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A Review on Power Quality Problems

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***Abstract* — In today's scenario Power Quality issues are turn into a serious matter for both electric power utilities and for power system engineers. Equipment used in power distribution are highly responsive to the disturbances which arises in the supply systems. Moreover, these equipment are connected together in supply system and in industries for the purpose of manufacturing. As a result the effect of any issue or problem on the equipment is very large. Usually some of the power system equipment generates disruptions, which consecutively affect the other equipment, and are supposed to develop the harmonics distortion. These distortion results in inefficient usage of power and are the major source of abrupt failure of the equipment. It affects the production process in industries, which causes financial loss, it reduces generation of power, also affects data processing activities such as in bank transaction process may lost, affects ticket booking process and generates many service sector problems in real time. The main purpose of this paper is to overlook the sources and determine the most common power quality problems occurring in the power system and study the methods available for improving these problems.**

Keywords— Power Quality; Transients; Filters; Power Conditioning Equipment; Energy Storage Systems; Custom Power Devices ; IEEE Standards; IEC Standards.

I. INTRODUCTION

Power Quality (PQ) is explained as the cooperation of power with the electrical equipment. The electrical power quality is considered to be good, if the equipment operates properly whereas if the equipment malfunctions, or is deteriorate with the use, then we resolve that the power quality is deficient. Electric power system comprises of generation, transmission and at last distribution of power to consumers. The system is very complex. This complex system in combination with variation in power generation, load demand, weather variation and other factors provides many chances for the quality of power to get loss or sacrificed.

According to IEEE, POWER QUALITY is described as "The concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment"[1]. Ensuring that equipment and power are convenient to one another means that there should be consistency among the equipment and the system. Also there must be consistency in the equipment which allocate the common electrical power distribution space. This theory is termed as EMC or Electromagnetic Compatibility and can be explained as [2] "the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment".

Another definition, "Power Quality can be prescribe as the electrical limits which permit the equipment to operate in an intended way without making any major loss in its way of working or in the longevity."

Generally power quality refers the voltage quality rather than current quality. It can be described as – the test, measurement and advancement of bus voltage in order to maintain the sine wave at the standard voltage and at desired frequency.

II. SOURCES OF POWER QUALITY PROBLEM

The primary sources of power quality problems are [4], [27]:-

A. *Nonlinear Load*

With nonlinear load voltage and current do not follow each other linearly. It results in the harmonic distortion which causes overheating of the equipment and are admitted to voltage dips if they are not properly protected [3].

B. *IT and Office Equipment (sensitive loads)*

The brain of the computer is IC chips and is sensitive to change in the power supply. Any deviation in voltage can cause data to be damaged.

C. Large Motor Starting

During starting, the current in the induction machines is about six times of an ordinary current. It increases the network loading and hence cause voltage sag [7]. Nowadays modern motors uses power electronic converter also called 'drive', which control the motors starting current to a desired level.

D. Arc Producing Devices

These are non-linear devices and are main cause of harmonic distortion. Example are- electricity discharge lamps, electric arc furnaces and arc welders etc [5], [6].

E. Load Switching

These are the transient [16] occurs due to switching of massive load of single-phase. Electrical isolation are done in order to preserve the equipment from these disturbances.

F. Inter-connection of Power System

In the recent years the extent of interconnection in the power system is increased and is supposed to have great impact on the quality of power and it is very difficult to isolate them. Harmonics and flicker [7] are some power quality problems which are transferred from one utility to another utility via interconnection [26].

G. Lightning Strikes and Environmental issues

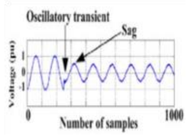
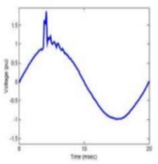
The Lightning strike produces transient over voltage issues and also it frequently leads to fault in power system. When the lightning strike hits the overhead transmission lines it causes 'flash-over' to the neighbouring conductors. It consists of transient overvoltage, voltage dips and also fault-clearing interruptions [14].

III. Major Power Quality Problems

ATransient

These are the unexpected and small duration interruption which is occur due to intense variation in balanced situation of current ,voltage or both [9],[13],[16].

TABLE I - TRANSIENT CLASSIFICATION

Disturbance Category	Causes	Effects	Waveform
Oscillatory Transient	Switching of capacitive or inductive loads.	Loss of data, possible damage.	
Impulsive Transient	Utility fault clearing, lightning, switching impulses.	Loss of data, possible damage, and system halts.	

A. Voltage Imbalance

It can be described as the variation in voltage of a three phase system where both magnitude of voltage and their phase difference are unequal [7].

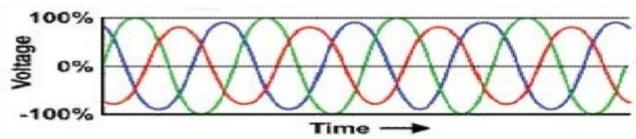


Fig. 1- Voltage Imbalance

B. Short Duration Voltage Variation

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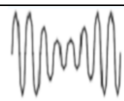
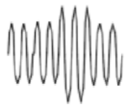
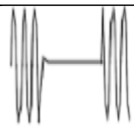
It is defined as any variation in supply voltage for very short period which is not more than 1 minute [7]-[13].
CAUSES-Sudden excitation of large loads, loose wiring connections.

TABLE II - SHORT DURATION VOLTAGE VARIATION CLASSIFICATION

Disturbance Category	Causes	Effects	Waveform
Voltage Sag	Start up loads, faults.	Loss of data, system halts, shutdown	
Voltage Swell	Load changes, utility failure.	Damages equipment, tripping of circuit breaker.	
Interruptions	Switching, utility faults, component failure.	Shutdown, loss of data and damages.	

C. Long Duration Voltage Variation

It can be described as the voltage deviation which occur for the time interval exceeding 1 minute [7], [9], [12],[13].

D. Blackout

It can be represented as a condition of zero-voltage which exists for larger than two cycles [20].

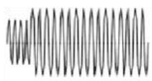
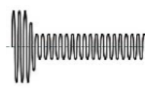
E. Brownouts

It is defined as intended or unintended voltage drop in power system. Intended brownouts are principally used for reduction of load in emergency conditions. This reduction lasts from few minutes or hours [19].
EFFECTS:-Loss of data, systems can experiences glitches and equipment failure.

F. Wave Form Distortion

If there is any deviation in the voltage and current waveform of power supply from ideal sine wave then it is called wave form distortion[7],[9],[17].

TABLE III -LONG DURATION VOLTAGE VARIATION CLASSIFICATION

Disturbance Category	Causes	Effects	Waveform
Over Voltage	System load change, utility faults.	Loss of data, system shutdown, and system halts.	
Under Voltage	System load changes, utility faults.	Equipment damage, reduced life of equipment.	

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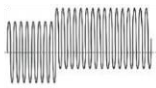
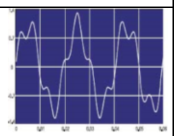
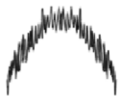
Sustained Interruption	Utility faults, tripping of breaker, component failure.	System shutdown, loss of data and damages.	

TABLE IV – WAVEFORM DISTORTION CLASSIFICATION

Disturb-ance Category	Causes	Effects	Waveform
DC Offset	Power supplies, faulty rectifier.	Ground fault, current nuisance tripping, transformer heating.	
Harmo-nics	Due to Nonlinear loads.	Measurement error, Equipment overheating, loss in machines efficiency, communication interference.	
Interharmonic	Induction motor, faulty equipment, arcing device.	Heating, Communication interference, light flicker etc.	
Noise	Improper grounding, electromagnetic interferences.	Data loss and data processing errors.	
Notching	Arc welders, light dimmers, variable speed drive etc.	Loss of system data, system halts.	

G. Voltage Fluctuations

IEEE described it as voltage envelope variation, or the random voltage fluctuation, whose magnitude lies in the limits of voltage provided by the standard ANSI C84.1. In general, variation range is about 0.1% to 7% of the system voltage and frequency is under 25 Hz [7], [13], [18].

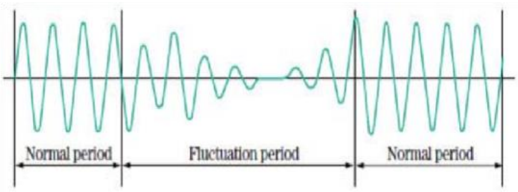


Fig. 2- Voltage Fluctuation

H. Power Frequency Variations

For the adequate working of any network or system the necessary frequency limit is specified ,if there is a deviation in its desired limit suppose from 50 Hz to 60 Hz ,then it is called as frequency variation of power system[9],[13].

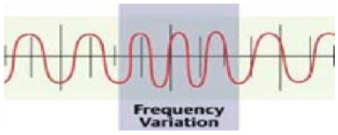


Fig. 3- Power Frequency Variation

TABLE V- SHOWING DETAILS OF POWER QUALITY PROBLEMS [13]

Categories	Typical Spectral Content	Typical Duration	Typical Voltage Magnitude
1.0 Transients			
1.1 Impulsive			
1.1.1 Nanosecond	5 ns rise	< 50 ns	
1.1.2 Microsecond	1 ȝs rise	50 ns-1ms	
1.1.3 Millisecond	0.1 ms rise	> 1ms	
1.2 Oscillatory			
1.2.1 Low frequency	< 5 kHz	0.3-50 ms	0-4 pu
1.2.2 Medium frequency	5-500 kHz	20 ȝs	0-8 pu
1.2.3 High frequency	0.5-5 MHz	5 ȝs	0-4 pu
2.0 Short duration variation			
2.1 Instantaneous			
2.1.1 Sag		0.5 – 30 cycles	0.1-0.9 pu
2.1.2 Swell		0.5 – 30 cycles	1.1-1.8 pu
2.2 Momentary			
2.2.1 Interruption		0.5 cycles -3 s	< 0.1 pu
2.2.2 Sag		30 cycles - 3 s	0.1-0.9 pu
2.2.3 Swell		30 cycles -3 s	1.1-1.4 pu
2.3 Temporary			
2.3.1 Interruption		3 s -1 min	< 0.1 pu
2.3.2 Sag		3 s -1 min	0.1-0.9 pu
2.3.3 Swell		3 s -1 min	1.1-1.2 pu
3.0 Long duration variations			
3.1 Interruption sustained		> 1 min	0.0 pu
3.2 Undervoltages		> 1 min	0.8-0.9 pu
3.3 Overvoltages		> 1 min	1.1-1.2 pu
4.0 Voltage imbalance		steady state	0.5-2%
5.0 Waveform distortion			
5.1 DC offset		steady state	0-0.1%
5.2 Harmonics	0-100th H	steady state	0-20%
5.3 Interharmonics	0-6 kHz	steady state	0-2%

5.4 Notching		steady state	
5.5 Noise	broad-band	steady state	0-1%
6.0 Voltage fluctuation	< 25 Hz	intermittent	0.1-7%
7.0 Power frequency variation		< 10 s	

IV. Power Quality Solutions

A. Power Quality Improvement/Conditioning Equipment

Variety of electric power improvement devices are evolved over the span of years in order to protect equipment from the disturbances.

Following devices forms an important part in building the impressive power quality scheme.

1) *Transient Voltage Surge Eliminator or Suppressors (TVSS):* It gives protection from surges which are originated in the high voltage system by shunting them to ground into the low voltage system[17].

2) *Filters*

Noise Filter: They prohibits the undesirable frequency noise or current from reaching the susceptive equipment. It uses the combination of both the capacitors and the inductors, and provides path of lower impedance to basic frequency and path of higher impedance to greater frequencies, means lower order frequency pass filter. These filters are required when the noise of frequency range (kHz) are substantial [17].

*Harmonic Reduction Filter:*These filters plays a major role in reducing the unexpected harmonics[22].

CLASSIFICATION

i) *Passive Filters:* It provides lower impedance path to the harmonic frequencies which is to mitigate with the help of passive components such as resistors, capacitors and inductors [36].

ii) *Active Filters*: It employs the technique of harmonic minimization in an order to upgrade the quality of power flowing in the system by including equal amount of current or voltage distortion in the system which cancels the actual distortion in the circuit but in opposite magnitude[22].

3) *Isolation Transformers:* Basically it is used for the separation or isolation of the susceptive loads from the transients and from noise that are drawing from the main supply. It confer high level of separation and filteration and reduces normal and common mode noises[17]. DISADVANTAGE- It is unable to provide compensation for fluctuation of voltage and power supply outages [23].

4) *Voltage Controller or Regulator:* These are designed to automatically maintain a constant voltage level. It keeps control over the output voltage in normal as well as in severe condition of input voltage variations. These are installed at those places where voltage of input side varies, but the total power failure is quite substantial.

TABLE VI – CLASSIFICATION OF VOLTAGE REGULATOR

Types	Advantages	Disadvantages
TAP CHANGER	Wide input limits. Large current capability. Fair noise isolation. High efficiency.	During taps changing noise is observed. Waveform correction is not possible.

BUCK-BOOST	High efficiency. Capable of withstanding high inrush currents.	Noise isolation is poor. Noise is produced when changing taps. No waveform correction.
CONSTANT VOLTAGE TRANSFOR-MER (CVT):	Provides remarkable noise isolation. Good current limitation.	Low efficiency. Large size. Audible noises.

5) Motor Generator Set: M-G set comprise of motor and generator. They are coupled mechanically via same shaft. It give protection from coming disturbances ,voltage transients and sags [15].

*6) Uninterruptible Power Supply (UPS):*It provides security in the blackout condition or in the case of power cut, gives regularity in power flowing to the load in an instance of transient interruptions and also provides protection from noise, surges on the basis of technology employed [21].

TABLE VII- UPS CLASSIFICATION

UPS	ADVANTAGES	DISADVANTAGES
Standby or Off-Line UPS	Minimum cost. High efficiency. High reliability.	Noticeable transfer time. Poor voltage regulation.
Line Interactive UPS	High efficiency. Good voltage regulation.	Noticeable transfer time. Difficulty in unit comparison.
True On-Line UPS	Protection from voltage fluctuations. Elimination of any transfer time.	Low efficiency. Higher audible noise.

\

B. Energy Storage Systems

These are used mainly for protection purpose [25].It safeguard the susceptible equipments from the shutdown These are of direct and indirect storage type like batteries, UPS, SMES [24] etc. Their output are given to the system via an inverter on transitory basis with the help of an electronic switch. In this sufficient energy is given to the system in order to recover the energy loss.

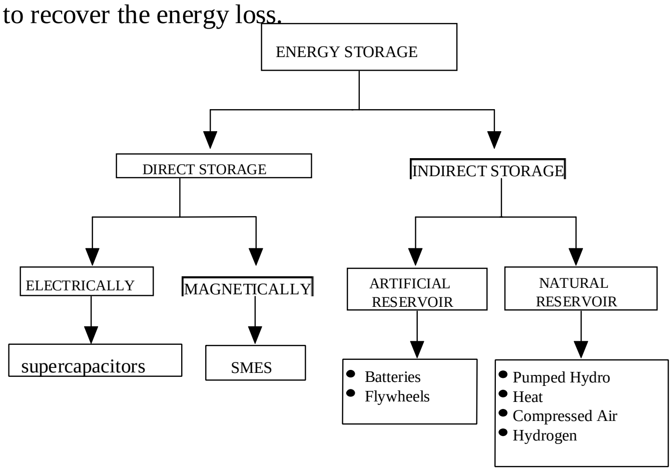


Fig. 4 – Classification of Energy Storage System [45]

C. Custom Power Devices

To overcome the power quality issues various measures have been taken which includes the uses of passive filters, active filters, CVT, tap changers, etc but due to their disadvantages these are discarded. Hence customer power devices are introduced. They provides stable power to the consumers and

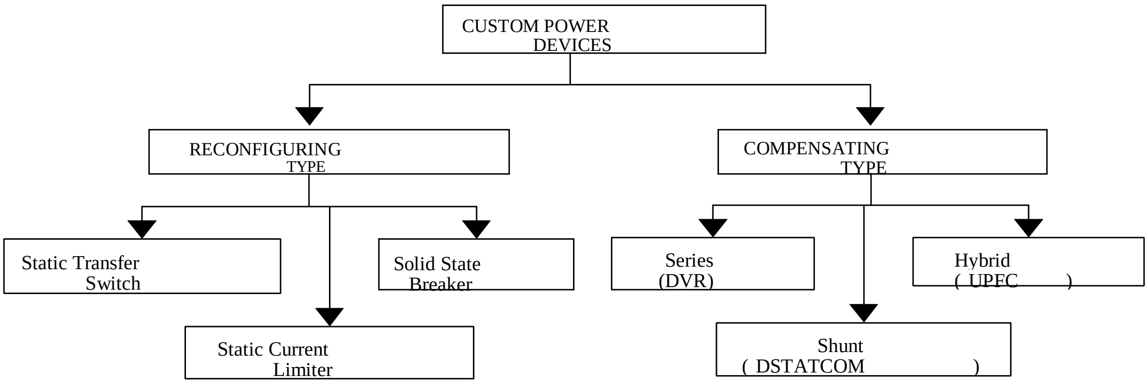


Fig. 5- Classification of Custom Power Devices

1) Reconfiguring Type: They are Thyristor or GTO base devices intended for limiting the fault current as well as provides braking of circuit. These are classified as:-

a) Static Transfer Switch (STS): It is a device which is connected between the AC supply mains and inverter to provide uninterruptible AC power. It gives approximately 20 times quicker transfer of load, as compared to conventional automatic transfer switches [28].

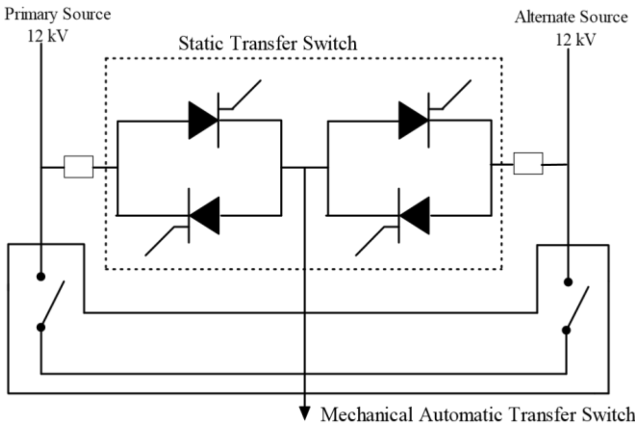


Fig. 6 - STS System

DISADVANTAGES

- High transfer time and it increases with regenerative load such as in an induction motors [29].
- Thyristor, which is the base of STS is not pure therefore it is a source of many problems like problems of cooling, losses which results in loss of efficiency [30].

b) *Static Current Limiter (SCL):* These are mainly used to limit high value of fault current and offers high impedance

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in fault condition and low impedance in normal condition.

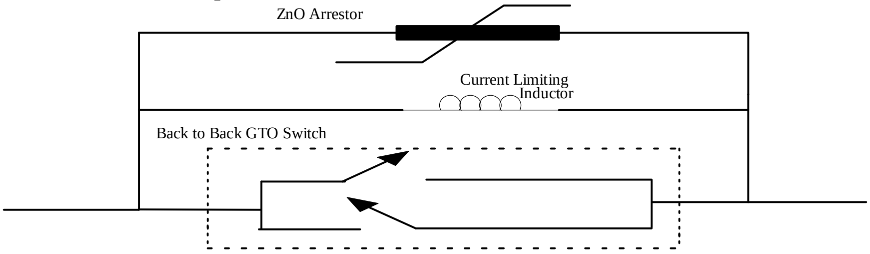

Fig.7 - Static Current Limiter

c) *Static Circuit Breaker (SCB):* It is a device used in distribution system for protection purpose. It operates faster than mechanical circuit breaker. It employs GTO or thyristor switching technology. The circuit has high sensitivity which ensures safety from electric flash and from short circuit

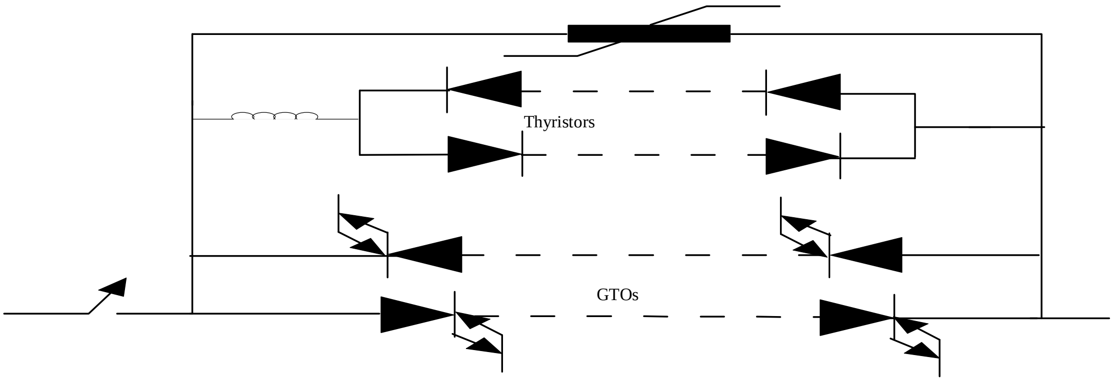

Fig. 8 - Static Circuit Breaker

2) Compensating Type: These are used for power factor improvement, for filtering purpose, balancing of load current, regulation of voltage .These are classified as:-

a) Dynamic Voltage Restorer(DVR): It provides an economical solution to reduce the voltage sag by regulating the desired level of voltage needed by the consumer [33],[34].

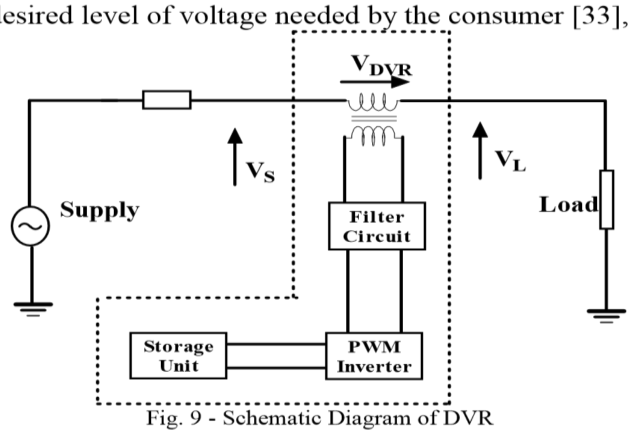

Fig. 9 - Schematic Diagram of DVR

The latest research in an area of DVR on the basis of Ultra Capacitor are done [35]. The results are shown below-

TABLE VIII - THD COMPARISON [35]

System	THD For Voltage Sag	THD For Voltage Swell

Uncompensated	7.35 %	8.45 %
Conventional	3.22 %	4.02 %
Integrated UCAP-DVR	1.55 %	1.71

b) Distribution Static Compensator (DSTATCOM): It is capable of overcoming the variation in voltages. It limits the reactive power and hence improves the power factor. It perform linear and continuous compensation for inductive and capacitive currents[37],[38].

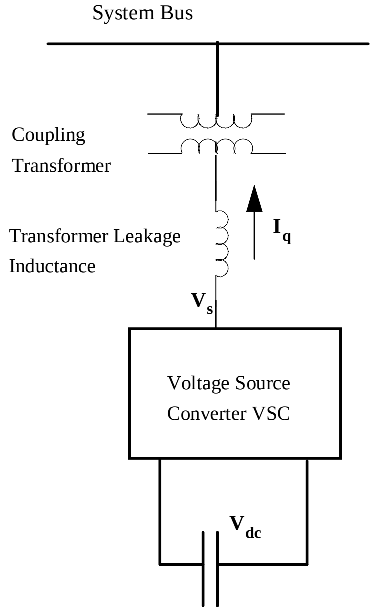

Fig.10 – Basic Scheme of DSTATCOM

c) Unified Power Flow Compensator (UPFC): It is considered as an extremely accomplished and complicated FACTS devices [39],[40]. It comprise of both SSSC and STATCOM. It gives concurrent control over power system variables, like phase angle, transmission line voltage and impedances.

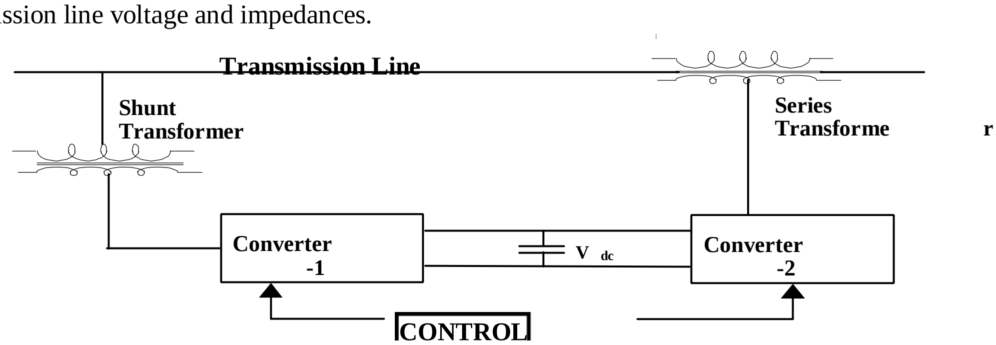

Fig. 11 - UPFC-Basic Scheme

TABLE IX- BENEFITS OF CUSTOM POWER DEVICES

DEVICES	BENEFITS
STS	Protection from voltage (dip or swell). Transmits power from distinct feeder.
SCL SCB	Used in limiting the fault current. To break the faulted network.
D-STATCOM	Improvement of power factor. Compensation of current harmonic. Balancing of current flowing over load. Compensation of flicker effect.
DVR	Protection from voltage (dip or swell). Balancing and regulation of voltage. Eliminates flicker.
UPQC	Balancing of voltages and current. Harmonic suppression. Control of reactive and active power.

V. Power Quality Standard

There are several standards available for power quality issues some of them are national and some are international. But the most accepted and widely known standard are- IEEE (Institute of Electrical and Electronics Engineers) and IEC (International Electrotechnical Commission). These are standard organizations and they provides minimum stratum and also put recommendations on technical problems.

Table X - IEEE and IEC Standard on Power Quality Issues

P	ower Quality Issues	Appropriate Standards
1	Voltage Sag/Swell	IEEE P1564, IEC 61000-4-11, IEC 61000-4-31
2	Voltage Flickers	IEC 61000-2-2, IEEE P1453
3	Harmonics	IEC SC 77 A, IEEE 1346, IEEE SA - 519-2014
4	PQ test, Monitoring and Measurements	IEEE 1159, IEC SC 77 A/WG 9, IEC 61000-4-1, IEC 61000-4-30

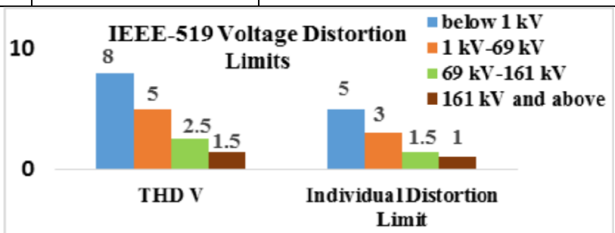

Fig. 12 – Voltage Distortion Limits [44]

Table XI - Major Power Quality Problems and Solutions

POWER QUALITY PROBLEM	SOME SOLUTIONS
Transient	SVC
Voltage Sag	CVT ,UPS,DVR
Voltage Surge/ Swell	Power Conditioners, UPS
Voltage Variation/Fluctuation	SVC
Interruption	UPS

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Voltage Inequality/ Imbalance	Protective Scheme
Distortion	Active Filters
Flickering of Voltage	Voltage Imbalance Relay
Blackouts	Using Generators
Brownouts	Voltage Regulators, UPS

Utilities have taken several methods in order to control the quality of power flowing in the system. In this first step is the creation of CBEMA curve [41]. It was formed in 1970 by Computer and Business Equipment Manufacturer's Association. It clearly explains minimum tolerance level of an electronic equipment against disturbances. Next step is ITIC curve, which is developed by Information Technology Industry Council [42]. It is a modified version of CBEMA

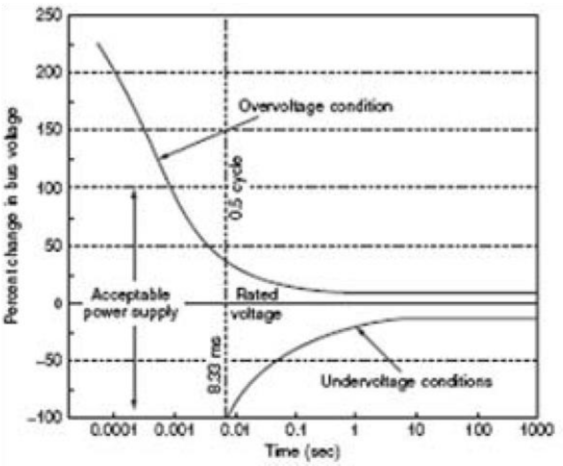

Fig. 13 – Showing CBEMA Curve [43]

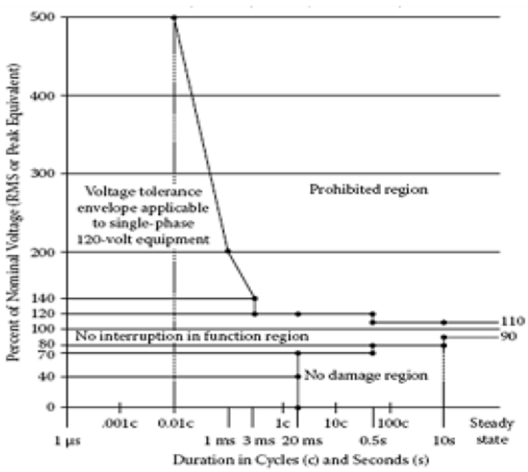

Fig. 14 – ITIC Curve [42]

This curves acts as a standard for the safety of equipment from disturbance by determining its tolerant ability

IV - CONCLUSIONS

This paper briefly explains, "What is power quality".

Poor power quality causes serious effect on the power system like over loading condition, generation of harmonics, voltage fluctuation, waveform distortion, and overheating in system equipment etc. therefore we have to mitigate these power quality issues. This paper gives an idea about appropriate standards for various power quality issues and also provides solution to major power quality problems. While, it is not possible to completely eliminate the causes of power quality but the quality of power supply can be improved and their effect could be reduced. The mitigating techniques includes use of power conditioning equipments such as TVSS, filters, voltage regulators, isolation transformer, use of energy storage systems, and also with use of custom power devices like - STS, SCL, SCB, DVR, STATCOM and UPFC etc. This paper will helps the researchers and electrical power utilities to get an overview of power quality issues so that they come up with latest technology.

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