filtering technology i.e. passive filters, active power filters, hybrid filters have applied from time to time for giving the solution of power quality problems to users, But could not fully satisfied them. Now day's a new concept of custom power is used for customers' satisfaction. This paper present a comprehensive survey of custom power devises in distribution level. Classified references are also presented, would be very useful for researchers dealing with power quality problems.**

Keywords*- *Custom power, Distribution Static Compensator (DSTATCOM),* Dynamic Voltage Restorer (*DVR*)*, Unified Power Quality Compensator (UPQC).

I. INTRODUCTION

Recently, Power quality problems have become an important issues for electricity consumers at all the level of usage. The deregulation of electric power energy has boosted the public awareness toward power quality among the different categories of users. The subject power quality and its problems related to electric power network has discussed in publications [1]-[10].

To provide an active & flexible solution for power quality problems, various efforts have done from time to time. Among these power quality solution lossless passive filters [11-13] consists of L-C tuned component have been widely used to suppress harmonic. Passive filters are advantageous as its initial cost is low and high efficiency. on the other hand it have various drawbacks of instability, fixed compensation , resonance with supply as well as loads and utility impedance. To overcome these limitations active power filters [14-16] have been used .active power filter has various configurations: shunt, series and hybrid. Hybrid is the combination of series and shunt types. Shunt APF is used for compensating current based distortions while series APF compensates voltage based distortions. Hybrid APF [17-19] is applied for filtering high order harmonics. However, they have a problem that their rating is sometimes very close to load (up to load 80 %) in typical applications. Due to this reason, power quality level is not obtained. This causes power disturbances and customer dissatisfaction. According to contingency planning research company's annual study [20] a power disturbance in distribution system produces an economical losses is shown in Fig 1. To increase the reliability of the distribution system and face the power disturbance problems, an advanced power electronics controller devices have launched over last decades. The evolution of power electronics controller devices has given to the birth of custom power [21]-[22].

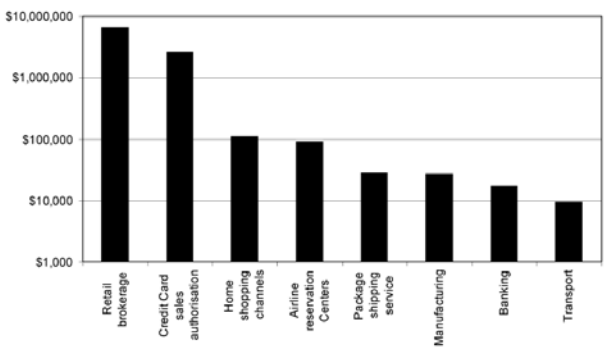

Fig 1.Average hourly impact of downtime and data loss by business sector [20]

II. CUSTOM POWER DEVICES

Custom power is a strategy, which is intended principally to convene the requirement of industrial and commercial consumers. The concept of the custom power is tools of application of power electronics controller devices into power distribution system to supply a quality of power, demanded by the sensitive users. These power electronics controller devices are also called custom power devices because through these valuable powers is applied to the customers. They have good performance at medium distribution levels and most are available as commercial products. For the generation of custom power devices VSI is generally used, due to self-supporting of dc bus voltage with a large dc capacitor. The custom power devices are mainly divided into two groups: network reconfiguring type and compensating type. The complete classification of custom power devices is shown in the Fig 2.

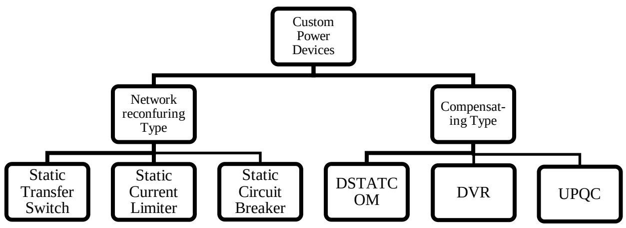

Fig2 Classification of Custom Power Devices

According to the IEEE P1409 Custom Power Task Force, the number of custom power devices in service up to May 2000 is as follows[23].

- Transfer switches: 23 devices.
- Static series compensators: 7 devices.
- Static shunt compensators: 17 devices

III. NETWORK RECONFIGURING TYPE CP DEVICES

These are GTO or Thyristor based devices, generally used for fast current limiting and current breaking. The main network reconfiguring type custom power devices are: solid state current limiter, static transfer switch, static breaker, ups,

A. Static Current Limiter

it is a GTO based device applied for high fault current limiting. It insert a limiting inductor in the fault circuit .when the fault is cleared, removes the inductor from circuit [25].

B. Static Transfer Switch

Static Transform Switch (STS) is used to protect sensitive load voltage sag or swell. It is composed of two parallel connected Thyristor or GTO blocks. Each block consists of three GTO or thyristor corresponding to the three phase of the system. The common configuration of STS in distribution system is shown in Fig 3.

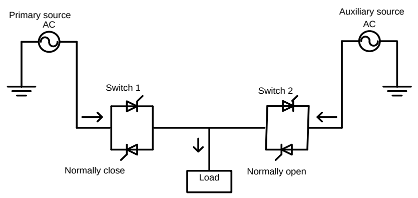

Fig.3 Static transfer switch (STS) [27].

As shown in the Fig 3 two independent power sources are used, named as primary and auxiliary. Generally Primary source feeds the load through switch 1. When fault occurs primary source affected, and then load is fed from alternating source through switch 2. The transfer switching time of STS varies from 0.25 to 0.5 cycle of the fundamental frequency. The main advantage of STS is that it conducts the load current continuously. Which means it supplied an uninterrupted power at distribution level to customers. The limitation of this switch is that, In high power application the load current leads the conducting losses. The conducting losses are in the range of 0.5 to 1% of the load power [27].

A hybrid STS has been proposed in [30].in this switch a conservative circuit breaker is connected in shunt with thyristors or GTO's. Only in study state current will flow through it. The current commutations from primary to alternative source acquire less than a half cycle but the total transfer time is depending on the response time of voltage dip detection.

C. Solid State Breaker

The solid state breaker is based on the GTO or thyristor switching technology. It is a high-speed switching device, applied to reduces the electrical fault and protect from large current in distribution system. It can be used in a single switch, static transfer switch, hybrid switch or a low level fault interrupter. The voltage and current rating of the breaker describes the requirement of no. of switching devices, cost and the losses of the breaker. It perform auto- reclosing function [25].

D. *Uninterruptible Power Supply*

Uninterruptible power supply (UPS) is the conventional response to circumvent production interruption and outage costs. The single line diagram of ups is shown in the Fig 4.

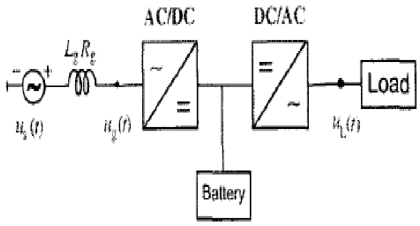

Fig.4 Single line diagram of UPS [31].

In UPS load has received the power from source via two stage operation: conversion (ac/dc) and inversion (dc/ac). During voltage dip or an interruption, the load voltage is made constant by energy, generated through battery. The performance of ups is depending on energy storage capacity of battery. According To P. bowler UPS are needed where the power losses can causes economical lose greater than ups cost [31]. For high power load financially, it is not suitable because of two conversions the maintenance cost of battery has become too high [32]. Hu]

IV. COMPENSATING POWER DEVICES

The compensating custom power devices are used for active filtering, load balancing, power factor improvement voltage regulating (sag/ swell) [33]. These devices are mainly three types: static shunt compensator, series and hybrid compensator. These are also called as DSTATCOM, DVR and UPQC respectively.

A. Distribution Static Compensator (DSTATCOM)

DSTATCOM is a Voltage source inverter (VSI) based static compensator device (STATCOM, FACTS controller) applied to maintain bus voltage sags at the required level by supplying or receiving of reactive power in the distribution system [33]-[34]. It is connected in shunt with distribution feeder with the help of coupling transformer. The single line diag. of DSTATCOM is shown in shown fig.5. The DSTATCOM consists of a VSI, dc energy storage device, an ac filter and coupling transformer.

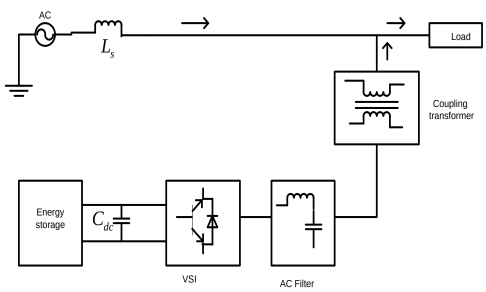

Fig.5 Single line diagram of DSTATCOM [33].

In the power circuit, VSI converts DC voltage into controllable ac voltage, synchronized by ac filter and connected to AC distribution line through coupling transformer. The DSTATCOM can also rely and absorbed active power, by using energy storage in sufficient amount [35]. The operating principle of DSTATCOM that it continuously monitors the load voltages and currents, determines the amount of compensation required by distribution system for a verity of disturbances. In this scheme The active power flow is controlled by the angle between the ac system and VSI voltages , the reactive power flow is controlled by the difference between the magnitudes of these voltages [36]. The DSTATCOM operates in both current and voltage control modes [37]-[39].

From the single line diagram of DSTATCOM it is clear that the distribution bus voltage (V_{bus})is equal to the sum of inverter voltage (V_I) and voltage across the coupling transformer (reactive voltage V_t) in both capacitive and inductive modes. This means, the output voltage of bus (V_{bus}) is in phase with output voltage of DSTATCOM (V_I). If V_{bus} is greater than output voltage of VSI (V_I) a reactive current (I_q) will flow through DSTATCOM, it observe reactive power from the distribution system. But when V_{bus} is less than V_I, will provide reactive power to system. [25]The vector diag. for releasing and receiving of reactive power in both capacitive and inductive current modes at fundamental frequency is shown in Fig.6.

Practically in ac system losses are not negligible. The losses in the transformer winding and in converter switches is generate, which consume ac power in distribution system.

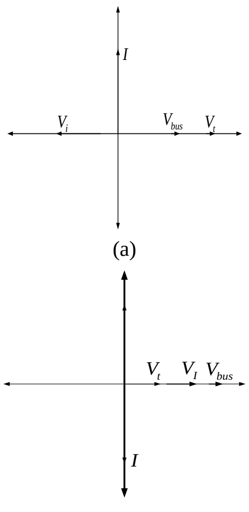

Fig.6 Vector diagram of DSTATCOM; (a) Reactive power suppl,(b) Reactive power received

Therefore there will be a small phase difference of angle $\pm\alpha$ between V_{bus} and V_I to compensate the losses of transformer winding, inverter switching and attract active power from the system. In inductive mode phase angle α will positive while capacitive mode it becomes negative. The vector diag. of DSTATCOM for active power in both mode at fundamental frequency is shown in Fig 7. The active and reactive power can be calculated by following questions:

$$P = (V_{bus} V_I / X_L) \sin\alpha \quad (1)$$

$$Q = (V_{bus}^2 / X_L) - (V_{bus} V_I / X_L) \cos\alpha \quad (2)$$

The first DSTATCOM was installed for reactive power compensation at timber mill in British Columbia, Canada [40].

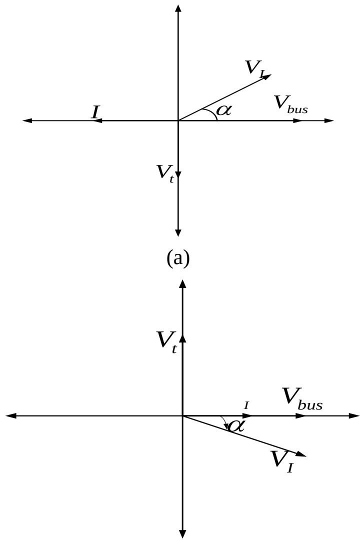

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Fig.7 Vector diagram of DSTATCOM; (a) Active power relies,(b) Active power receive

The correction capability of DSTATCOM for an actual power system is sown in Fig 8.

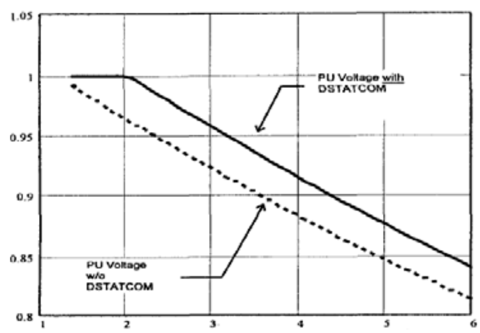

Fig.8 DSTATCOM correction capability function of total facility load [41]

*B. Static Series Compensato*r

Commercially, static series compensator is known as Dynamic Voltage Restorer (DVR). It is a high-speed switching power electronic controlling device. The world's first DVR has been installed in the Dukey power distribution system to protect a sensitive textile customer from voltage dips on August 26, 1996 [42]. DVR is a series connected custom power device, designed to inject a dynamically controlled voltage in magnitude and phase in to distribution line via coupling transformer to correct load voltage. The generalized block diag. of DVR is shown in the Fig 9.

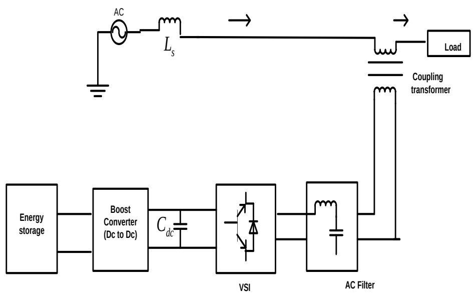

Fig.9 Generalized block diag. of DVR [43]

It consists of a energy storage device, a boost converter (dc to dc), voltage source inverter, ac filter and coupling transformer, connected in series. Here dc capacitor bank is used as energy storage device, which is interface by a boost converter. The boost converter regulates the voltage across the dc link capacitor that uses as a common voltage source for the inverters. The inverter generates a compensating voltage, which is inserted into distribution system through series matching transformer. In the case of voltage irreregulation, the DVR controllers generate a reference voltage, and compare it with source voltage and injects synchronized voltage to maintain the load voltage constant. The energy storage device provide the required power to synchronized injected voltage. The ac filter overcome the effects on winding of coupling transformer and switching losses of control signal generating techniques for VSI [44]-[46].
Principle of operation: The simplified single phase equivalent circuit of DVR connected distribution feeder is shown in the Fig.10

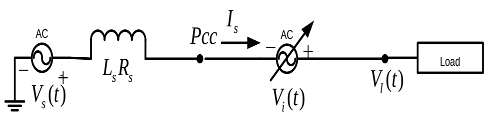

Fig.10 simplified equivalent circuit DVR

Where $V_s(t)$ is supply voltage, $V_i(t)$ injection voltage of DVR ,and $V_l(t)$ is load voltage are connected in series. From Fig 10 the load voltage is given as:

$$V_l(t) = V_i(t) + V_s(t) \quad (3)$$

Therefore DVR is supposing as an external voltage source of controlled amplitude, frequency, and phase angle. The aim of using DVR is to maintain the amplitude, and phase angle of fixed load voltage. If the source voltage is fluctuated due to voltage sag or swell problem, the value of injected voltage $V_i(t)$ should be is selected such that load voltage remains constant as before fault. The correction capability of 2 MVA-rated DVR with the load ranging from 2-5 MVA is shown in Fig.11

C. Unified Power Quality Compensator (UPQC)

It is the combination of back to back connected shunt and series compensators through a common dc bus voltage. In this dc link storage capacitor is connected between two voltage source inverters for operating as combination of shunt and series compensator. The single line diagram of unified power quality compensator is shown in Fig 12.

It is a most flexible device, can suppress current in shunt and voltage in series simultaneously. It can balance the terminal voltage and eliminate negative sequence current components at the same time. Two type of are UPQC are suggested in literature surveys. One is called Left- Shunt UPQC [48] and another is known as Right-Shunt UPQC [25]. The overall performance of right-shunt UPQC is better than left-shunt UPQC. When UPQC is connected between two feeders then, called Interline Unified Power Quality Compensator (IUPQC) [49].

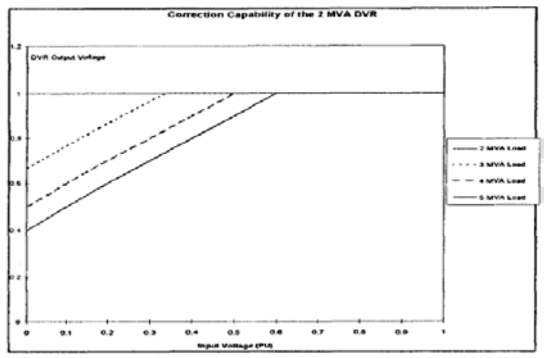

Fig.11 Correction capability of 2 MVA- rated DVR [47]

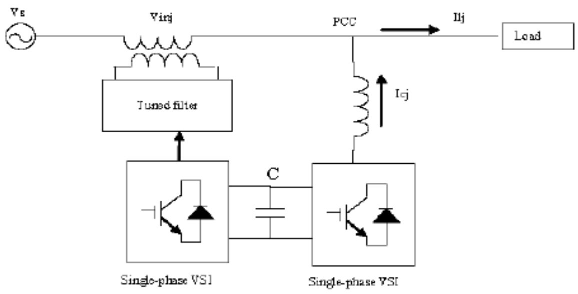

Fig.12 single line diagram of UPQC [48]

TABLE-I
APPLICATIONS OF EACH CUSTOM POWER DEVICES

Custom Power Devices	**Applications**
Static Shunt Compensator (D -STATCOM)	• Power factor improvement • Current Harmonic compensation • Load current balancing • Flicker effect compensation
Static Series Compensator (DVR)	• Voltage sag and swell protection • Voltage balancing • Voltage regulation • Flicker attenuation
Unified Power Quality Compensator (UPQC)	• Voltage sag and swell correction • Voltage balancing

	• Voltage regulation • Flicker attenuation • VAR compensation • Harmonic suppression • Current balancing • Active and reactive power control
Static transfer switch (STS)	• Voltage sag and swell protection
Solid state breaker	• Fault current protection and limitation

V. Conclusions

This paper provides a literature review of custom power devices which has been proposed/installed in power distribution system to eliminate various power quality problems; voltage sag/swells, flicker, dip, current harmonics, power factor reduction. These devices can be used by the customers at practical cast for high quality power. The DSTATCOM, which is connected in shunt can provide good power quality in both transmission and distribution level. UPQC is the key of custom power devices, can compensate both voltage and current related problems at the same time.

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