Comprehensive Review of Various Custom Power Devices for Power-Quality Enhancement in Multi-Feeder Distribution Systems

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Abstract:

At present, increasing the industries and/or domestic load demands leads to poor power-quality standards. Severe technical & economic impacts are experienced due to voltage and current imperfections at common-point of distribution systems. A new custom-power technology is introduced which embraces the group of devices provides the enhanced power-quality features. The custom power devices are highly offered by utilizing power-electronic converters. Over the various custom power devices, the highly recognized universal device is Unified Power Flow Controller, but is un-suitable for multi-feeders distribution system. In this work, the multi-feeder compensation devices has been studied and presented for enhancing the power-quality features occurred in single and/or multi-feeders. Thus, the multi-feeder power-quality enhancement devices satisfy the unique performance over the single-feeder compensation devices. The multi-feeder PQ compensators furnishes the superior enhanced all PQ features in power distribution systems.

Keywords: Custom-Power Devices, Multi-Feeder Distribution Systems, Multi-Feeder Compensation Devices, Power-Quality Enhancement, Universal Controllers.

I. INTRODUCTION

In general, power quality features are acquired by contrasting in between the quality nature of provided power supply and consumed demanded power for attaining reliable operating characteristics of various load appliances. In previous chapter-3 reviews the various power-quality issues and power-quality standards are clearly presented, for attaining enhanced quality features; a power quality mitigation device is pre-requisite. The optimal selection of power-quality mitigation device is greatly dependent by PQ concerns for achieving greater flexibility and reliability. Novel contemporary mitigation schemes are engaged by power semi-conductor technology often exhibited when instantaneous response is necessitated for counteracting the disturbances and deviations [1]-[3].

In this view, two aspects are well defined to mitigate PQ related issues such as load-conditioning scheme and by placing line-conditioners. As per regulations, conventional solutions are well supervised for steady-state analysis. The primary mitigation technique is load-conditioning scheme, it is clinched by process apparatus which have very sensitive on disturbances and should be it allowable rides, but it is more flexible for low-power distribution system. The secondary scheme provides line-conditioners for mitigating PQ issues, which counteracts the disturbances and deviations in a power system network [4]. The attractive mitigation schemes may vary in size, structure; it can be placed under any voltage ratings (high/medium/low) of a power-system network. The custom-power apparatus plays a vital role in both single feeder and/or multi-feeder power system networks, mainly comprises of power semi-conductor technology to provide PQ compensation, reliable operation, DG integration and also valuable add-on to consumers [5].

The word “Custom-Power” is commonly employed to define the advanced mitigation techniques, that can be administer to utility system for enhancing the power-quality terms in end-user level consumers [6]. The custom power is acquired by employing the static controllers and/or power-electronic controllers in medium-voltage distribution systems for the occasion of furnishing the greater level of PQ reliability required by power consumers, these consumers are highly sensitive to PQ disturbances. The custom power controllers incorporate, static switches, converters, inverters, injected transformers, control schemes and battery energy storage elements, that have more ability to accomplish the functions of voltage regulation and/or current interruptions in a multi-feeder power distribution system to enhance the power-quality and reliability.

II. CUSTOM-POWER COMPENSATION TECHNOLOGY

Custom power technology embraces a group of devices, which cooperatively develop a toolbox for furnishing the PQ enhancement features at single and/or multi-feeder distribution systems. Utilizing the power semi-conductor technology in power distribution system is to control the power system dynamics as custom-power solution [7]. This technology is categorized as two ways such as network reconfiguration scheme and/or compensation scheme as depicted in Table.1. The attractive network re-configurable schemes are greatly utilized for current breaking, current limiting and current transforming apparatus like Static Transfer Switches (STS’s). The imperative compensation apparatus either compensate the loads i.e., mitigate the harmonics, correct the power-factor, load balancing, etc., and/or enhance the quality of the supplying voltage. These apparatus are either integrated as shunt and/or series as individual or its combination, these apparatus includes;

- Static Transfer Switches (STS’s)
- Active Power Filters (APF’s)
- Distributed Static Compensation Scheme (DSTATCOM)
- Dynamic Voltage Restoring Devices (DVR)
- Unified Power-quality Conditioner (UPQC)

For basic load devices, feasible choice of unique compensation devices is relatively forthright. Although, all constraints of the large sized power distribution system with many load apparatus must be carefully with pre-requisite of diverse sensitive load devices [8]-[14].

Considering the probable interaction is sustained in between the compensation devices, integrated load apparatus and power distribution systems (single and/or multi-feeder)

Table.1 Type of Custom Power Techniques

Custom Power Devices	Types of Devices	Compensation Task
Network Re-Configurable	Static Transfer Switch	Against Voltage Sag-Swell, Voltage Interruptions.
Compensation Type	Active Power Filter Distributed STATCOM, Dynamic Voltage Restorer Unified Power-Quality Conditioner	Harmonic elimination, Power-factor correction, Reactive power control, Voltage Sag-Swell mitigation, Voltage regulation, Compensates all voltage-current related PQ issues.

2.1. STATIC TRANSFER-SWITCH (STS)

The Static Transfer Switch (STS) plays a vital role to secure the sensitive load devices over the voltage sag, voltage swells and other power disturbances. This STS assures the continuous function of greater power-supply quality to sensitive loads by transforming, within the range of milliseconds, the load apparatus from a faulted feeder to a healthy feeder. The STS comprises of two and/or more switching elements that enables the transforming a load apparatus from a one feeder to another feeder as depicted in Fig.1. The STS is integrated into feeder as bus-tie arrangement when a sensitive load device is powered by two adjacent feeders. It safe-guard the load apparatus from sag and/or swell by rapidly transforming as faulty feeder to the healthy feeder as well as current travels to load through SW1 switch. In crucial situation, a deep voltage interruption and/or sag are recognized in own feeder, switch SW1 is conducted and other switch SW2 is non-conducted.

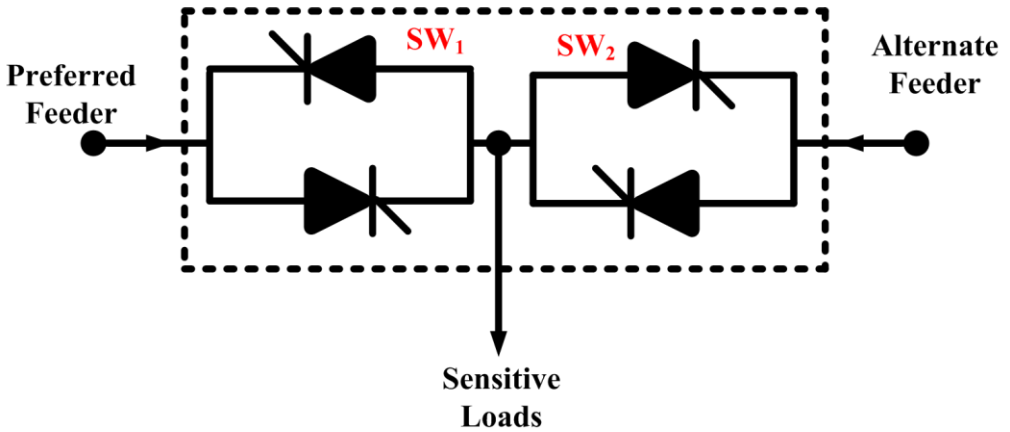

Fig.1 Basic Diagram of a STS

The switches in STS have been controlled by mechanically and transforming loads apparatus to adjacent feeder and/or back-power supply generation to counteract voltage interruptions on preferred feeder.

The seamless transferring is not acquired due to the presence of electro-mechanical switching elements, generally switches are transferred respect to transfer time ranges about 100 milli-seconds to nearly 10 seconds. On the occasion of voltage interruptions/disturbances, the effective STS device is automatically transfers the load apparatus from present source to a substituted healthy source system or adjacent feeder system in multi-feeder power system. This is the very attractive way for mitigating issues related to both voltage sags and voltage interruptions by limiting the time-range as furnished by load apparatus.

The affluence of STS device is mainly on performance levels and low cost over the other compensated solutions. The secondary injection is pre-requisite and independent from main source, this solution is attractively for provision of mechanical transferring switches, upgrade to a static switching doesn't requires high changes in power-distribution system. The control scheme is the most fabulous part of the STS device and has several reflections of control function in a STS which includes, issues related to sag identification, gating devices, transforming strategy. The main contribution to thrysitor switches in STS makes the possibility of firing control without any delays at current-zero instants and inhibits the instantaneous fault detection transfer of down-level faults. Thus, the STS device must fulfill the followed requirements as per IEEE standards as summarized as below;

- As possible as it must identify the voltage interruptions and fluctuations rapidly in intended power system network.
- In any abnormal situation the operating source fails, it must accomplish the rapid load changing to substituted source.
- Avoid the parallel processing of dual sources under the transferring to control the present system by effective gating sequence.
- Identification & transforming the control functions properly for acquired operating sequences.
- The voltage identification scheme must be in-sensitive to temporary voltage interruptions like sudden switching of capacitors.

2.2 ACTIVE POWER FILTER (APF)

At present the usage of power-electronic converter was increased in many industries and domestic applications which causes the serious harmonic injection into power grid, increases the reactive power requirement. Existence of odd harmonics and reactive power requirement is too dangerous may create the additional heat losses and mis-operation of grid elements. Traditionally, passive filters are broadly used for minimization of harmonics because of high efficiency and low initial cost; it consists of auto-tuned passive LC elements integrated as either shunt and/or series. Although, it has many disadvantages like mis-tuning, resonance issues with source impedance and load, instable performance, large-sized, etc. Due to the inadequate performance of passive LC-filters administers to retrieve the novel solutions for harmonic minimization by using Active Power Filter (APF).

The APF's are also integrated either series and/or parallel to the network feeder/line, several types of APF's are implemented to solve PQ issues by utilizing PWM inverters with DC-link capacitor source.

These APF's are becoming a substitute of possible solution for regulating current harmonics in low to medium range power distribution levels and controlling reactive power at high range distribution networks. At present, APF's not only attains harmonic minimization but also mitigate the several PQ concerns like reactive power control, load-balancing, voltage flicker and fluctuations. Active filters is developed either as shunt or series, it's both combined as hybrid APF for increasing the reliability of network due to compensation of all PQ issues.

In real-time applications, shunt type APF's are highly encouraged and preferred for eradicating current harmonics coming from non-linear loads, controlling the reactive current flow. The block diagram representation of shunt APF is depicted in Fig.2. The key operating principle of shunt connected APF is first identifying the harmonics by using harmonic analyzers from the distorted current components supplied from non-linear loads and injects the reverse harmonized currents components to power distribution system to counteract the harmonic currents from supply current components. Shunt APF can also acquires the load balancing, reactive power control, voltage regulation, flicker minimization effected by non-linear load devices.

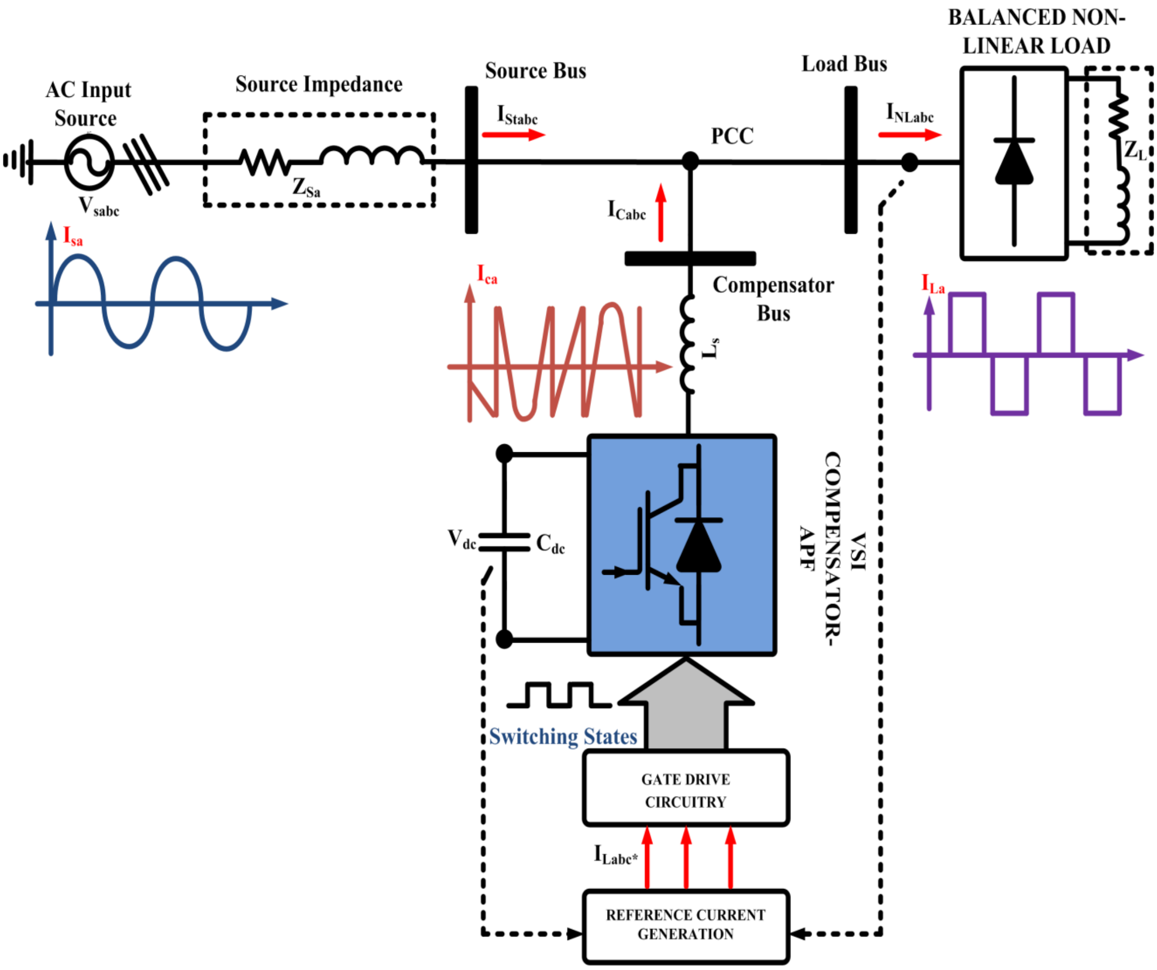

Fig.2 Block Diagram Representation of Shunt APF

Generally APFs are utilized in low power range (<0.1MVA), medium power range (0.1MVA-10MVA) and high power range (>10 MVA) power system networks. For low-power range applications, these power filters can be employed in three-phase and single-phase supply systems. In single-phase supply systems, APF is generally accepted for harmonic elimination and in three-phase supply systems; APF is generally attractive solution for compensating current harmonics and un-balanced load currents. For medium power range applications, the main intension is to minimize or eliminate the current related harmonics and based on various economic aspects, reactive-power mitigation by using APFs at high power distribution system is regarded as non-viable. For high power range applications, harmonic pollution doesn't create any major issues as in low power range distribution systems. The another solution in high power range distribution systems is installing several APFs as parallel combinations due to coordination and control requirements are so complicated.

The high range commercial and domestic appliances such as shopping malls, hospitals, etc., are normally sourced from three-phase 4-wire system due to third order harmonized currents of individual single-phase NL-loads and un-balanced loading is occurred and flows the high zero-sequence neutral current is produced in neutral conductor. Generally, third sequence harmonized sequences cannot counteracted by three-phase 3-wire APF, so as to furnish better solution for compensating aforementioned issues by using three-phase 4-wire APF are widely used over the split-phase APF. Normally three-phase loads are developed from balanced circuitry and third order harmonized sequences are encountered rarely that depends on industrial appliances, thus three-phase 3-wire APFs are typically used in many industries.

The APF comprises of two divisions, such as power circuitry and control circuitry. The power module of APF is comprised as combination of various sub-modules such as DC-AC inverter, energy storage device, line interfacing filter and protection units, etc. Control module of APF is consisted of current/voltage sensors and measurements, reference current generators, capacitor voltage-balance circuit, gate-drive circuitry, etc. The DC-link capacitor in APF serves dual purposes such as, it sustains DC-link voltage with low ripple content under steady-state response, and it acts as energy storage component to exchange real power difference in between the source and load during the sudden transient instants. The value of DC-link voltage should be greater than peak-to-peak value of source voltage, it can be sustain the DC-link voltage as constant and controlled by using PI controller. The VSI plays a vital role in APF and integrated to network or line/feeder by using interfacing filters as current smoothen LC units to minimize the harmonic quantities at different frequencies. The association of various LC filters is attenuated for switching the ripple currents, elimination of harmonics at diverse frequency values, reactive power mitigation, etc.

Harmonic extraction schemes have incredible role in active compensation schemes so as to attain imperative harmonic compensation, the generation of reference currents must be measured accurately and precisely. Various types of harmonic extraction schemes are developed by several researchers, these schemes can be categorized as time-domain & frequency-domain methods and the most prominent harmonic extraction schemes are illustrated in Table.2.

Table.2 Harmonic Extraction Schemes

Harmonic Extraction Schemes	
Time Domain Schemes	**Frequency Domain Schemes**
Real & Reactive (PQ) theory	Discrete Fourier Transform (DFT) Analysis
Synchronous Reference Frame (SRF) Theory	Fast Fourier Transform (FFT) Analysis
Band-Pass Filtering Methods	Recursive Discrete Fourier Transform (RDFT) Analysis
Adaptive Filter Circuit	Wavelet Transform (WT) Analysis
Neural Networks	Kalman Filter (KF) units

2.3. DYNAMIC VOLTAGE RESTORER (DVR)

Dynamic Voltage Restorer (DVR) also named as Static Synchronous Series Compensator or Series Interfaced APF, mitigates the voltage-related issues like voltage sag-swell, voltage interruptions, and voltage harmonics, etc., in any power system network (both single and multi-feeder systems). It sustains the load-voltage as constant at a defined magnitude and phase quantities attained at PCC point. So as to compensate voltage related issues, DVR administers the respective voltage with a suitable phase and magnitude in series with the network/line as depicted in Fig.3. Generally, DVR neither delivers nor absorbs active power in stand-by mode. Whenever voltage sag and/or voltage swell happens in the network, DVR provides active power to affected network as delivering/absorbing predominantly to/from battery energy source or DC-link source. Different loads assisted in industries such as process-control, variable speed drives, these appliances are capable to sense faults as low as s few seconds and DVR is responded rapidly based on loads sensitivity.

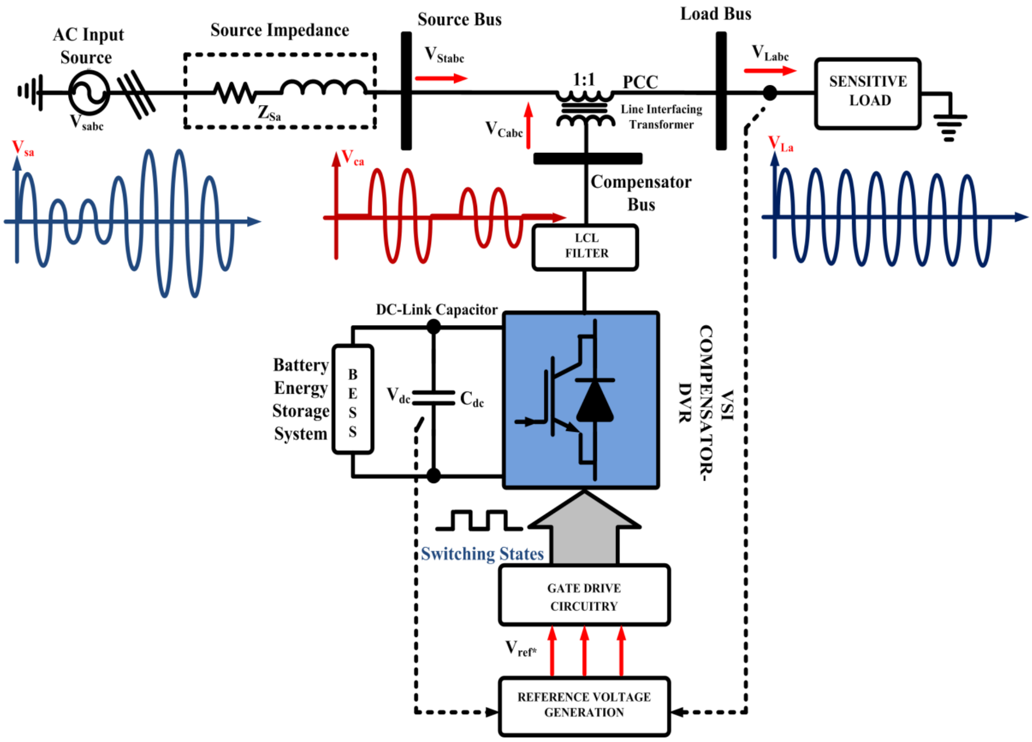

Fig.3 Block Diagram of DVR

Typically, DVR can be opted for low and/or medium voltage ranges, as well as it is developed as 3-phase 3-wire and 4-wire systems and single phase systems, the available DVR topologies are with transformer, transformer-less, H-bridge DVR, four-leg DVR, multi-level DVR. As usual, the DVR power-circuitry comprised of DC-AC inverter, DC-link/battery energy source, LC filter units and injection transformer. During voltage sag-swell and/or voltage harmonics, DVR provides required load power to PCC/load for optimal compensation through DC-link battery energy storage system based conditioner, which sustains the load-voltage as constant. The optimal selection and ratings of DVR topology is totally related with distribution level voltage, investment cost, outage cost, etc.

The DC-AC inverters is the heart of the DVR, among VSI plays a vital role and converts the DC energy to AC energy and injects required load voltage by using line-interfacing transformers and filter units. This filter unit minimizes the dominant harmonized sequences generated by VSI for getting RMS quantity of voltage wave-shape and it consists of inductor-capacitor (LC) elements. By using inverter side filtering scheme, it is more advantageous because being nearer to harmonic values thus higher order harmonized values are intercepted. Whenever, the DVR is operated under stand-by mode, the line-interfacing transformer acts as short-circuited secondary transformer by utilizing auxiliary IGBT switches for furnishing utility energy immediately to PCC/load apparatus. Coming to control schemes of DVR includes, voltage sag-swell detectors, reference voltage generation for required injected voltage, voltage-injection schemes and switching pattern scheme, etc. generally used voltage-sag/swell detectors are Kalman filtering, Neural networks, Fourier and Wavelet transform analysis, etc. The reference voltage generation schemes are SRF theory, Instantaneous PQ theory, Artificial intelligent techniques, Sliding-mode control technique, etc. The reference voltage signals helps to furnish the optimal switching states of the VSI, to obtain sag-swell mitigation, several PWM switching schemes are Sinusoidal PWM technique, Space-vector PWM scheme, hysteresis and dead-beat controllers, etc. Over the hysteresis methodology, PWM have very high impact on higher capability of operating frequency and transients characteristics, it is widely used switching pattern scheme in custom-power technology. Thus, space-vector PWM can produce outcome currents and/or voltages with low harmonic content response over the deadbeat control technique. The load characteristics determines the sag-swell compensation methodology, the DVR should assures the un-changed load-voltage injection with minimum energy-loss. Several methods for voltage-injection at PCC/load can be categorized into four-types, such as;

- Pre-sag Compensation Method
- In-phase Injection Method,
- Phase-advancing Method
- Voltage-Tolerance Method (under minimum energy injection)

In Pre-sag compensation, the source voltage is tracked continuously and the pre-requisite voltage at PCC/load is compensated. Coming to, In-phase compensation, the injected DVR voltage is consistently in-phase with the calculated actual source voltage despite of pre-sag voltage and load current. On other side, phase-advancing method provides the injected DVR voltage by diminishing the phase-angle in between the load-current and voltage which reduces the real-acquired by DVR.

Finally, the voltage tolerance method operated as minimum energy injected principle, provides the sag-swell compensation by regulating the magnitude and phase angle of load voltage within the range of changed voltage, it is tolerated by phase-angle jump and voltage drop which limits the size of energy storage elements and reduces the cost, etc.

2.4 UNIFIED POWER-QUALITY CONDITIONER (UPQC)

The Unified Power-Quality Conditioner or UPQC is a universal custom power device to mitigate both voltage and/or current related issues by utilizing dual conditioners via common DC-link, which furnishes the active-power sharing. The UPQC comprises of combined operation of both series/shunt active power filters operated in voltage/current controlled modes. The active series compensator mitigates the voltage related issues like voltage sag-swell, voltage harmonics, voltage flicker, unbalanced voltages and active shunt compensator mitigates the current-related issues like current harmonics, reactive current, unbalanced currents, etc., as depicted in Fig.4. Generally, UPQC is merely used in low-voltage medium-power range power distribution systems; it is normally developed as three-phase 3-wire and 4-wire system, where 4th wire used for providing neutral of line-interfacing transformer. The UPQC device can be distinguished into two parts, one is power circuitry and another is control circuitry.

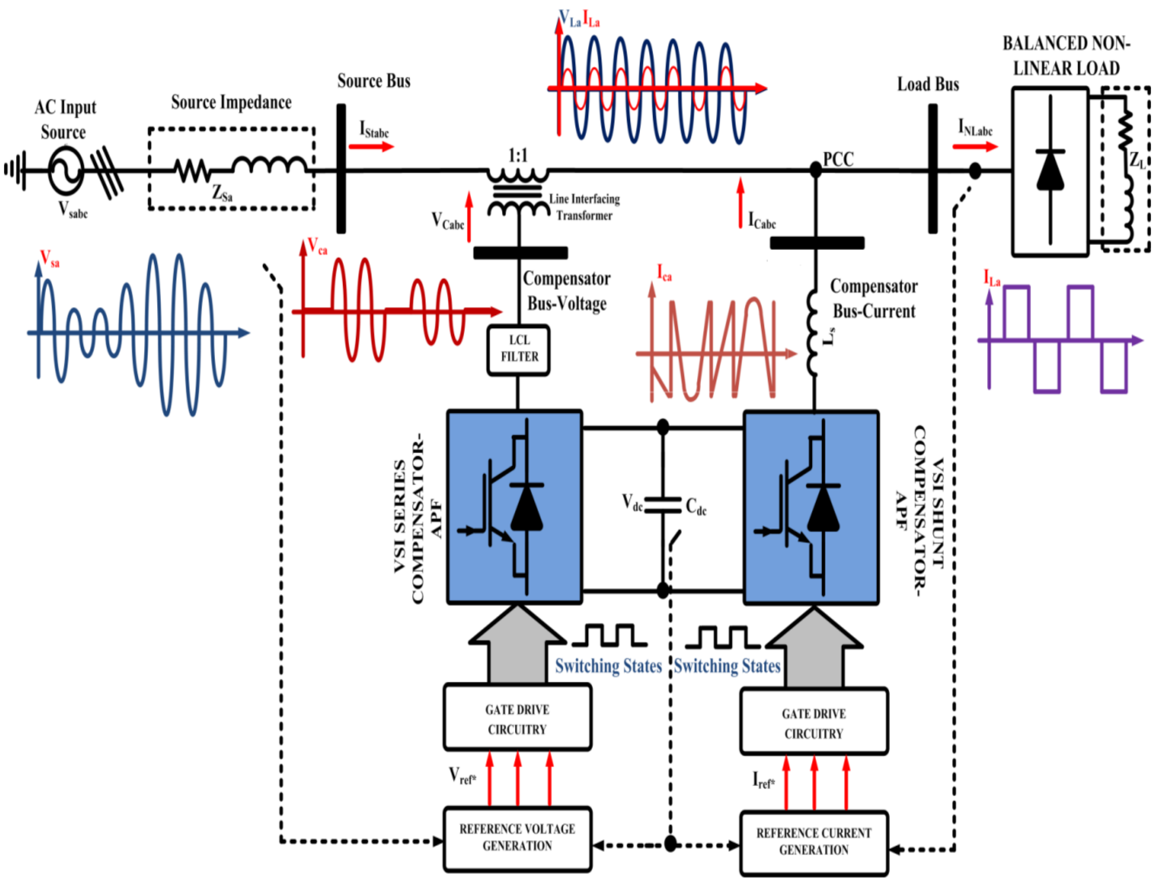

Fig.4 Block Diagram of UPQC

The power-circuit of UPQC consists of dual Voltage-Source Inverters (VSIs), system protection schemes, DC-link capacitors, line-interfacing transformers, harmonized LC filter units. The both shunt and series VSI's are designed by using IGBT switches which is operated and separated by common DC-link capacitor and requires 6 IGBT switches formed as H-bridge shaped modules separated by DC-link.

The energy storage DC-link capacitor provides pre-requisite energy for compensation of current harmonics and voltage sag-swell issues, etc. The influence of harmonic injection provided by shunt-VSI can be reduced as line-side or inverter side filtering through LC filter units; these LCL filters are also highly preferred in series compensator for filtering the higher-order harmonics, ripples, etc.

The another important part in UPQC is control unit, which includes disturbance sensing elements, reference current/voltage signal generation modules, switching pattern selection schemes or gate drive generators, current/voltage measuring devices, etc. The prime essentials of control unit for attractive compensation principles are, high-speed detection of distorted signal at greater accuracy point, rapid processing of reference voltage or current signals, high transients mode control operations are the most important tasks in control objective of UPQC device. Several voltage detection schemes for series VSI is Synchronous Reference Frame (D-Q) scheme, RMS method, FFT method, Wavelet transform analysis, Peak Sequence Analysis (PSA) scheme, Intelligent methods like ANN, Fuzzy, ANFIS methods, Kalman filtering, etc. Several current detection schemes for shunt-VSI is Least-Mean Square analysis, SRF theory, P-Q theory, Positive-Sequence Component theory, Artificial Intelligence, Kalman Filtering, Adaptive Filtering schemes, etc., are highly employed to generated reference voltage-current signals for both series and shunt VSI devices of UPQC. These reference signal generators provide reference voltage-current signals, which are compared to actual signals for finding the optimal switching states to both shunt and series VSI modules by using switching pattern selection schemes such as, Hysteresis Current Controller (HCC), Sinusoidal Pulse-Width Modulation (SPWM) schemes and Space-Vector Pulse-Width Modulation (SV-PWM) schemes, etc., are generally utilized.

III. MULTI-FEEDER COMPENSATION SCHEMES

In present situation, various solutions based on FACTS devices has appeared in power distribution systems resulting as new production of active compensation apparatus. A Unified Power-Quality Conditioner (UPQC) is supplement device of Unified Power-Flow Controller (UPFC) in power distribution systems. It comprises of combined operation of both shunt/series VSI's for synchronic compensation of current/voltage related imperfections on particular feeder of power distribution systems. The shunt and series compensators like APFs, DSTATCOMs, DVRs and UPQCs are generally suitable for single feeder based power distribution systems; these are unable to compensate the PQ imperfections in adjacent feeders of distribution system [15].

In recent developments, the concept of multi-converter based multi-feeder FACTS controllers furnishes the optimal compensation features in multi-feeder distribution systems such as Inter-line Power-Flow Controller (IPFC), Interline Dynamic Voltage Restorer (IDVR), Generalized Unified PF Conditioner (GUPFC), Interline Unified PQ Conditioner (IUPQC) and Interline Voltage Conditioner (IVOLCON), etc. These Interline Custom Power (ICP) devices can be interfaced between two adjacent feeders to compensate power-quality issues in main and adjacent feeders, load-current sharing; can improve the transient stability under sudden disturbances, etc [16]-[18].

It consists of two VSIs are integrated back-to-back via common DC-link capacitor to two adjacent feeders and can be of shunt-shunt, shunt-series and series-shunt combinations. The main merit of multi-feeder FACTS device is that they provide PQ enhancement features in single feeder and other neighboring feeder provides energy for mitigating PQ issues. Thus, the multi-feeder PQ compensation devices ensure the superior performance over the single-feeder FACTS devices.

3.1 INTERLINE DYNAMIC VOLTAGE RESTORER (IDVR)

The Interline Custom-Power (ICP) device was first introduced by in the year of 2004, it is known as Interline Dynamic Voltage Restorer (IDVR). It consists of dual DVRs integrated to distinct feeders in power distribution system and these dual DVR’s are supplied from a common DC-link source. The operating principle of IDVR is compensates voltage related issues in main and adjacent feeders, one of the IDVR device compensates voltage-sag, swells while other device sustains the DC-link voltage as constant to a defined level by absorbing active power from the AC source of adjacent feeder.

The block diagram representation of Interline-Dynamic Voltage Restorer device is depicted in Fig.5. In IDVR device, the dual series VSI’s acted as compensators, which are integrated to two adjacent distribution feeders as series formation with the help of line-interfacing transformer and supplied from a common DC-link source. These distribution feeders may be of equal and/or un-equal voltage ratings and it have superior merits when the consumer loads are routinely fed from two definite feeders. When one of the DVR in IDVR device may compensate the voltage sag issues by exchanging active power through DC-link point. And the, other DVR in IDVR device operated in power-flow control region to restore the DC-link energy to sustain the DC-link voltage as constant at a specified range. The respective energy is exhausted due to active power carrying from DVR operating in voltage sag-swell compensation mode. The IDVR device furnishes a path to transfer active power in between the highly sensitive loads in individual feeder via common DC-link source of IDVRs.

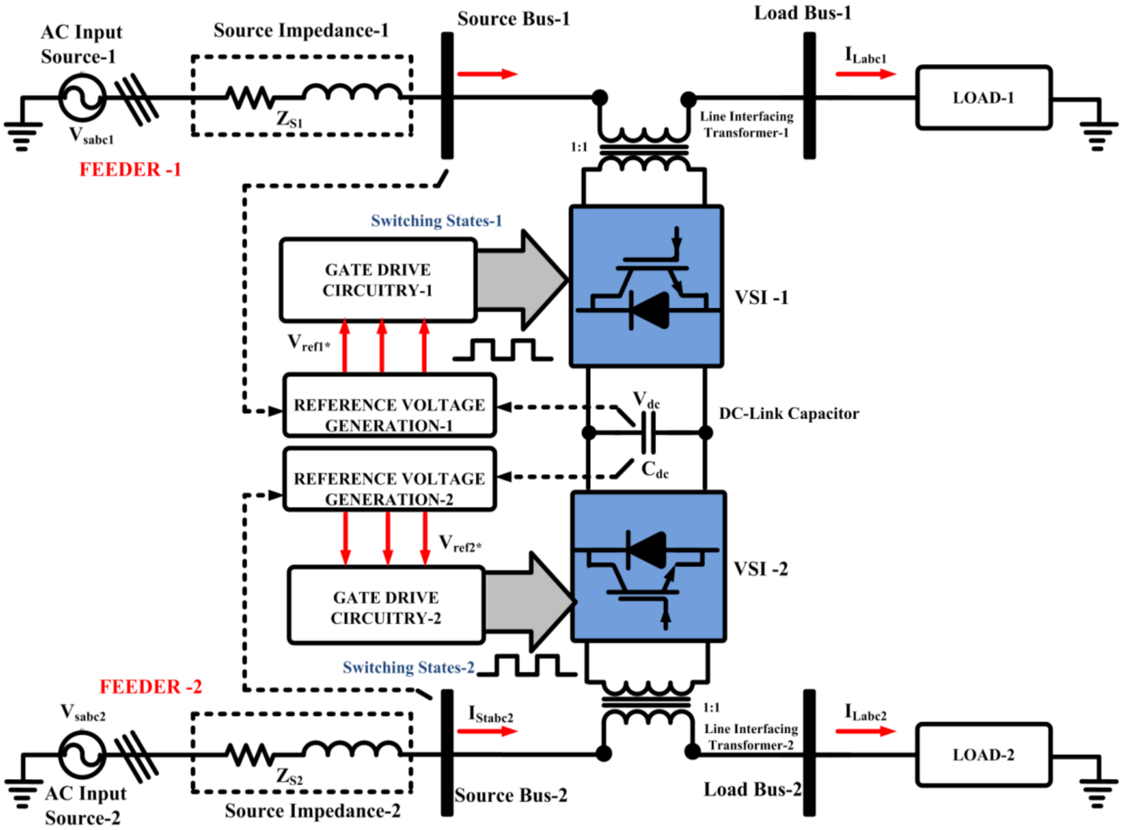

Fig.5. Block Diagram of IDVR Device

3.2 INTERLINE VOLTAGE CONTROLLER (IVOLCON)

The Interline Voltage Controller (IVOLCON) device is adopted from the idea of IDVR compensator with some additional components operated in multi-feeder power distribution system. The IVOLCON comprised of dual shunt VSIs, which is combined via common DC-link source and integrated to various distribution feeders, the block diagram representation of IVOLCON device is depicted in Fig.6.

The main intension of IVOLCON device is to regulate the PCC voltages in dual feeders to pre-defined amplitudes with a common assistance by furnishing the bi-directional power-flow via DC-link capacitor. The phase-angle of PCC feeder voltages are attained, such that the voltages at common DC-link capacitor remain constant, supplying the many loads such as non-linear loads and unbalanced loads by dual feeder power distribution system. The IVOLCON was determined; it can absorb power one feeder to another feeder to sustain the PCC voltage as constant in case of voltage-related issues line voltage sag, voltage-swell, etc. This can be attained by providing power from feeder-1 to other loads via common DC-link source to achieve the load condition. The behaviour of IVOLCON can be evaluated under several conditions like voltage sag-swells in own and/or adjacent feeders, sudden load change or entire loss of another feeder, etc.

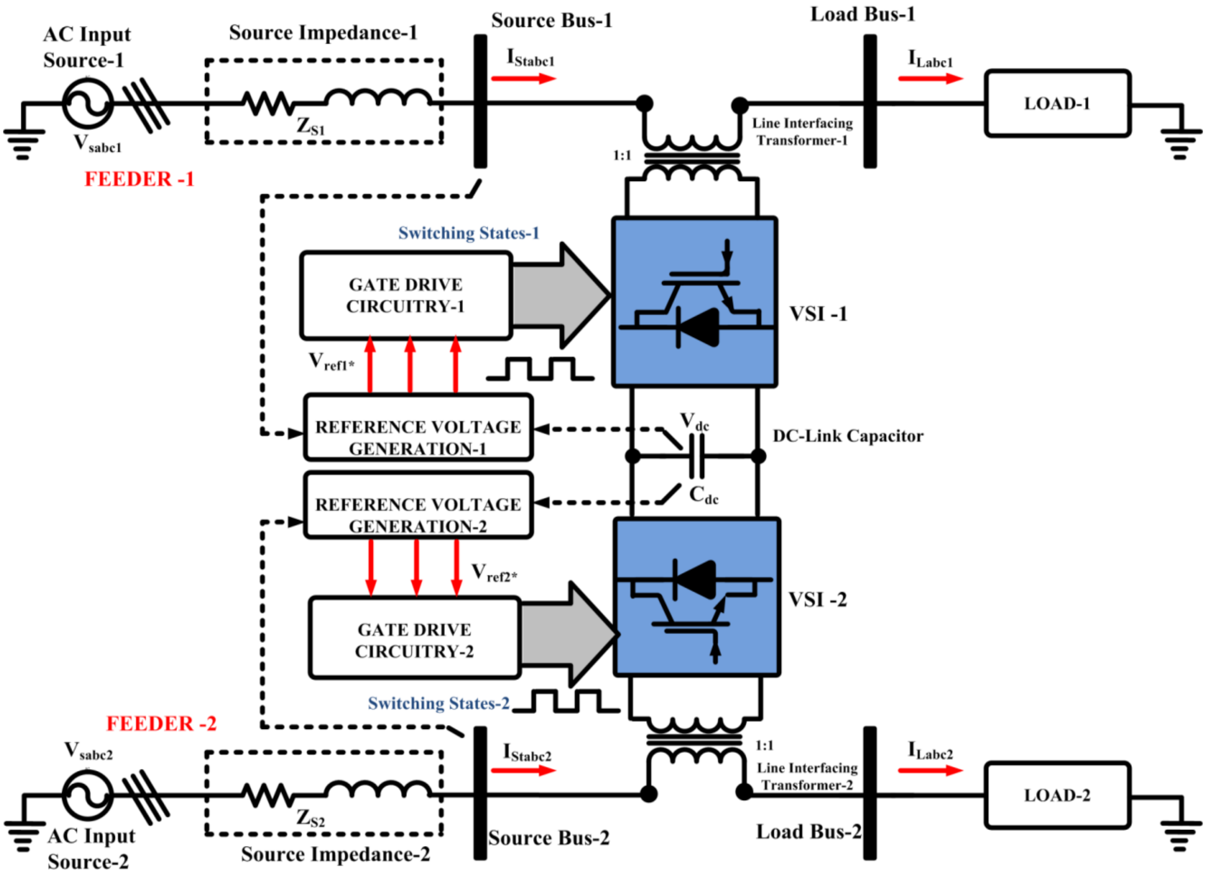

Fig.6. Block Diagram of IVOLCON Device

3.3 INTERLINE UNIFIED POWER-QUALITY CONDITIONER (IUPQC)

The succeeding idea of IVOLCON and IDVR devices, a novel concept was identified, named as Interline Unified Power-Quality Conditioner (IUPQC) which is the supplement of IPFC device in power distribution system. This device can also be contemplated as the development of UPQC structure in two definite feeders. In traditional UPQC device existing dual VSI topologies, one of them is interfaced in shunt and other is series to a single line/feeder. In this IUPQC device, dual independent feeders are pre-requisite over the single feeder to enhance the power-quality in interconnected power distribution systems. A non-linear based un-balanced load-1/sensitive load-2 is supplied by feeder-1/feeder-2, the block diagram representation of an IUPQC device is depicted in Fig.7.

Generally, IUPQC comprising of one shunt and one series VSI topologies are interfaced to two neighboring feeders with energy supplying from common DC-link source. This IUPQC device furnishes power exchanging between the two neighboring feeders via DC-link capacitor and it has superior features over the traditional UPQC device in a single feeder. The main intension of IUPQC device is to adjust and sustaining the PCC voltage of feeder-1, while controlling the voltage over the sensitive load in feeder-2.

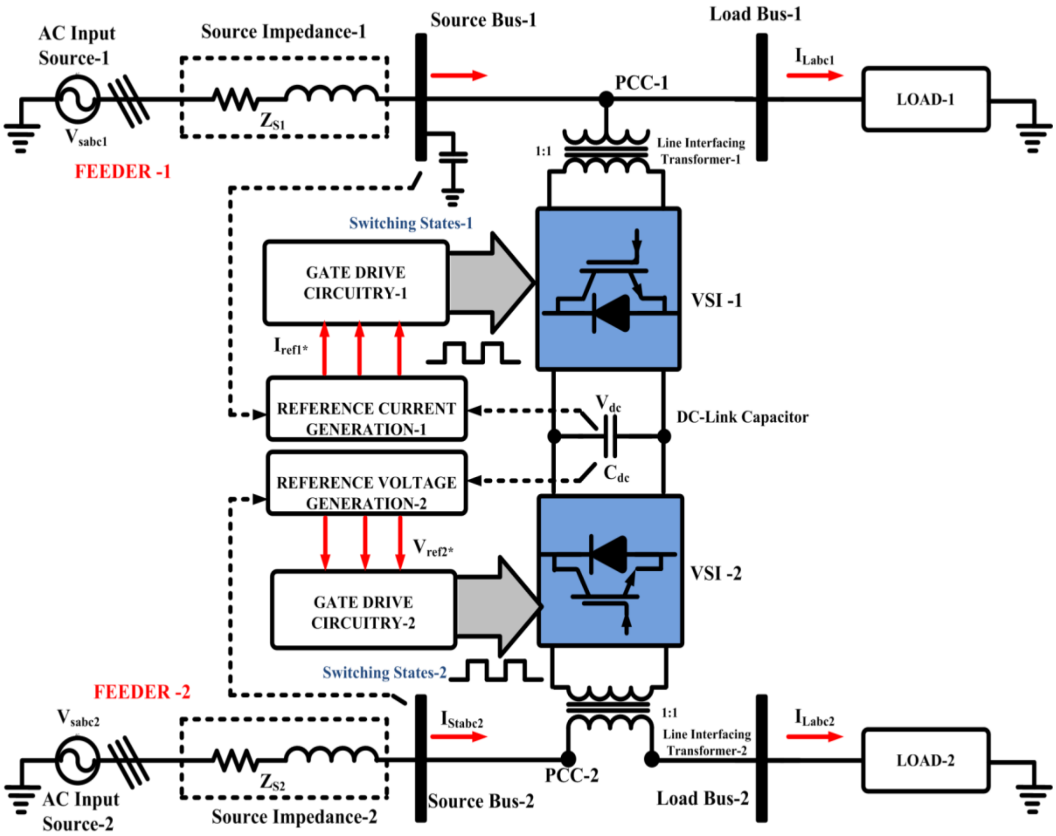

Fig.7. Block Diagram of IUPQC Device

In this arrangement, the voltage controlling in feeder-1 is performed by shunt-VSI device and sensitive load in feeder-2 is fully defended by series VSI device against of voltage sag, voltage swells and interruptions. In this device, since the source side impedance is very small, a large current is required to boost the feeder voltage during the voltage-sag, swell mitigation, which is un-feasible. It has low dynamic response due to DC-link capacitor voltage, which is not adjusted.

3.4 MULTI-CONVERTER UNIFIED POWER-QUALITY CONDITIONER (MC-UPQC)

The Multi-Converter Power-Quality Conditioner (MC-UPQC) is the recent implementation of power distributed compensator in multi-feeder network for compensating all power-quality issues in own and neighboring feeder. The basic MC-UPQC device comprises of two series VSI structure and one shunt VSI structure with a common DC-link source. The one series VSI and one shunt VSI is interfaced to feeder-1 and another series VSI is interfaced to neighboring feeder-2 with the help of line-interfacing transformer and all dual series-VSI and shunt-VSI is driven by common DC-link capacitor. The MC-UPQC device is used to compensate the both source-voltage and load current PQ issues on own feeder-1 and ample compensation of source-voltage PQ issues on another feeder-2. The power-circuit of MCUPQC is depicted in Fig.8.

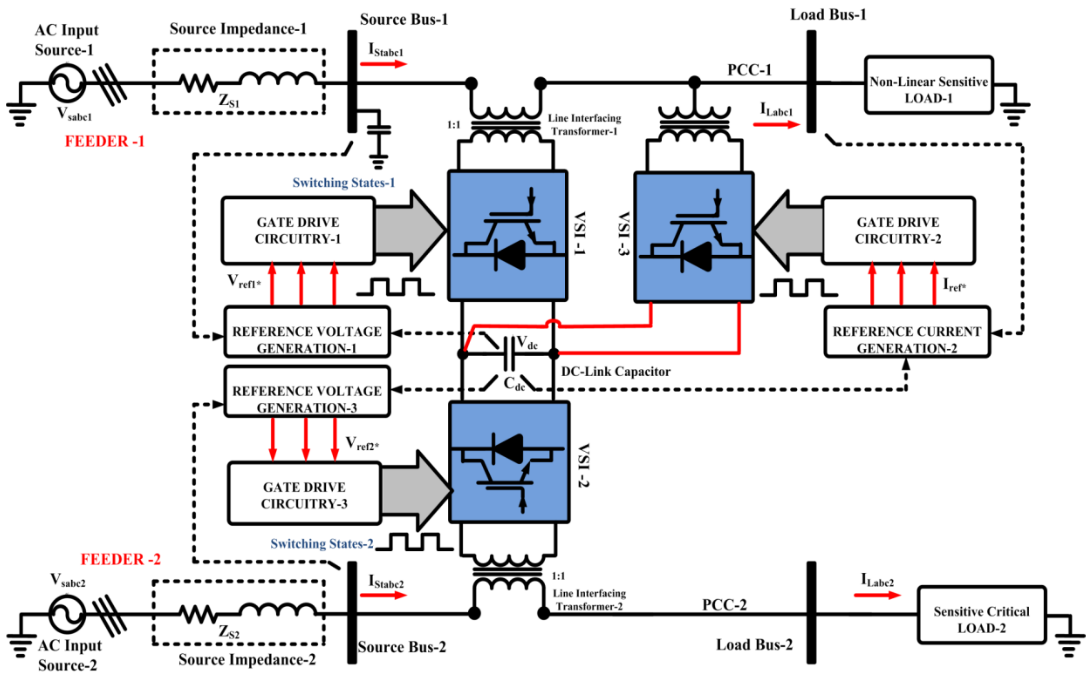

Fig.8 Power-Circuit of MCUPQC Device

The MC-UPQC is novel multi-feeder FACTS device and has several advantages such as;

- It has high power transfer capability between two feeders and load sharing between the feeders
- The intended MC-UPQC device is used to compensate the both current and voltage related PQ issues and most suffering interruptions, achieves enhanced PQ features in power distribution system.
- Compensation is achieved without the requirement of any battery energy storage scheme and accordingly without any storage capability limitations.

The MC-UPQC device can be expanded to multi-feeder power distribution systems by interfacing VSI's to neighboring feeders by driving the common DC-link source. The above-mentioned advantages remarked that MC-UPQC device can be applicable as multi-purposed custom-power device, compensates highly suffered PQ issues. The type of Custom Power Technology for Single-Feeder & Multi-Feeder Distribution Systems is illustrated in Table.3.

Table.3 Type of Custom Power Technology for Single-Feeder & Multi-Feeder Distribution Systems

S.No	Name of Compensation Device	Integration Method	Compensation Features
1	Static Transfer Switch	Series	Compensation of Voltage Sag-Swell, Voltage Interruptions
2	Active Power Filter	Shunt or Series	Compensation of Current Harmonics/Voltage Harmonics
3	DSTATCOM	Shunt	Compensation of Current

			Harmonics, Power-factor correction, Reactive power control
4	Dynamic Voltage Restorer	Series	Mitigation of Voltage Sag-Swell mitigation, Voltage regulation.
5	Unified Power-Quality Conditioner	Series/Shunt	Mitigation of Voltage Sag-Swell mitigation, Voltage regulation during Series Compensation. Mitigation of Current Harmonics, Power-factor correction, Reactive Power Control During Shunt Compensation.
6	Interline Dynamic Voltage Restorer	Series/Series	Mitigation of Voltage Sag-Swell mitigation, Voltage regulation in Multi-Feeders.
7	Interline Voltage Controller	Shunt/Shunt	Compensation of Current Harmonics, Power-factor correction, Reactive power control in Multi-Feeders.
8	Interline Unified Power-Quality Conditioner	Shunt/Series	Mitigation of Current Harmonics, Power-factor correction, Reactive Power Control During Shunt Compensation. And Also, mitigation of Voltage Sag-Swell mitigation, Voltage regulation during Series Compensation in Multi-Feeders.
9	Multi-Converter Power-Quality Conditioner	Series-Series/Shunt	Mitigation of Voltage Sag-Swell mitigation, Voltage regulation during Series Compensation in Dual Feeders. Mitigation of Current Harmonics, Power-factor correction, Reactive Power Control During Shunt Compensation in Multi-Feeder Distribution System.

IV. CONCLUSION

Now-a-days, power-quality problems are prominently increased in multi-feeder distribution networks and consumer levels. Compensation of PQ issues like, current harmonics, voltage sag-swell, voltage interruptions, unbalanced load, faults, etc., are gained predominant importance in present days. New custom-power devices provide the good compensation characteristics as recently introduced, which are developed by utilizing power-electronics converters to regulate the both current and voltage. To overcome the PQ issues in multi-feeder distribution networks, compensation based on FACTS controller are introduced related to distribution systems has reviewed the novel developments of Interline Custom-Power devices. This Interline CP devices has good potential to supply the various feeders interfaced to many substations, results the disturbances in existed feeders in that area never always occurs concurrently. For these cases, the flexibility and reliability of distribution network can be intensified by Interline CP devices. The Interline CP devices can be interfaced in between two adjacent feeders and the main merits of these Interline CP devices is, if any PQ issues occurs in one feeder and the other neighbor feeder provides energy for mitigating the PQ issues. Various Interline CP devices are studied in literature review such as, Interline Dynamic Voltage Restorer (IDVR), Interline Voltage Controller (IVOLCON) and Interline Unified Power-Quality Conditioner (IUPQC) and based on above-specified devices, an introducing the novel Multi-Converter based Unified Power-Quality Conditioner (MC-UPQC) is the best topology for enhancing PQ features in multi-feeder power distribution systems.

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