Custom power technology: concept and definition

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Abstract:

State-of-the-art of custom power system is a new technology that is used to mitigate power quality problems in power distribution systems. It can increase power quality of the system with the help of power electronic and control technology based devices. This paper presents principle and concepts of custom power and custom power devices, which are presently used in power distribution systems in some developed countries. It also presents basic idea of custom power, types of custom power devices, power converter topologies, and applications of this new technology in practical distribution systems.

1. Introduction

Presently, power systems are complicated systems, which consist of hundreds of generating stations and thousand of load centers, complicatedly connected through power transmission system. Electric power system can be divided into three parts, namely, power generation, power transmission, and power distribution [1]. Power generation is mainly generated by synchronous generators located in power stations. Most of the generation stations are located far from the load center. Power generation has to be transmitted over a long distance to load centers through long transmission system. This may cause stability and quality problems to the power system due to the angle separation and voltage reduction. In addition, the system may face other problems such as frequency fluctuation, etc.

Custom power is a new technology, which is based on power electronic and control technology [2-13]. It is a general term for equipment capable of mitigating numerous power quality problems by injecting or absorbing both active and reactive power. By introducing the custom power to the distribution system, the quality of the power system can be improved. Custom power is new to many utilities. Concepts and fundamental behind the new technology is interesting to practical engineers who work in distribution levels. Thus, it would be useful to present the fundamental and concepts behind the custom power. This will provide information to engineers in utilities to have more idea about new technology to improve power quality of the distribution system.

This paper is structured as follows. Section 2 introduces the types of power quality problems occurred in the distribution systems. Technology based on power electronic devices is presented in Section 3. In Section 4, power converter topologies are briefly presented. Present

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custom power technology is summarized in Section 5 including reconfiguration and compensation technology. Finally, in Section 6, conclusion and recommendation are given.

2. Types of Power Quality Problems

Power distribution network is considered from 115 kV transformers down to the customer load, which are normally commercial and residential types. Voltage level of commercial customers is normally 115 kV and 22 kV, whereas voltage level of the residential consumers is 380-400 V (line-to-line). There are various stages between generation and load points. The correct operation of all components in the power system is very critical for a reliable power delivery [2]. There are many issues involved such as the maintenance of power apparatus and system, the stability of the system operation, the operation of power distribution system, etc.

Power quality problems are generally complex and difficult to detect. Normally electricity should be in the form of pure sinusoidal wave with fundamental frequency. If the electricity is distorted from the pure sinusoidal waveform, it may have power quality problem. There are many ways to relive the system from power quality problem [1].

3. Power Semiconductor Technology

Voltage level in power systems is in the rank of 22-115 kV. Selecting the rating of power semiconductor devices that can be used in the power system is important. Presently, the highest nominal voltage of the semiconductor devices is about 9 kV and the maximum nominal current is 8 kA [14]. Fig.1 shows the development of power semiconductors from 1980's to present.

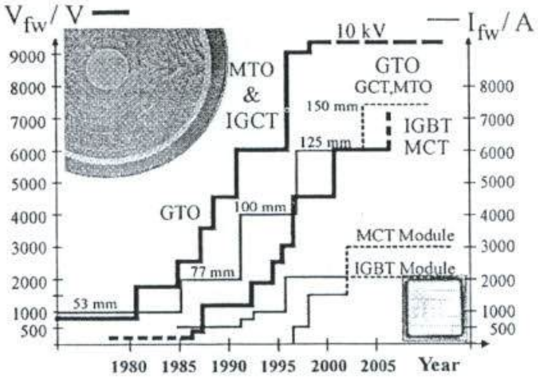
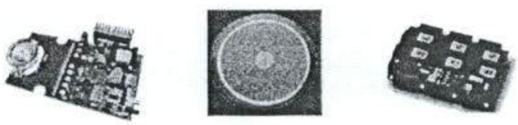


Fig. 1: Development of power semiconductor devices.

The development of all types of semiconductor devices includes their highest operating voltages. From Fig.1, Insulated Gate Commutated Turn-off (IGCT) offers the highest operating voltage. In the custom power, only three types of semiconductors, namely, insulated gate bipolar transistor (IGBT), gate commutated turn-off (GCT), and gate-turn-off (GTO) can be used. Currently, GTO is the most popular device used in custom power, whereas IGCT is emerging due to the low losses occurred in the devices. IGBT can not be used in custom power since it has high losses than other devices. Fig.2 shows pictures of power semiconductors used in the custom power devices [15].



(a) IGCT (b) GTO (c) IGBT

Fig. 2: Power semiconductors devices.

In addition a turn-on snubbers, which is mandatory for GTO and IGCT in inverter applications is not needed. When just considering the losses, only the special IGCT would be chosen for the circuit breaker. Although the losses of the GTO are higher, the material costs nevertheless are much lower. So for the design of the solid-state switch, the GTO still has to be considered. However, they depend on the rating of power, which wants to install.

4. Power converter topologies

The selection of power converter and power semiconductors are necessary for finding the best converter topology. There are many converter topologies on the system. Different converter topologies offer different performance characteristic in terms of construction and control complexity, ability to handle higher powers, number of power semiconductors used, and harmonics. Converter topologies can be classified into two groups, namely, two level and multilevel voltage source converter (VSC) [9]. These two topologies are presented in the following subsections.

4.1 Two-level VSC

The two-level VSC is the most popular VSC. Fig.3 shows the scheme diagram of a three-phase two level VSC. From Fig.3, the output of each phase is connected to either the positive or negative terminals, which leads to a two-level PWM waveform. Six power semiconductor devices are required, each consisting of an IGCT and an anti-parallel connected diode. For high power applications, series and/or parallel combinations of IGCT devices become mandatory.

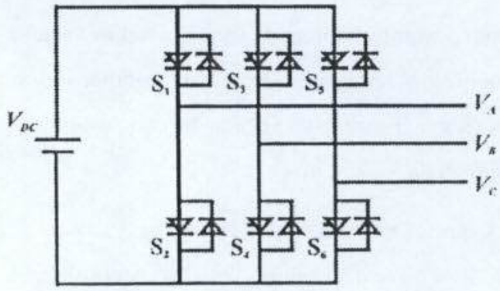
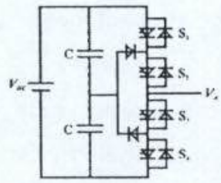


Fig. 3: Two-level voltage source converter.

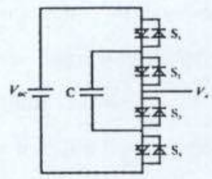
4.2 Multilevel VSC

The multilevel VSC provides significant advantages over the two-level VSC in terms of the spectral quality and device ratings. The multilevel VSC can be classified into 3 groups as follows:

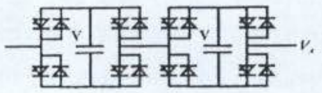
- Neutral Pole Converter (NPC), Fig.4a
- Flying Capacitor Converter (FCC), Fig.4b
- Cascade Converter (CCC), Fig.4c.



(a) NCC



(b) FCC



(c) CCC

Fig. 4: 3-level multilevel converter for custom power applications: only phase A.

The most popular used of the multilevel VSC is NPC because it is easy to generate the modulation signal compared to other types. The modulation signal scheme can be generated by many methods such as Multi-carrier Sine-triangle pulse width modulation , Space vector pulse width modulation, etc.

5. **Custom Power Technology**

The concept of custom power was firstly introduced by N.G. Hingorani. Similar to Flexible AC Transmission Systems (FACTS) for transmission systems, the term custom power pertains to the use of power electronics controllers of distribution system. "Custom power" thus refers to premium power "quality customized to meet the customers" needs. Further, the term "custom power technology" describes the equipment used for providing custom power [7].

Custom power technology is a general term for equipment capable of mitigating numerous power quality problems. Basic functions are fast switching and current/voltage injection for correcting anomalies in supply voltage or load current. Injecting or absorbing both active and reactive power is possible. There are two types of custom power: network reconfiguring and network compensating types. The network reconfiguration types include current limiting, current breaking and current transferring devices. This type of device includes Solid State Current Limiter (SSCL), Solid State Breaker (SSB) and Solid State Transfer Switch (SSTS). Compensating devices can either compensate load or improve the power quality by supplying voltage and current. These devices are either connected in shunt or in series or in a combination of both series and shunt. The types of devices includes Distribution static compensator (DSTATCOM), Dynamic voltage Restorer (DVR) and Unified Power Quality Conditioner (UPQC). Based on the above, there are six well-known custom power devices, namely, SSCL, SSB, SSTC, DSTATCOM, DVR and UPQC. These devices are explained in details in the following subsections.

5.1 **Solid State Current Limiter (SSCL)**

SSCL inserts a fault current limiting inductor if the fault is detected. A schematic diagram of SSCL is shown in Fig.5. From Fig. 5, the GTOs are in the on-state during normal condition. All of the current will flow through the GTOs. When the fault is occurred, the GTOs will be in the off-state. The fault current will then flow through limiting inductor (L_m) to limit the fault current.

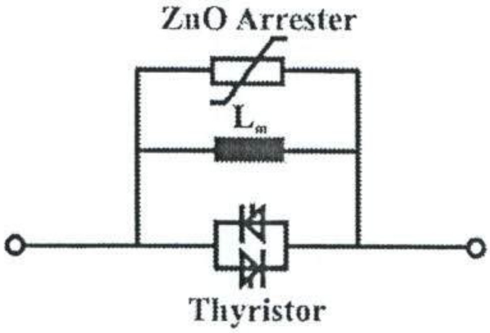


Fig. 5: GTO-based Series Reactor SSCL.

5.2 **Solid State Circuit Breaker (SSCB)**

SSCB can interrupt a fault current very rapidly and can also perform auto-reclosing function. It is based on a combination of GTOs and thyristor switches, so this makes the operating time of SSCB much faster than conventional device, which is based on mechanical counterpart. This device is therefore considered as an ideal device for custom power applications. Fig.6 shows a schematic diagram of a SSCB, which is constructed from a number of anti-parallel GTO modules. From Fig. 6, GTO elements are the normal current caring element in the normal condition. When the fault is occurred, GTOs are turned off and thyristors in SCR are turned on such that the fault current now starts flowing through the current limiting inductor.

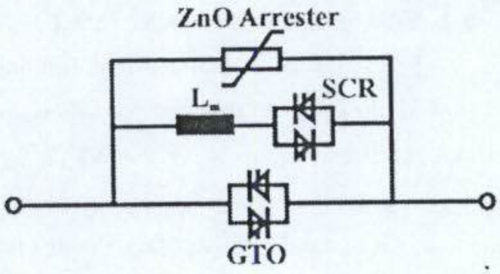


Fig. 6: Solid state circuit breaker.

5.3 Solid State Transfer Switch (SSTS)

SSTS is a thyristor-based device that is used to protect sensitive loads from voltage sag/swell. It can perform a sub-cycle transfer of the sensitive load from a supplying feeder to an alternate feeder when a voltage sag/swell is detected in the supplying feeder. An SSTS can also be connected as a bus coupler between two incoming feeders. Fig.7 shows a typical configuration for a SSTS application, in which the transferring of load between two separate sources is performed.

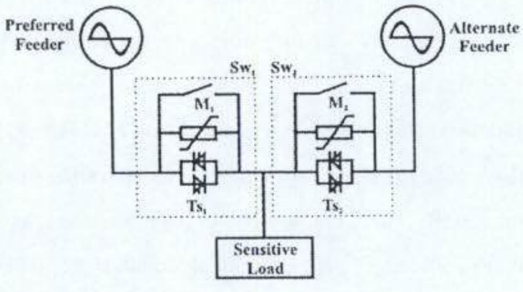


Fig. 7: Solid state transfer switch.

SSTS include the thyristors, the arrester and a pair of high-speed mechanical switches. During the normal operation, the mechanical switch M_1 is closed while M_2 is open. Once a power transfer is requested, M_1 is open and simultaneously the thyristor pair T_{S1} is turned on. Then, the current is commutated to T_{S1} and it is blocked at the next zero crossing. As soon as the current is completely blocked, the thyristor pair T_{S2} is turned on enabling the alternate feeder to supply the load. Once the current through T_{S2} is stabilized, the mechanical switch M_2 is closed to bypass the current. The thyristor pair T_{S2} is then blocked.

5.4 Distribution STATCOM (DSTATCOM)

DSTATCOM is a shunt-connected device that has the same structure as that of a STATCOM. It can perform load compensation i.e., power factor correction, harmonic filtering, load balancing etc., when connected at the load terminals. It can also perform voltage regulation when connected to a distribution bus. It can hold the bus voltage constant against any unbalance or distortion in the distribution system. Fig.8 shows schematic diagram of DSTACOM.

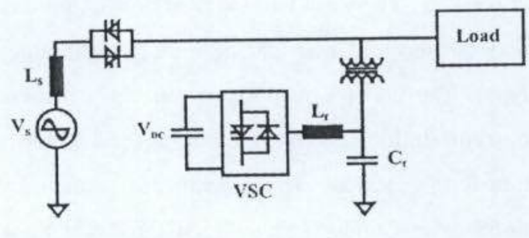


Fig. 8: The system configuration of DSTATCOM.

5.5 Dynamic Voltage Restorer (DVR)

DVR is a series-connected device that has the same structure as that of a Static Synchronous Series Compensators (SSSC). The main purpose of this device is to protect sensitive loads from voltage sag/swell, interruptions in the supply side, etc. This is accomplished by rapid series voltage injection to compensate for the drop/rise in the supply voltage. Since it is a series device, it can also be used as a series active filter. DVR may have to inject unbalanced voltage to maintain the voltage at the load terminal in case of an unbalanced sag in the supply side. Furthermore when there is a distortion in the source voltage, the DVR may also have to inject a distorted voltage to counteract the harmonic voltage.

Basic structure can be shown in Fig. 9.

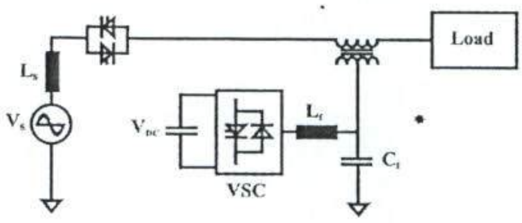


Fig. 9: The structure of DVR.

5.6 Unified Power Quality Conditioner (UPQC)

UPQC has the same structure as that of a Unified Power Flow Controller (UPFC). It is a versatile device that can inject current in shunt and voltage in series simultaneously in a dual control mode. Therefore it can perform both the functions of load compensation and voltage control at the same time. As in the case of DSTATCOM or DVR, the UPQC also inject unbalanced and distorted and current and hence its operating characteristics are different than of a UPFC. Fig. 10 shows the structure of UPQC.

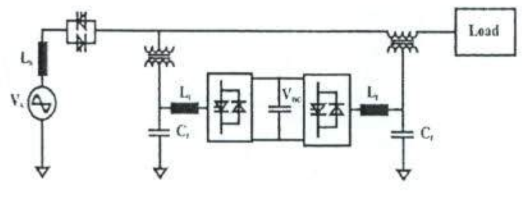


Fig. 10: The structure of UPQC.

6. Summary

This paper presents concepts and definitions of custom power and custom power devices as applied to power distribution system. The custom power devices are focused in developing technology option to allow utilities to improve overall distribution system reliability and performance. Custom power is expected to be an integral part of the future utility distribution system. Custom power devices integrate power electronic controllers, advanced communication protocols, and lightning research and development, which all together enable utilities to meet the needs and expectations of industrial and commercial customers of sensitive loads.

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