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A Review on Custom Power Devices for Voltage Quality Improvement

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Abstract- Power quality is a pressing concern and of the utmost importance for advanced and high-tech equipment in particular, whose performance relies heavily on the supply's quality. Power quality issues like voltage sags/swells, harmonics, interruptions, etc. are defined as any deviations in current, voltage, or frequency that result in end-use equipment damage or failure. Sensitive loads like medical equipment in hospitals and health clinics, schools, prisons, etc. malfunction for the outages and interruptions, thereby causing substantial economic losses. For enhancing power quality, custom power devices (CPDs) are recommended, among which the Dynamic Voltage Restorer (DVR) is considered as the best and cost-effective solution. DVR is a power electronic-based solution to mitigate and compensate voltage sags. This paper provides a thorough discussion and comprehensive review of DVR topologies based on operations, power converters and voltage quality issues.

Keywords- DVR, Power Quality, Voltage quality issues, DVR topologies etc.

I. INTRODUCTION

Over the past few years, the number of sensitive loads such as medical equipment in hospitals and health clinics, schools, prisons, etc. has quadrupled which makes the power quality of the sensitive loads a pressing concern. If the power quality is not high, there could be dire consequences like substantial economic losses, production losses, sensitive and critical loads outage and missing data [1].

This is why having high power quality is key to the customers, utilities, and also electrical devices producers. Voltage sags, voltage swells, transients, harmonics, fluctuations, flickers, and interruptions are the essential power quality issues. They will be all explained further in the following section. These power quality issues and voltage disturbances must be averted when it comes to sensitive and critical loads. To that end, a wide variety of solutions have been presented among which, power electronics-based devices known as Custom Power Devices (CPDs) are considered as the best and the most cost-effective solution for compensating and mitigating voltage disturbances [2,3].

Dynamic voltage restorer is a series connected device for mitigating voltage sag and swell. The first DVR was installed by the Westinghouse in 1996. Since, then a lot of installations have taken place world wide along with wide spread research in different aspects of DVR and control philosophies implement. DVR protects the precision manufacturing processes and sophisticate sensitive electronic equipments from the voltage fluctuations and power outages [4].

DVR offers subcycle Protection restores the quality of electric power delivered to the sensitive load. The DVR regulates voltage within acceptable tolerances and meet the critical sensitive power quality needs [5].

II. POWER QUALITY ISSUES

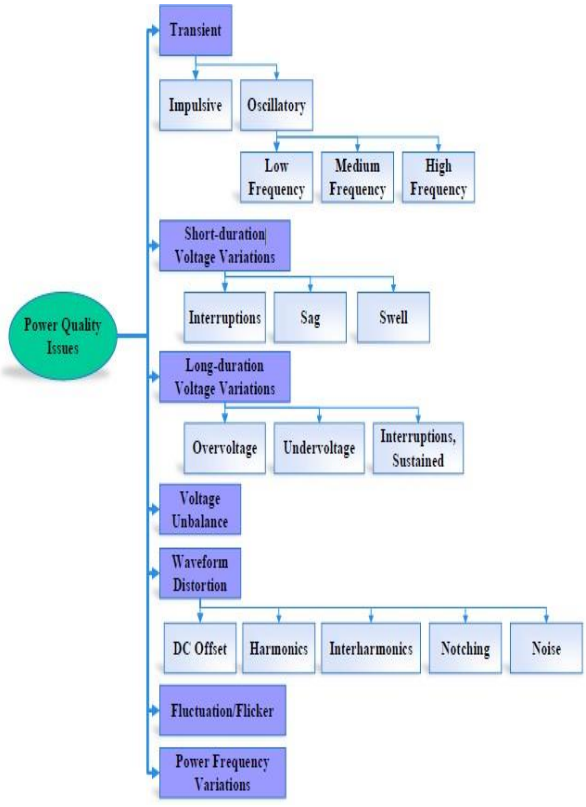

Fig 1. Classification of power quality issues.

Power quality issues can be rapid events such as voltage impulses, voltage transients, high-frequency noise, faults, voltage swells/sags, and total power loss. Thus, power quality issues have a direct effect on electrical equipment [6–8]. The disturbances that may cause power quality issues can be lightning and natural phenomena, energization of capacitor banks and transformers, start-up or switching of large loads like motors, operation of non- linear and unbalanced loads, or failure of equipment like transformers and cables.

The classification of power quality issues based on IEEE 519 standards is shown in Figure 1 [9].

The most critical power quality issues, their definitions, causes, and effects are provided in Table 1 below-

Table 1. Power quality issues and their definitions, causes, and effects.

Problem	Definition	Causes	Effects
Voltage sag/dip	A decrease in Root-Mean-Square (RMS) voltage	Faults, starting of large loads, grid loading, supplyvoltage variations, inrush current, inaccurate connection	Overloading or stalling of motors, lock-up, unreliable data
Voltage swell/rise	An increase in RMS voltage	Start/stop of heavy loads, supply voltage variation, inrush current, inaccurate connection	Data loss, damage to equipment, lock-up, unreliable data
Transient	An abrupt change in voltage, current or both	Snubber circuits, lightning, start/stop of heavy loads, inaccurate transformers connection	Disturbance in electrical equipment, data loss, the flickering of lights, damage of sensitive equipment
Harmonic	Integral multiples of the fundamental frequency, resulting in a distorted voltage or current waveform	Non-linear loads	Losses in electrical equipment, transformers and motors overheating, lock-up unreliable data
Voltage fluctuation/ flicker	Variations or random alteration in the voltage magnitude	Load switching, fluctuation of supplyvoltage	Over and under voltages,the flickering of lights, damage the equipment at the load-side
Power frequency variation	Deviations of the system frequency	Heavy load	Inefficiency in motors and sensitive devices, heating up, gradual breakdown
Voltage interruption	A decrease to less than 0.1pu in supply voltage or load current	Failure of protecting devices, insulation failure,control malfunction	Malfunction in data processing equipment

III. CUSTOM POWER DEVICES

Table 2. Custom Power Devices (Cpds) and Their Functions/Applications.

CPD	Functions/Applications
APF	Transient, harmonic distortion
DSTATCOM	Power factor, current harmonics, flicker, loadvoltage/current balancing
DVR	Voltage sags/swells, voltage regulation, flicker, voltagebalancing
IPFC	Reactive power flow control, transient, voltage control,damping oscillation
SSTS	Interruption, voltage sag/swell, power transferring fromdifferent feeder
SCL, SSCB	Fault current limitation, breaks the faulted circuit
STATCOM	Transient, voltage fluctuation/flicker, dampingoscillation
SSSC	Current control, fault current limitation, active/reactivepower flow control
SVC	Flicker, unsymmetrical loads
TVSS	Voltage transient
UPFC	Voltage control, active/reactive power flow control,transient, fault current limitation
UPQC	Voltage sags/swells, fluctuations, harmonic, voltage/current balancing, power factor, current loadharmonic
UPS	Emergency power shortage

Storage units are used for critical equipment protection against interruption, leading to voltage sags. Uninterruptible Power Supply (UPS), Superconducting Magnetic Energy Storage (SMES), Ultra-capacitors (UCAP), Flywheel Energy Storage System (FESS), and Batteries are some examples of storage systems. These are used to compensate for the energy that is needed because of faults and voltage sags. Among the many different methods of mitigating voltage sags/swells, custom power devices (CPDs) are the most efficient method. Just as Flexible AC Transmission Systems (FACTS) can improve the power quality and stability of the modern power system, CPDs make sure customers receive high quality and reliability of supply [10,11]. The most essential CPDs are provided below.

IV. DYNAMIC VOLTAGE RESTORER

Sensitive loads are increasing day by day in the distribution system, so it is a dire need to enhance the power quality. These sensitive loads can be protected against voltage disturbances with DVR. DVR is a solid-state power electronic switching device connected in series which injects a voltage tothe load then line voltage to the sensitive loads is restored dueto voltage sag [12].
Fig. 2 shows the conventional DVR which consists of a Voltage Source Inverter, Filter, Voltage Injection Transformer, and Energy Storage Unit [13].

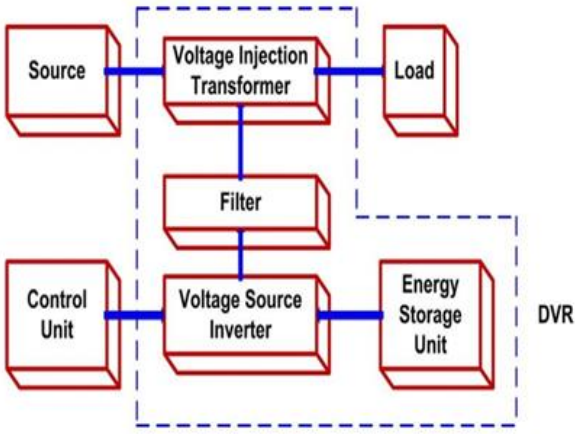

Fig 2. Conventional DVR.

1. Components of DVR:
As can be seen in Figure 2, a typical DVR, in general, includes injection transformers, VSI, energy storage unit, passive filters and control unit.

2. Energy Storage Unit and DC-Link:
The energy storage device and DC-link provide the real power and the required energy of DVR in throughout the compensation stage. This energy storage unit is applied by either AC/DC rectifiers (topology without energy) [14] or rechargeable storage systems (topology with energy storage) [15].

3. Series Booster/Injection Transformer:
The injection transformers are used to link the DVR to the grid through High Voltage (HV) windings, transforms and couples the injected voltages generated by the VSI to the supply voltage, and isolating the load from the grid [16].

4. Voltage Source Inverter:
The VSI is used in the DVR to convert the DC voltage (energy storage or DC-link) to the desired voltage at any required magnitude, frequency, and phase angle. That way, the load voltage is kept balanced.

5. Harmonic Filter Unit:
As the output of the inverter contains high-frequency Switching harmonics as a result of using high-frequency switching strategies, a low-pass harmonic filter is used to remove or keep these harmonic contents within the acceptable level [17]. These filters can be applied eitheron the Low Voltage LV (inverter) or the High Voltage HV (load) side of the injection transformer [18].

6. DVR: System Topologies:
Depending on energy storage, or the lack thereof, there are two topologies of the DVR. Figure 3 shows the categorization of the DVR that has or lackenergy storage [19,20].

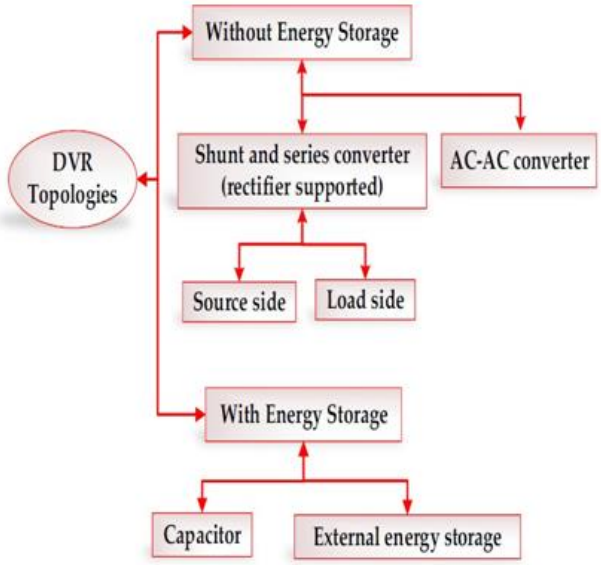

Fig 3. DVR topologies from the energy storage perspective.

V. CONCLUSION

Voltage sag is a commonly occurring power quality problem in the electrical power distribution network and resulting in power loss, equipment failure, and financial loss. So the simple, effective, and cheapest device for compensation of the small and large value of voltage sag to improve the voltage profile in the distribution network

is the DVR, which is a custom power device as compared to other devices for voltage sag compensation.

In this paper, a comprehensive review of various types of DVR systems, and its practical difficulties and future scope for research trends are presented. Studies that have reviewed the DVR are many, but different power quality issues along with the DVR components, the DVR topologies based on energy storage, or the lack thereof are discussed in this paper.

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