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Enhancement of PQ parameters in Distribution System by DGs: A Taxonomical Review

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Abstract –This paper presents the enhancements of PQ parameters such as voltage swell, voltage sag, harmonics, etc. in Distribution system by Distributed Generation (DGs). This paper also presents the challenges and opportunities of PQ parameters in Distribution system by DGs. This survey article is very much useful for researchers, scientific engineers and industrial persons in conjunction with improvements of PQ parameters in distribution systems by DGs.

Keywords: Voltage sag, Voltage swell, Harmonics, Distribution systems, Distributed generation

Nomenclature

CD	Conventional devices
CPD	Custom power devices
FACTS	Flexible AC transmission system
DGs	Distributed generation
UPQC	Unified power quality conditioner
OLTC	Online tap change transformer
SSSC	Static sub synchronous condenser
STATCOM	Static compensator
DSTATCOM	Distributed static compensator
IPFC	Interlink power flow controller
HPFC	Hybrid power flow controller
UPFC	Unified power quality conditioner
GIPFC	Generalized interlink power flow controller
DVR	Dynamic voltage restorer
TCSC	Thyrised controlled series capacitor
PQ	Power Quality
GUPFC	Generalized unified power flow controller
SVC	Static var compensator
PCC	Point of common coupling
DG1,DG2,DG3 &DG4	Different types of distributed generation

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I. INTRODUCTION

Operation of a large power system with maintaining proper power quality is always been a difficult task. It becomes more difficult to maintain the power quality when rapid expansion of previously designed power system occurred. To redesign of such a power system is not feasible and also cost effective. To improve the quality of power of such a large system, conventional methods of compensation can be used. With increasing applications of nonlinear and electronically switched devices in distribution systems and industries, Power-Quality (PQ) problems, like harmonics, neutral current elimination, reactive power has become an unavoidable issue.
This effects can be compensated in distribution system using conventional devices (OLTC, Phase modifier circuit, Bank of capacitor, bank of inductor etc.), DGs (Different types of DGs such as DG1, DG2, DG3 and DG4), and FACTS controllers (SVC, TCSC, SSSC, UPFC, IPFC, UPQC, GUPFC, HPFC) or Custom power devices (DVR, STATCOM and D-STATCOM etc.) are used in distribution systems .

The important factors to be considered in power quality measurement are the active power, reactive power, variation of voltage and current, flicker, harmonics, and electrical behavior of switching operation [1]. According to definition of power quality given in IEEE standard, "Power quality is the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment." Serious problems in electrical systems is the increasing number of electronic components of devices that are used by industry as well as residences and increasing use of nonlinear loads is the main cause for increased voltage, current and harmonics issues[2][3].
In recent years, the development of power electronics devices has been led for the implementation of electronic equipment which is suitable for electrical power systems [4]. These types of devices allow great flexibility in: a) controlling the power flow in transmission systems using Flexible AC Transmission System (FACTS) devices, b) enhancing the power quality in distribution systems employing Custom Power devices [5][6]. Harmonic current components create several problems like as follows :1) Increase in power system losses, 2) Overheating and insulator failures in transformers, rotating machinery, conductor, and cables, 3) Reactive power burden, 4) Low system efficiency, 5) Poor power factor, 6) System unbalances and causes excessive neutral currents, 7) Malfunctioning of the protective relays and untimely tripping.
One of the effective approaches is to use a UPQC at PCC for the protection of sensitive loads. It is a combination of shunt and series active power filters, sharing a common dc link as shown in Fig.1 [7]. It is the only versatile device which can easily mitigate many power quality problems related with voltage and current simultaneously. It also compensates almost all power quality problems like voltage harmonics, voltage unbalance, voltage flickers, voltage sags & swells, current harmonics, reactive current, current unbalance, and can also be used to prevent harmonic load current from entering into the power system [8].

Electric PQ is a term which has captured increasing attention in distribution system. The measure of PQ depends upon the needs of the equipment that is being supplied. Usually the term PQ refers to maintaining a sinusoidal waveform of bus voltages at rated voltage and frequency. There are two approaches to the mitigation of PQ problems [9]. The first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances.

The application of power electronics to power distribution system for the benefit of a customer or group of customers is called custom power devices. Like Flexible AC Transmission System (FACTS), the term custom power use for distribution system. The UPQC is one of the key custom power device, which can compensate both current and voltage related problems, simultaneously [10]. The UPQC is connected before the load to make the load voltage free from any distortions and at the same time, the reactive current drawn from source should be compensated in such a way that the currents at source side, would be in phase with utility voltages [11]. Control strategy plays the most significant role in any power electronics based system. It is the control strategy which decides the behavior and desired operation of a particular system. The effectiveness of a UPQC system solely depends upon its control algorithm. The UPQC control strategy determines the reference signals (current and voltage) and, thus, decides the switching instants of inverter switches, such that the desired performance can be achieved [12-13].

The voltage sag/dip is the most frequently occurring problem. There are many methods to overcome this problem. Among them the use of FACT devices is an efficient one. In the open literatures are presented an overview of the FACT devices like- DVR, D-STATCOM, and Auto-Transformer in mitigating voltage sag.
The quality of the power is affected if there is any deviation in the voltage and frequency values at which the power is being supplied. This affects the performance and life time of the end user equipment. Whereas, the continuity of the power supplied is affected by the faults which occur in the power system. So to maintain the continuity of the power being supplied, the faults should be cleared at a faster rate and for this the power system switchgear should be designed to operate without any time lag. The power quality is affected many problems which occur in transmission system and distribution system. Some of them are like- harmonics, transients, sudden switching operations, voltage fluctuations, frequency variations etc. These problems are also responsible in deteriorating the consumer appliances. In order to enhance the behavior of the power system, these all problems should be eliminated.

With the recent advancements in power electronic devices, there are many possibilities to reduce these problems in the power system. One of them is the use of Flexible AC Transmission System (FACTS) devices. The connection of these devices in the power system helps in improving the power quality and reliability [14].

This paper organized as follows: Section II introduced Power Quality problems, key issues, opportunities and challenges Section III Presented the taxonomical review of enhancement of PQ parameters with conventional devices, DGs, FACTS controllers or custom power devices. Section IV presented conclusion of paper.

II. POWER QUALITY: KEY ISSUES, OPPORTUNITIES AND CHALLENGES

The electric power network has undergone several modifications from the time of its invention. The modern electric power network has many challenges that should be met in order to deliver qualitative power in a reliable manner. There are many factors both internal and external that affect the quality and quantity of power that is being delivered. [14]

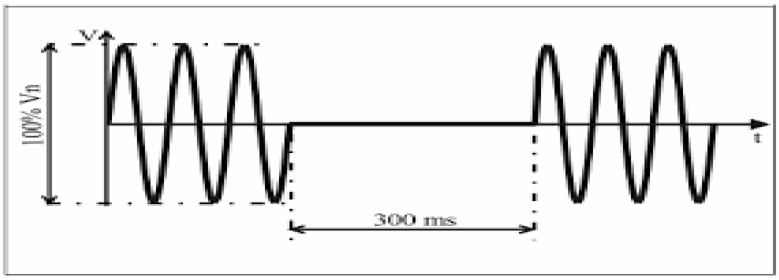
Power Quality:

The quality of electric power delivered is characterized by two factors namely- “continuity” of supply and the “quality” of voltage. As indicated by IEEE standard 1100,
Power Quality is characterized as-
"The idea of controlling and establishing the touchy supplies in a manner that is suitable for the operation of the gear."

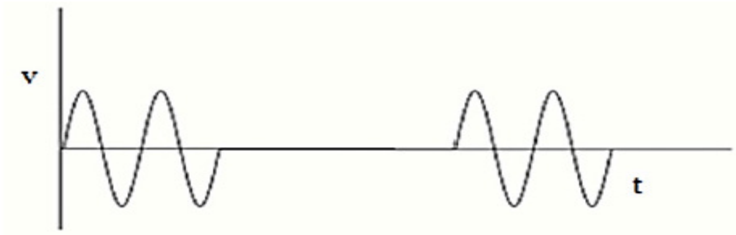
Power quality Issues:

There are many reasons by which the power quality is affected. The occurrence of such problems in the power system network is almost indispensable. Therefore, to maintain the quality of power care must be taken that suitable devices are kept in operation to prevent the consequences of these problems. Here an overview of different power quality issues with their causes and consequences is presented.

- **Interruptions:** It is the failure in the continuity of supply for a period of time. Here the supply signal (voltage or current) may be close to zero. This is defined by *IEC* (International Electro technical Committee) as “lower than 1% of the declared value” and by the *IEEE* (IEEE Std. 1159:1995) as “lower than 10%”.Based on the time period of the interruption, these are classified into two types:[15]

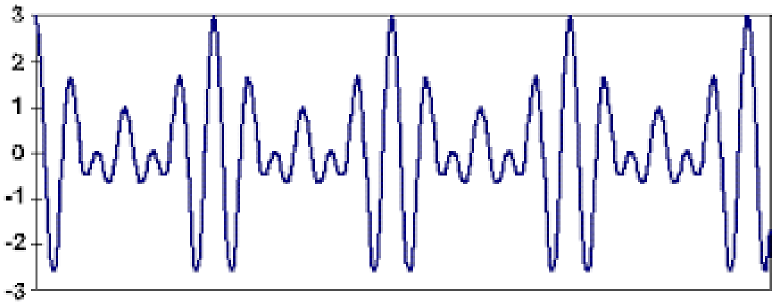


Short Interruptions: If the duration for which the interruption occurs is of few mille seconds then it is called as short interruption.
Long Interruptions: If the duration for which the interruption occur is large ranging from few mille seconds to several seconds then it is noticed as long interruption.

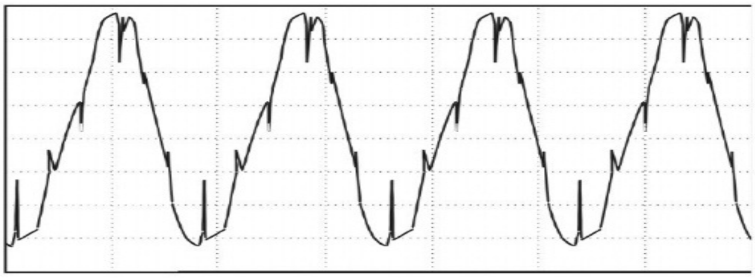


- **Waveform Distortion:** The power system network tries to generate and transmit sinusoidal voltage and current signals. But the sinusoidal nature is not maintained and distortions occur in the signal. The cause of waveform distortions are discussed in reference [15].
  DC Offset: The DC voltage which is present in the signal is known as DC offset. Due to the presence of DC offset, the signal shifts by certain level from its actual reference level.
  Harmonics: These are voltage and current signals at frequencies which are integral multiples of the fundamental frequency. These are caused due to the presence of non-linear loads in the power system network.

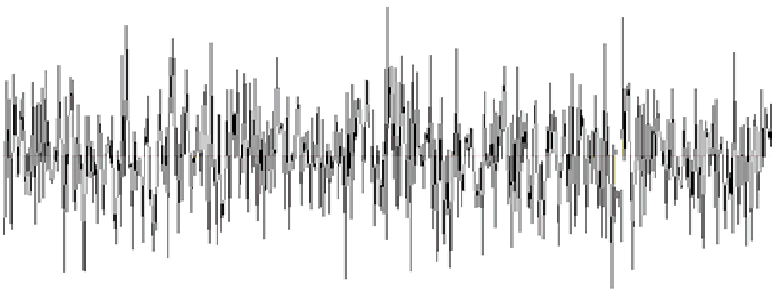
Inter Harmonics: These are the harmonics at frequencies which are not the integral multiples of fundamental frequency.



Notching: This is a periodic disturbance caused by the transfer of current from one phase to another during the commutation of a power electronic device.

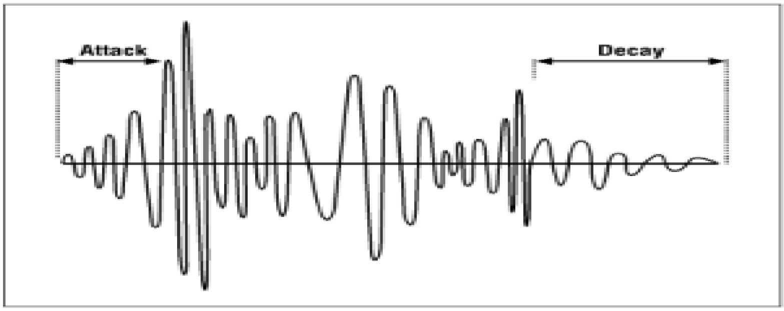


Noise: This is caused by the presence of unwanted signals. Noise is caused due to interference with communication networks.

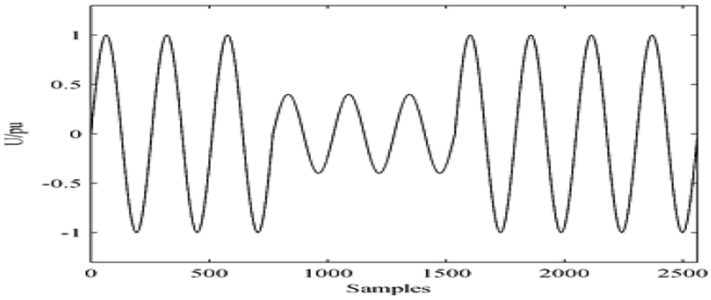


- **Frequency Variations:** The electric power network is designed to operate at a specified value (50 Hz) of frequency. The frequency of the framework is identified with the rotational rate of the generators in the system. The frequency variations are caused if there is any imbalance in the supply and demand. Large variations in the frequency are caused due to the failure of a generator or sudden switching of loads.

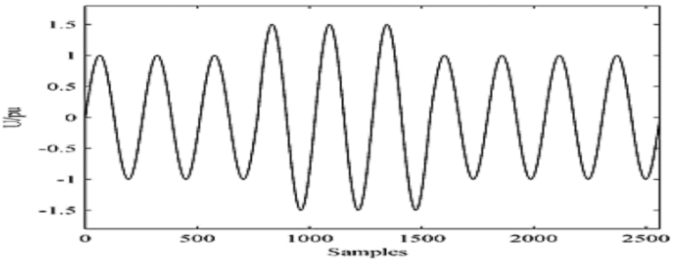
- **Transients:** The transients are the momentary changes in voltage and current signals in the power system over a short period of time. These transients are categorized into two types- impulsive, oscillatory. The impulsive transients are unidirectional whereas the oscillatory transients have swings with rapid change of polarity.



- **Voltage Sag:** The voltage sag is defined as the dip in the voltage level by 10% to 90% for a period of half cycle or more [16] [17] [18] [19].



- **Voltage Swell:** Voltage swell is defined as the rise in the voltage beyond the normal value by 10% to 80% for a period of half cycle or more [18].



- **Voltage Unbalance:** The unbalance in the voltage is defined as the situation where the magnitudes and phase angles between the voltage signals of different phases are not equal.
- **Voltage Fluctuation:** These are a series of a random voltage changes that exist within the specified voltage ranges.
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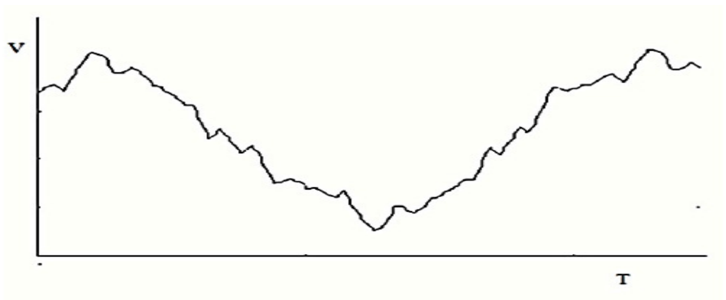

Among the different power quality problems discussed, the under voltage or voltage sag is the prominent one as it occurs often and affects the power system network largely.

III. CLASSIFICATION OF MULTILEVEL INVERTERS

Table 1: Taxonomy for PQ improvement with conventional devices in distribution system

S.NO.	REFERENCE NO	PUBLICATION YEAR	AUTHERS	PQ PARAMETERS	TYPE OF CONVENTIONAL DEVICES USED FOR PQ IMPROVEMENT	REMARK
1	[20]	2011	Nazmus Sahadat *et.al.*	VOLTAGE SAG & SWELL	BANK OF CAPACITORS	SHUNT COMPENSATION
2	[21]	2013	B. Saritha	REACTIVE POWER CONSUMPTION	ISOLATED ASYNCHRONOUS GENERATOR	ELECTRIC LOAD CONTROLLER
4	[22]	2014	M.Senthikumar	HARMONICS	DC/DC CONVERTER	GRID INTERCONNECTION
5	[23]	2013	Amitava Das	Z-SOURCE & T-SOURCE INVERTER	COUPLED INDUCTOR	BOOST CONTROL
6	[24]	2013	M.Rekha	HARMONICS	ACTIVE POWER FILTER	SRF CONTROL METHOD
7	[25]	2014	M.Kalyanasundaram	REACTIVE POWER COMPENSATION	VOLTAGE SOURCE INVERTER	SYNCHRONOUS REFERENCE FRAME
8	[26]	2013	Shazyl A. Mohammed	VOLTAGE SAG MITIGATION	DYNAMIC VOLTAGE RESTORER	VOLTAGE SAG AT CRITICAL LOADS
9	[27]	2008	Seon-Ju Ahu	VOLTAGE SAG	RELATIVE LOCATION	POWER QUALITY
10	[28]	2006	II-Yop Chung	POWER QUALITY	DIAGNOSIS SYSTEM	MONITORING SYSTEM
11	[29]	2006	Chang-Hyun Park	VOLTAGE SAG	OOP (OBJECT ORIENTED PROGRAMMING)	POWER SYSTEM
12	[30]	2003	Milan Prodanovic	POWER QUALITY	CURRENT ESTIMATOR	GRID CONNECTION
13	[31]	2005	L.H.Tey	POWER QUALITY	ADAPTIVE SHUNT ACTIVE FILTER	ARTIFICIAL NEURAL NETWORK
14	[32]	2005	Yunwei Li	POWER QUALITY	GRID INTERFACING COMPENSATOR	PQ COMPENSATOR
15	[33]	2006	Omer Nezih Gerek	PQ (VOLTAGE WAVEFORM)	COVARIANCE ANALYSIS	PQ EVENT CLASSIFICATION

16	[34]	2007	Hee-Sang Ko	FUZZY LOGIC	LINEAR QUADRATIC CONTROL	LQR CONTROLLER
17	[35]	2008	Bhim Singh	POWER QUALITY	CONVENTIONAL ELECTRONIC LOAD CONTROLLER	ISOLATED POWER GENERATION
18	[36]	2014	Jinwei He	ADAPTIVE HYBRID VOLTAGE	HCM APPROACH	VOLTAGE CONTROL
19	[37]	2011	S. Rajasekar	CASCADED MULTILEVEL INVERTER	MULTICARRIER PWM TECHNIQUE	POWER FACTOR CORRECTION
20	[38]	2000	Hyen Young Choi	VOLTAGE SAG	PI AND PID CONTROL	VOLTAGE SAG COMPENSATION

Table 2: Taxonomy for PQ improvement with DGs in distributed system

S.NO.	REFERENCE NO	PUBLICATION YEAR	AUTHERS	PQ PARAMETERS	TYPE OF DGS USED FOR PQ IMPROVEMENT	REMARK
1	[39]	2012	Veeraiah Kumbha	D-STATCOM	POWER QUALITY	--
2	[40]	2015	Madhu GM	STATCOM	POWER QUALITY	--
3	[41]	2015	P.K Mani	DSTATCOM	CURRENT HARMONICS	CURRENT & VOLTAGE COMPENSATION
4	[42]	2014	P.Venkata Kishore	DSTATCOM	POWER QUALITY	--
5	[43]	2012	Mohammed Shafiuddin	STATCOM	POWER QUALITY	
6	[44]	2015	G.Srinivas	D-STATCOM	POWER QUALITY	SOURCE CURRENT MITIGATION
7	[45]	2009	Chandana Jayampathi Gajanayake	POWER QUALITY	Z-SOURCE-INVERTER-BASED FLEXIBLE DG	Z-SOURCE INVERTER

Table 3: Taxonomy for PQ improvement with FACTS Controllers and custom power devices in distribution system

S.NO.	REFERENCE NO	PUBLICATION YEAR	AUTHORS	PQ PARAMETERS	TYPE OF FACTS CONTROLLERS ARE CUSTOM POWER DEVICES USED FOR PQ IMPROVEMENTS	REMARK
2	[46]	2010	ALOK KUMAR MOHANTY	SVC	PQ PARAMETERS	Semiconductor technology
3	[47]	2014	A.PRAVEEN	DVR	VOLTAGE SAG	Pi controller

4	[48]	2013	C.K. SUNDARABALAN	DVR	VOLTAGE SAG	Artificial Neural Network
5	[49]	2012	SANDESH JAIN	DVR	POWER QUALITY	d-q method
6	[50]	2000	JOHN J. PASERBA	STATCOM & SSTS	POWER QUALITY	Back-to-back tie
7	[51]	2013	DR. K. RAVICHANDRUDU	UPFC	VOLTAGE MAGNITUDE & PHASE ANGLE	Shunt connected
8	[52]	2014	PRAFULL A.DESALE	DVR	POWER QUALITY	--
9	[53]	2013	A.RADHA KRISHNA	FACTS	POWER QUALITY	Installation factor
10	[54]	2012	KULDEEP KUMAR SINGH	UPFC	POWER QUALITY	PID & Fuzzy Controller
12	[55]	2005	DONG-JUN WON	UPQC	HARMONICS & VOLTAGE SAG	Cp95
13	[56]	2003	J.W. LIU	DVR	VOLTAGE MAGNITUDE	PHASE ANGLE SHIFT
14	[57]	2011	AHMET TEKE	UPQC	POWER QUALITY	REFERENCE SIGNAL GENERATION

IV. CONCLUSION

This paper presents the enhancement of PQ parameters by conventional devices (OLTC, Phase modifier circuit, Bank of capacitor, bank of inductor etc.), DGs (Different types of DGs such as DG1, DG2, DG3 and DG4), and FACTS controllers (SVC, TCSC, SSSC, UPFC, IPFC, GUPFC, HPFC) or Custom power devices (DVR, STATCOM and D-STATCOM etc.) are used in distribution systems .

Future scope regarding with this work as follows:

- Enhancement of PQ parameters by optimal placement and proper coordinated operation of similar type of conventional devices.
- Enhancement of PQ parameters by optimal placement and proper coordinated operation of dissimilar type of conventional devices.
- Enhancement of PQ parameters by optimal placement and proper coordinated operation of similar type of DGs.
- Enhancement of PQ parameters by optimal placement and proper coordinated operation of dissimilar type of DGs.
- Enhancement of PQ parameters by optimal placement and proper coordinated operation of similar type of FACTS controllers.
- Enhancement of PQ parameters by optimal placement and proper coordinated operation of dissimilar type of FACTS controllers.
- Enhancement of PQ parameters by optimal placement and proper coordinated operation of similar type of custom power devices.
- Enhancement of PQ parameters by optimal placement and proper coordinated operation of dissimilar type of custom power devices.
- Enhancement of PQ parameters by optimal placement and proper coordinated operation of Hybrid of any two devices or more than two devices.

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