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A Review on Power Quality Problems and its Improvement Techniques

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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 tothe disturbances which arises in the supply systems. Moreover, these equipment are connected together in supply system and in industriesforthepurposeofmanufacturing.Asaresulttheeffect of any issue or problem on the equipment is very large. Usually some of the power system equipment generates disruptions,whichconsecutivelyaffecttheotherequipment,andares upposed 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 theproductionprocess in industries, which causes financial loss, it reduces generation of power, also affectsdata processing activities such as in bank transaction process may lost, affects ticket booking process and generates many service sector problemsin real time. The main purpose of this paper is to overlook the sources and determinethemostcommonpowerqualityproblemsoccurringinthep ower 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 deteriorateswiththe use,thenweresolvethatthepowerquality 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 mannerthatissuitabletotheoperationofthatequipmentand 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 ElectromagneticCompatibilityandcanbeexplainedas[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. SOURCESOFPOWERQUALITYPROBLEM

Theprimarysourcesofpowerqualityproblemsare[4],[27]:-

A. NonlinearLoad

Withnonlinearloadvoltageand currentdo not followeach otherlinearly.Itresultsintheharmonicdistortionwhichcauses overheating of the equipment and are admitted to voltage dips if they are not properly protected [3].

B. ITandOfficeEquipment(sensitiveloads)

The brain of the computer is IC chips and is sensitive to changeinthepowersupply.Anydeviationinvoltagecancause data to be damaged.

C. LargeMotorStarting

During starting, the current in the induction machines is about six times of an ordinarycurrent.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. ArcProducingDevices

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. LoadSwitching

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-connectionofPowerSystem

In the recent years the extent of interconnection in the powersystemisincreasedandissupposedtohavegreatimpact 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. LightningStrikesandEnvironmentalissues

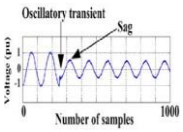
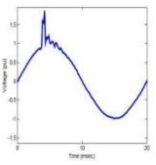
TheLightningstrikeproducestransientovervoltageissues and also it frequentlyleads tofault inpower system. Whenthe lightning strike hits the overhead transmission lines it causes 'flash-over' to the neighbouring conductors. It consists of transient overvoltage, voltage dips and also fault-clearing interruptions [14].

III. MAJORPOWERQUALITYPROBLEMS

A. Transient

These are the unexpected and small duration interruption whichis occur due to intensevariationinbalanced situationof current ,voltage or both [9],[13],[16].

TABLEI-
TRANSIENTCLASSIFICATION

Disturbance Category	Causes	Effects	Waveform
Oscillatory Transient	Switchingo fcapacitive orinductive loads.	Loss of data, possible damage.	
Impulsive Transient	Utilityfault clearing, lightning, switching impulses.	Loss of data, possible damage, andsystem halts.	

B. VoltageImbalance

It can be described as the variation in voltage of a three phasesystemwherebothmagnitudeofvoltageandtheirphase difference are unequal [7].

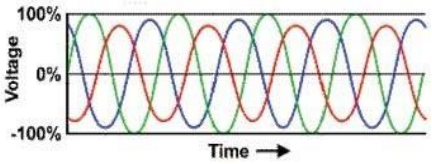
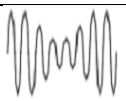
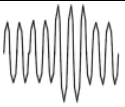
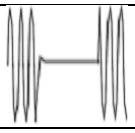


Fig.1-VoltageImbalance

C. ShortDurationVoltageVariation

Itisdefinedasanyvariationinsupplyvoltageforvery short period which is not more than 1 minute [7]-[13].
CAUSES-Suddenexcitationoflargeloads,loosewiring connections.

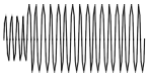
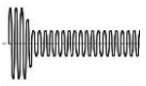
TABLEII-SHORTDURATIONVOLTAGEVARIATIONCLASSIFICATION

Disturbance Category	Causes	Effects	Waveform
VoltageSag	Startuploads, faults.	Lossofdata, systemhalts, shutdown	
Voltage Swell	Loadchanges, utilityfailure.	Damages equipment, tripping of circuitbreaker.	
Interruptions	Switching, utilityfaults, component failure.	Shutdown,loss of data and damages.	

D. LongDurationVoltageVariation

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

TABLEIII-LONGDURATIONVOLTAGEVARIATIONCLASSIFICATION

Disturbance Category	Causes	Effects	Waveform
Over Voltage	Systemload change,utility faults.	Loss of data, system shutdown,and systemhalts.	
Under Voltage	Systemload changes, utilityfaults.	Equipment damage, reducedlifeof equipment.	
Sustained Interruption	Utilityfaults, tripping of breaker, component failure.	System shutdown,loss of data and damages.	

E. Blackout

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

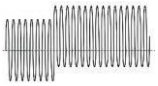
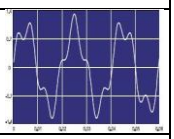
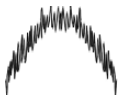
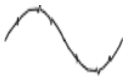
F. Brownouts

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 reductionlasts from few minutes or hours [19].
EFFECTS:-Loss of data, systems can experiences glitches and equipment failure.

G. *WaveFormDistortion*

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].

TABLEIV–WAVEFORMDISTORTIONCLASSIFICATION

Disturb-anceCategory	Causes	Effects	Waveform
DC Offset	Power supplies, faulty rectifier.	Ground fault, currentnuisance tripping, transformer heating.	
Harmo-nics	DuetoNon-linearloads.	Measurement error,Equipment overheating,loss inmachines efficiency, communication interference.	
Inter-harmonic	Induction motor, faulty equipment, arcingdevice.	Heating, Communication interference, lightflickeretc.	
Noise	Improper grounding, electro-magnetic interferences.	Data loss and dataprocessing errors.	
Notching	Arc welders, lightdimmers, variablespeed drive etc.	Lossofsystem data, system halts.	

H. *VoltageFluctuations*

IEEE described it as voltage envelope variation, or the randomvoltage fluctuation, whose magnitude lies inthe limits of voltage provided by the standardANSI 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].

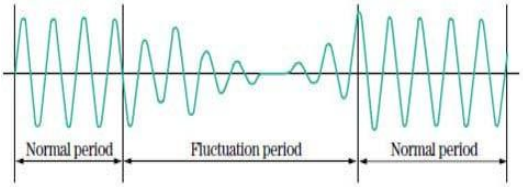


Fig.2-VoltageFluctuation

I. *PowerFrequencyVariations*

For the adequate working of any network or system the necessaryfrequencylimit isspecified ,ifthere isa deviation in its desired limit suppose from 50 Hz to 60 Hz ,then it is called as frequency variation of power system[9],[13].

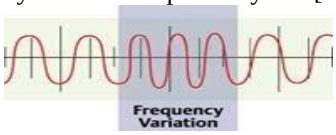


Fig.3-PowerFrequencyVariation

TABLEV-SHOWING DETAILSOFPOWER QUALITYPROBLEMS[13]

Categories	Typical Spectral Content	Typical Duration	Typical Voltage Magnitude
1.0 Transients			
1.1Impulsive			
1.1.1Nanosecond	5nsrise	<50ns	
1.1.2Microsecond	1μsrise	50ns-1ms	
1.1.3Millisecond	0.1msrise	>1ms	
1.2 Oscillatory			
1.2.1Lowfrequency	<5kHz	0.3-50ms	0-4pu
1.2.2Medium frequency	5-500kHz	20μs	0-8pu
1.2.3High frequency	0.5-5MHz	5μs	0-4pu
2.0Shortdurationvariation			
2.1 Instantaneous			
2.1.1Sag		0.5–30cycles	0.1-0.9pu
2.1.2Swell		0.5–30cycles	1.1-1.8pu
2.2Momentary			
2.2.1Interruption		0.5cycles-3s	<0.1pu
2.2.2Sag		30cycles-3 s	0.1-0.9pu
2.2.3Swell		30cycles-3s	1.1-1.4pu
2.3 Temporary			
2.3.1 Interruption		3 s-1min	<0.1pu
2.3.2Sag		3s-1min	0.1-0.9pu
2.3.3Swell		3s-1min	1.1-1.2pu
3.0Longduration variations			
3.1 Interruption sustained		>1min	0.0pu
3.2 Undervoltages		>1min	0.8-0.9pu
3.3Overvoltages		>1min	1.1-1.2pu
4.0Voltageimbalance		steadystate	0.5-2%
5.0Waveform distortion			
5.1DCoffset		steadystate	0-0.1%
5.2 Harmonics	0-100thH	steadystate	0-20%
5.3Interharmonics	0-6kHz	steadystate	0-2%
5.4 Notching		steadystate	
5.5 Noise	broad-band	steadystate	0-1%
6.0Voltagefluctuation	< 25Hz	intermittent	0.1-7%
7.0Powerfrequency variation		< 10s	

IV. POWERQUALITYSOLUTIONS

A. *PowerQualityImprovement/ConditioningEquipment*

Variety of electric power improvement devices areevolved 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): Itgives protection from surges which are originatedinthe highvoltage systembyshuntingthemto ground into the low voltage system[17].

2) Filters

a) Noise Filter: They prohibits the undesirablefrequency noise or current from reaching the susceptive equipment. It uses the combination of both the capacitors and the inductors, and provides path of lower impedanceto basic frequencyandpathofhigherimpedancetogreater

frequencies, meanslower order frequency pass filter. These filters are required when the noise of frequency range (kHz) are substantial [17].

*b) HarmonicReductionFilter:*Thesefiltersplaysa major role in reducing the unexpected harmonics[22]. CLASSIFICATION

*i) PassiveFilters:*Itprovideslowerimpedancepath 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) IsolationTransformers:*Basicallyitisusedforthe separationorisolationofthesusceptiveloadsfromthe transientsandfromnoisethataredrawingfromthemain supply.Itconferhighlevelofseparationandfilterationand reduces normal and common mode noises[17]. DISADVANTAGE- It is unable to provide compensation for fluctuation of voltage and power supply outages [23].

*4) VoltageControllerorRegulator:*Thesearedesignedto 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.

TABLEVI–CLASSIFICATIONOFVOLTAGEREGULATOR

Types	Advantages	Disadvantages
TAPCHANGER	Wideinputlimits. Large current capability. Fairnoiseisolation. Highefficiency.	Duringtapschanging noise is observed. Waveformcorrectionis not possible.
BUCK-BOOST	High efficiency. Capable of withstandinghighin-rush currents.	Noise isolation is poor. Noiseisproducedwhen changing taps. Nowaveform correction.
CONSTANT VOLTAGET RANSFOR-MER(CVT):	Providesremarkable noise isolation. Goodcurrent limitation.	Lowefficiency. Large size. Audiblenoises.

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 transientinterruptionsandalsoprovidesprotectionfromnoise, surges on the basis of technology employed [21].

TABLEVII-UPSCLASSIFICATION

UPS	ADVANTAGES	DISADVANTAGES
StandbyorOff-Line UPS	Minimumcost. Highefficiency. Highreliability.	Noticeabletransfertime. Poor voltage regulation.
Line InteractiveUPS	Highefficiency. Good voltage regulation.	Noticeabletransfertime. Difficulty in unit comparison.
TrueOn-Line UPS	Protection from voltagefluctuations. Eliminationofany transfer time.	Low efficiency. Higheraudiblenoise.

B. EnergyStorageSystems

These are used mainly for protection purpose [25].It safeguard the susceptible equipmentsfromthe shutdownThese 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 electronicswitch. In this sufficient energy is given to the system in order to recover the energy loss.

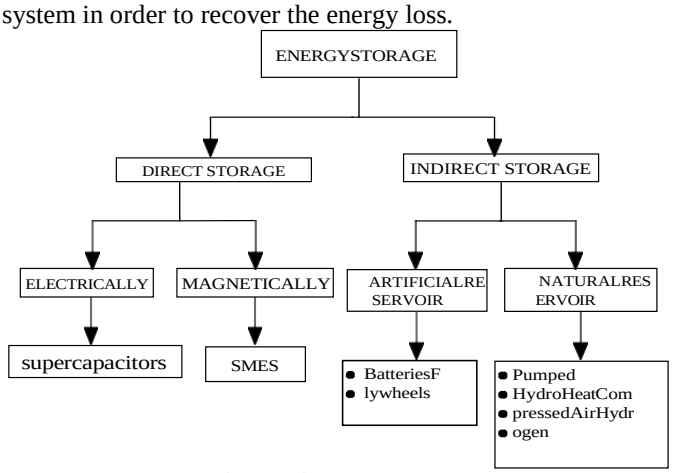


Fig.4–ClassificationofEnergyStorageSystem [45]

C. CustomPowerDevices

To overcome the power quality issues various measures havebeentakenwhichincludesthe usesofpassive 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 also raises the service quality of distribution system [26] [27].

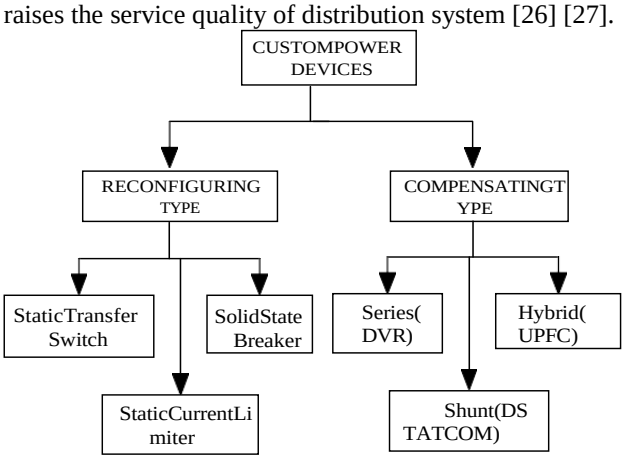


Fig.5-ClassificationofCustomPowerDevices

1) Reconfiguring Type: They are Thyristor or GTO base devices intended for limiting the fault current as well as provides braking ofcircuit. 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].

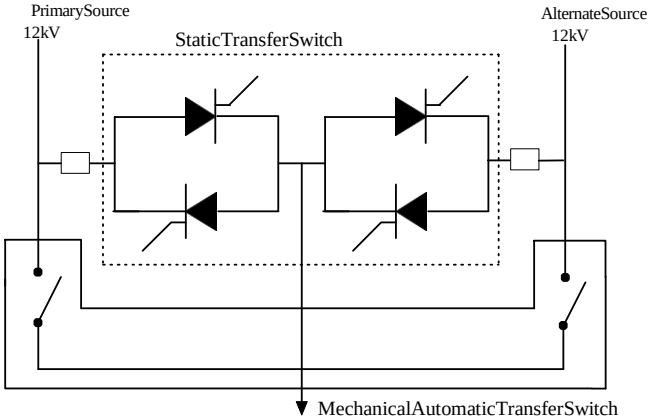


Fig.6 -STSSystem

DISADVANTAGES

- Hightransfertimeanditincreases withregenerativeload such as in an induction motors [29].
- Thyristor, which is the base of STS is not pure thereforeit is a source of manyproblems like problems ofcooling, 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 in fault condition and low impedance in normal condition.

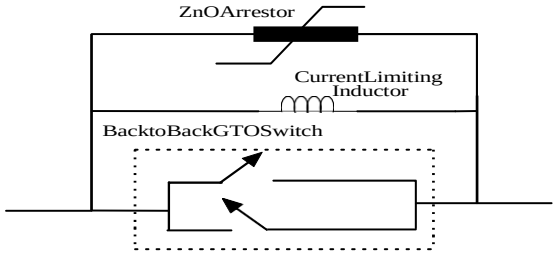


Fig.7-StaticCurrentLimiter

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 condition. It operates very fastly in microseconds [31], [32].

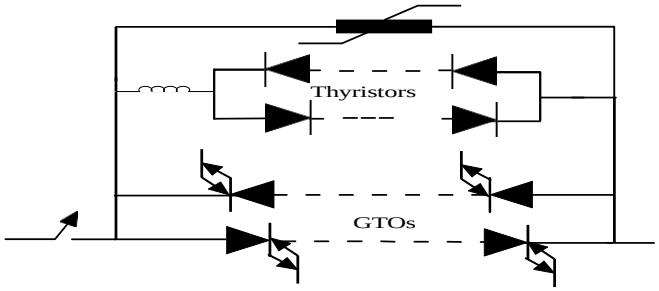


Fig.8-StaticCircuitBreaker

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 economicalsolution to reduce the voltage sag by regulating the desired level of voltage needed by the consumer [33],[34].

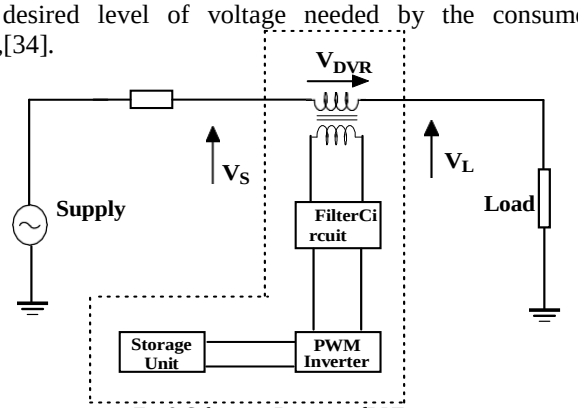


Fig.9-SchematicDiagramofDVR

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

TABLEVIII-THDCOMPARISON[35]

System	THDFor VoltageSag	THDFor VoltageSwell
Uncompensated	7.35%	8.45%
Conventional	3.22%	4.02%
IntegratedUCAP-DVR	1.55%	1.71

b) Distribution Static Compensator (DSTATCOM): It iscapableof overcoming the variation in voltages. Itlimits the reactive power and hence improves the power factor. It performlinear and continuous compensation for inductive and capacitive currents[37],[38].

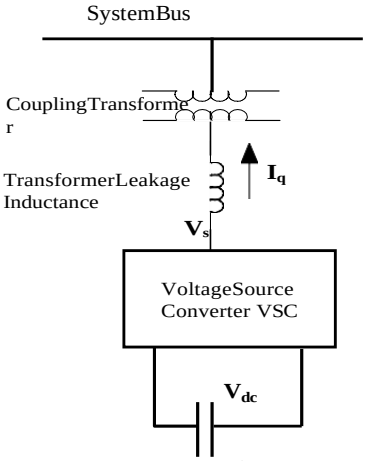


Fig.10–BasicSchemeofDSTATCOM

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

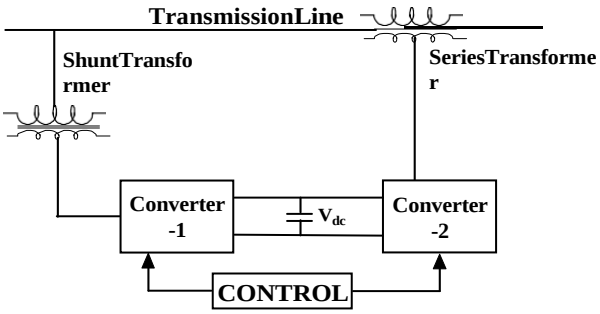


Fig.11-UPFC-BasicScheme

TABLEIX-BENEFITSOFCUSTOMPOWERDEVICES

DEVICES	BENEFITS
STS	Protectionfromvoltage(diporswell). Transmits power fromdistinct feeder.
SCL SCB	Usedinlimitingthefaultcurrent. To break the faulted network.
D-STATCOM	Improvement of power factor. Compensation of current harmonic. Balancingofcurrentflowingoverload. Compensationofflickereffect.
DVR	Protectionfromvoltage(diporswell). Balancingandregulationofvoltage. Eliminates flicker.
UPQC	Balancingofvoltagesandcurrent. Harmonic suppression. Controlofreactiveandactivepower.

V. POWERQUALITYSTANDARD

There are several standards available for power quality issues some of them are national and some are international. But the mostacceptedand widelyknown standardare-IEEE(Institute ofElectricalandElectronicsEngineers)andIEC(International Electrotechnical Commission). These are standard organizations and they provides minimum stratum and alsoput recommendations on technical problems.

TABLEX -IEEEANDIECSTANDARDONPOWERQUALITYISSUES

PowerQualityIssues		AppropriateStandards
1	VoltageSag/Swell	IEEE P1564, IEC 61000-4-11, IEC 61000-4-31
2	VoltageFlickers	IEC61000-2-2,IEEEP1453
3	Harmonics	IECSC77A,IEEE1346,IEEE SA - 519-2014
4	PQ test,Monitoring and Measurements	IEEE1159,IECSC77A/WG9, IEC61000-4-1,IEC61000-4-30

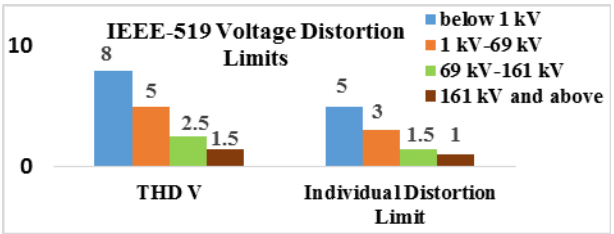


Fig.12–VoltageDistortionLimits[44]

TABLEXI-MAJORPOWERQUALITYPROBLEMSANDSOLUTIONS

POWERQUALITYPROBLEM	SOMESOLUTIONS
Transient	SVC
VoltageSag	CVT,UPS,DVR
VoltageSurge/Swell	PowerConditioners,UPS
VoltageVariation/Fluctuation	SVC
Interruption	UPS
VoltageInequality/Imbalance	ProtectiveScheme
Distortion	ActiveFilters
FlickeringofVoltage	VoltageImbalanceRelay
Blackouts	UsingGenerators
Brownouts	VoltageRegulators,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'sAssociation. It clearly explains minimum tolerance level of an electronic equipment against disturbances.

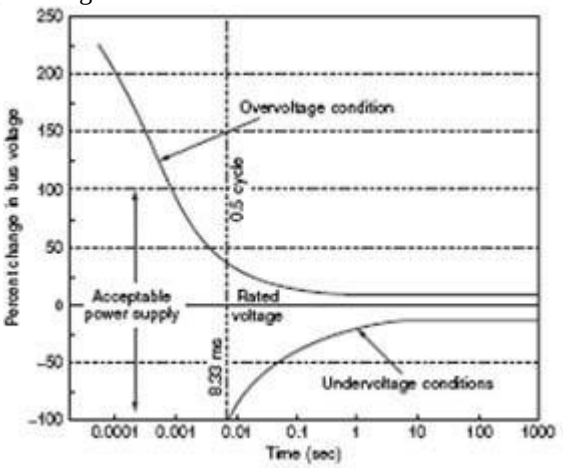


Fig.13–ShowingCBEMACurve[43]

Next step is ITIC curve, which is developed by Information Technology Industry Council [42]. It is a modified version of CBEMA. This curves acts as a standard for the safety of equipmentfromdisturbancebydeterminingitstolerantability.

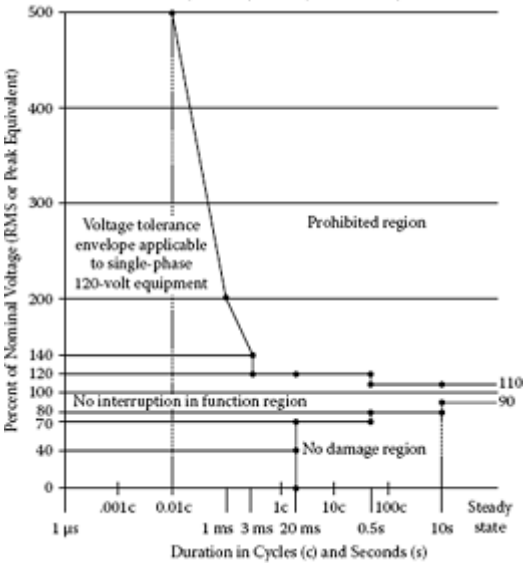


Fig.14–ITICCurve[42]

VI. CONCLUSION

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, isolationtransformer, use ofenergystorage 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 getan overviewof power quality issues so that they come up with latest technology.

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