Power Quality Improvement in Power Distribution System: Current and Future Trends in Research

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Abstract: Increased economic growth rate of India has resulted in increased energy needs at a very high pace. Managing the rapidly increasing energy needs is one of the major challenge is what India is facing today as from several decades; the supply of energy has fallen short of the demand. This gap can be bridged only with the structural reforms in the energy sector. These reforms will however take time to be implemented considering the numerous challenges involved. Distribution generation (DG) through renewable energy resources is presently trying to fill this gap. With a high penetration of DG unit, interfacing power converters, type and switching of loads etc. arises quality issues. This paper introduces a set of innovative technical measures to mitigate major power quality issues and also aims to provide some future scopes on the same for the benefit of research scholars and industrialist.

Keywords: Custom Power Devices (CPD), Distribution generation (DG), Filters, Power Quality (PQ), Power Converters.

1. Introduction

The power demand in real time world is rapidly increasing day by day. Starting from the daily needs of a human being to the industrial needs the electric power play a very crucial role. Supplying huge and continuous power is the biggest challenging task for the existing power system. In an attempt of supplying a continuous power for the consumers, the distributed generation (dispersed generation, decentralized generation and embedded generation) are introduced and it is integrated to the power grid. Distribution generation is the process of generating electricity at the customer end by the customer that may be interconnected to the distribution grids. Power generated by these distributed generation will be fed to the main grid through proper integration. The integration of DG's into the main grid imposes many problems on the grid. The integration of DG's, load fluctuation, sudden changes in loads, electronic equipments all are adversely effects on main grid power quality.

The main intention of penetration of DG's into the main grid is to supply peak load and to fulfil consumer demand. But the penetration point of DGs is selected by the customer that may inappropriate. Therefore it adversely effects on distribution system power, protection and power quality. The power quality issues include a deviation in the voltage level, frequency and current from its standard value as defined by the IEEE standard 929-2000. Also DG's will affect steady state stability of the power system for the consumer. In India, around 22% of electricity produced is lost in distribution system. Therefore reducing the system losses and improving the power quality attracts many researchers, academicians and industrialist in the last fifteen years [1]-[55].

This paper proposes taxonomy of power quality enhancement techniques and control strategies with and without DGs in distribution system, contributing a consolidated work carried out related to the subject. The handouts provides in depth knowledge about the work done in improving the power quality using various methods [1]-[55]. This literature survey serves as a guide for the researchers in power quality improvement. This paper put forward a various optimal control systems and ideas, offering the contributions towards PQI of all the reviewed papers.

This paper is arranged as follows: Section II presents the mathematical formulation and taxonomy reviewed for PQI. Section III discusses different methods for PQI techniques proposed by the authors. Section IV figured out the contribution of the investigated work. Section V summarised the future scope on power quality issues and in section VI Conclusions are derived.

2. Objective Function

2.1 General problem Statement

The mitigation of power quality issues is a challenging and a crucial problem. The power quality issues of a distribution system with and without DGs deals with the fortitude of voltage sag and swell, over and under voltage, frequency fluctuation and harmonics under various constraints including system losses.

2.2 Objectives

The main objective functions of this survey are: 1) minimisation of voltage fluctuation 2) Minimisation of supply frequency fluctuation 3) control of voltage (for short and long duration) 4) elimination of harmonics 5) reducing the real and reactive power losses 6) minimisation of utilisation cost. The objective functions of PQI methods can be single objective or multi objective which consisting of above scenario.

2.3 System Condition

The different distribution system can be more sensitive for various electrical variables such as voltage, reactive power etc. Therefore the analysis of system condition also plays a major role for designing a system to enhance power quality. The reviewed paper having different system condition without and with high and low penetration of DGs. The IEEE standard systems are also considered to test the proposed control system by the reviewer under faulty conditions.

2.4 Load Variables

The load profile is considered in PQI as: 1) balance loads 2) unbalanced loads 3) time varying loads 4) fuzzy 5) one load level 6) multi load level. The load can be connected to a system along the line or it may be concentrated on system buses. For concentrated type load, the loads are: 1) Constant power type 2) Variable power 3) balanced and 4) unbalanced.

2.5 Taxonomy

The details of taxonomical survey of literature regarding PQI in the distribution system presented in TABLE I.

TABLE I.TAXONOMY OF THE REVIEWED POWER QUALITY IMPROVEMENT MODELS

Reference	Objective Function	System Condition	Load Type	Methodology Used
[1]	Over Voltage	High penetration of DGs	Variable load	Power flow allocation using OV mitigation algorithm
[2]	Voltage sag/swell,	Distribution system Without DG	Static load	dynamic Voltage Restorer (DVR)
[3]	Voltage regulation + harmonics	Multi Machine System	Variable load	Synchronous PI Controller for STATCOM
[4]	Voltage Profile	With and Without DGs	Linear load	Number, Location and sizing of DGs using PSO
[5]	Voltage Regulation	PV System interfaced Grid	Non linear load	MPPT Controlled PV System with hysteresis current controlled inverter
[6]	Voltage Regulation	PV System interfaced Grid	Non linear load	MPC based controller is designed to coordinate BESS with a set of controllers.
[7]	Voltage profile + power losses	Faults with DG units	one load level	Calculating the voltage deviation at every point in loop distribution system to find optimal location of DG unit.
[8]	Voltage	Hybrid DG	Non linear	FACTS-DVS/GP based switched filter-Capacitor

	regulation		load	compensation scheme
[9]	Voltage regulation	DG connected grid	Non linear load	On load tap changer (OLTC) with automatic voltage (AVC) controller and line compensator device (LCD) to compensate reactive power.
[10]	Voltage profile	DG connected grid	one load level	Optimal placement and sizing of DG using sensitivity analysis
[11]	Voltage profile+ harmonic	With High penetration of DGs	Multi load level	Multi level control strategy with hierarchical control structure
[12]	THD	With PMSM	Variable load	A Shunt Active Power Filter (SAPF) using Anti-Hebbian control algorithm.
[13]	Voltage regulation + harmonics Compensation	With Onshore Grid network	Non linear loads	GTO-VSC based a three level 48 pulse STATCOM integrating using line-commutated high-voltage dc connection (LCC-HVDC).
[14]	Voltage Profile	Wind and Solar PV system with week utility grid during post fault	Varying load	STATCOM and Battery energy storage at point of common coupling (PCC)
[15]	Voltage Regulation + Reliability	DG interfaced with grid	Unbalanced and Non linear Load	Instantaneous symmetrical component theory (ISCT) Controlled Dual Voltage Source Inverter(DVSI)
[16]	Harmonics + Load balance+ power factor correction	Grid integrated solar PV System	Linear and non-linear load	Two stage -three phase solar PV –grid interfaced using multifunctional VSC controlled by Adaptive noise reduction technique.
[17]	Voltage Profile+ Reduce losses + power factor	IEEE 30 bus system with 5 DGs	One level load	PSO based optimal capacitor placement and its sizing
[18]	Voltage Sag and swell + SOC	Utility with Unbalanced Condition	Multi level Load	Fuzzy Controlled hybrid system consisting of Fuel cells and Battery.
[19]	Voltage regulation	PV System connected grid with	Sensitive load	Dynamic voltage restorer(DVR) employing PWM technique connected Incremental conductance algorithm (INC) based MPPT Solar PV system
[20]	Harmonics + active power filtering	DG connected grid	non linear loads	Vector Control Power Electronic interfaced DG
[21]	Voltage control + harmonics	High penetration of PV units to LV distribution network in unbalanced supply	non-linear unbalanced load conditions	PV system with Solar DSTATCOM
[22]	Voltage Regulation + real and Reactive power control	UPFC enabled Wind generated connected grid	non linear loads	UPFC

TABLE I(*Continued*).TAXONOMY OF THE REVIEWED POWER QUALITY IMPROVEMENT MODELS

Reference	Objective Function	System Condition	Load Type	Methodology Used
[23]	Voltage regulation + harmonics	System under steady state and transient state	One load level	Fuzzy based Extinction Angle Control, random PWM and Sinusoidal PWM control scheme ac-ac converter
[24]	Reactive power compensation + Harmonics	PV in Distribution network	Linear loads	Perturbation and observation (P & O) based MPPT PV System interconnects to utility through active filter.
[25]	THD	SOFC connected Grid	Non linear loads	The ANFIS uses GA for Space vector control of inverter.
[26]	Voltage Stabilization	Self excited IG connected to utility grid	hybrid loads	Facts based compensator device and PWM based PID controller
[27]	Voltage profile	Wind generating system connected grid	Varying load	Matrix converter based Wind turbine generator set under variable speed condition
[28]	Voltage Control +harmonics	Utility connected microgrid	Fuzzy load	ANFIS based Unified Power Quality Conditioner (UPQC).
[29]	Voltage sag + power loss	IEEE 37+69 bus system	Static load	GA for optimal placement of DG
[30]	Voltage + Loss	IEEE 15 bus radial network system	Static load	Particle swarm optimization based harmonic power flow and sensitivity analysis
[31]	Voltage Profile +Power loss	IEEE 33 bus	Time varying load	Hybrid weight-improved particle swarm optimization (WIPSO)- Gravitational Search Algorithm (GSA) algorithm
[32]	Voltage profile	IEEE 9 bus system with high penetration of RES	static load	Genetic algorithm
[33]	Voltage regulation	Distribution system	Dynamic load	PWM controlled VSI-based DG Interface
[34]	Voltage profile	IEEE 30 bus system	One level load	PSO
[35]	Voltage Profile + Power loss	IEEE 69 bus system	One level load	PSO & Bat Algorithm
[36]	Voltage profile + Power Loss	IEEE 30 bus system	One level load	Lagrangian Relaxation technique
[37]	Frequency + Voltage	Multi DG	Variable	Decentralized Controllable loads

	Control	connected System	load	
[38]	Current Harmonics	Distribution system under Steady State	Dynamic load condition	PSO assisted Kalman filter (KF) based PI Current controlled Shunt active power filter
[39]	Harmonic + Reactive power compensation	Distribution system without DG	Non linear load	Three Phase Infinite inverter level based DSTATCOM
[40]	Harmonics + Power factor correction	Grid connected	Fuzzy loads	Power Quality Enhancer(PQE) - Power factor correction (PFC) controller
[41]	THD	Multiple PV System connected Grid	non linear load	Unified Power Quality Control (UPQC)
[42]	THD	DFIG Connected Grid	Nonlinear loads	Double tuned PI-R Controller
[43]	Voltage Regulation + harmonics	DFIG connected Grid	Multi level load	Hybrid fuzzy based UPQC
[44]	Harmonics + Voltage Stabilization	Distribution Network with wind energy	Non linear load	Switched capacitor filter compensator controlled by dynamic tri loop error driven VSC.
[45]	Voltage control + Harmonics	High penetration of wind turbine	non linear load	ANFIS based STATCOM and ULTC transformer with a three phase harmonic filter
[46]	Harmonics	RES Connected grid	non linear load	Multi functional grid connected Inverter (MFGCI).
[47]	Voltage Sag + Harmonics	Wind Plant connected grid.	non linear loads	Fuzzy based PI +UPQC.
[48]	Voltage + Harmonics	Distribution System	Constant load	Hybrid power filter.
[49]	Harmonics	DG Connected Grid	Non linear loads	Dual SAPF controlled by instantaneous real and reactive power control theory
[50]	Reactive power + harmonics	PV System connected Grid	unbalanced and non linear loads	Reduced Switch Count Multi Level inverter (RSC-MLI) based DSTATCOM
[51]	Harmonics+ Reactive power	Autonomous Microgrid with weak AC Supply	Linear load	Online Control Strategy based Reinforcement Learning algorithm.
[52]	Harmonics + Reactive power	Distribution system without DG	non linear and reactive loads	Fuzzy Logic Controller based instantaneous p-q theory with SAF.
[53]	Voltage + Harmonics	Distribution	Static load	Voltage flux oriented control (VFOC)

	+PF	system		Algorithm
[54]	Voltage regulation + Harmonics	Distribution system without DG	Sensitive load	iCosθ Control Algorithm
[55]	Voltage Profile	IEEE- 33, 69 bus system	Time varying load	Exponential PSO with Reduced Search Space
[56]	Voltage & Current Compensation + harmonics	Distribution network without DG	Non linear load	Distributed Power Flow Controller
[57]	Frequency and voltage control	Grid connected WPGS	Non linear load	Pitch control and superconducting magnate energy storage(SMES)

3. PQI METHODS

3.1 Placement of DGs

The optimal placement of DGs in distribution system helps in improving the voltage compensation and also reduces the system power losses. The Particle swarm optimisation (PSO) techniques is applied to place DG in distribution system to improve voltage profile [4], also used to reduce the system power loss [34]. PSO based harmonic power flow and sensitivity analysis is applied to integrate Wind power plant with minimum losses and the best voltage profile with static loads [30]. In [31], the Hybrid weight-improved PSO (WIPSO)-Gravitational Search Algorithm (GSA) algorithm is tested to improve PQ with growing load. The PQI is also achieved by using PSO and Bat algorithm [35]. The exponential PSO with reduced search space found to be the best optimal location techniques compared to other PSO technique [55].

3.2 Custom Power Devices

Custom Power devices (CPD) play a crucial role in PQI of transmission and distribution system. The Dynamic voltage restorer (DVR) is used to mitigate the voltage sag and swell in distribution network [2]. The performance of DVR is improved by employing PWM technique connected Incremental conductance algorithm (INC) based MPPT Solar PV system with sensitive load in [19].

The STATCOM is connected to the system to improve both voltage regulation and total harmonic distortion (THD). The synchronous PI controller STATCOM is tested under network disturbance to provide voltage regulation and THD. The performance is compared with conventional PI STATCOM controller and multivariable STATCOM controller [3].Solar based DSTATCOM and fuel cell based DSTATCOM is proposed for high penetration of LV generators with Non linear loads [21],[54]. For the fast compensation of reactive power, the GTO-VSC based a three level 48 pulse STATCOM is designed [13]. Three Phase Infinite inverter level based DSTATCOM and Reduced Switch Count Multi Level inverter (RSC-MLI) based DSTATCOM is designed for supply the varying load compensation [39], [50]. For high penetration of wind turbine, the hybrid DSTATCOM is proposed using artificial intelligence with under load tap changer (ULTC) with variable load [45]. For weak AC grid, the novel online control strategy with RL algorithm based DSTATCOM is designed to improve voltage regulation and to suppress harmonics under non linear load [51].

The total harmonic distortion (THD) was reduced to 5.25%, the unified power quality controller (UPQC) is connected in multiple PV unit integrated grid under non linear load [41]. The THD is reduced to 0.46% and also regulated the voltage at point of common coupling (PCC) by using hybrid fuzzy logic controller based in double fed Induction generator (DFIG) connected utility system under varying load condition

[43],[47]. The artificial intelligence- fuzzy inference system (ANFIS) based UPQC is designed for PQI in various DG technologies and battery connect distribution system [28]. In [22], the unified power flow controller is designed and

simulated to improve voltage regulation and real and reactive power flow in DFIG connected grid. Along with the voltage regulation, voltage and current harmonics are reduced in DFIG using distributed power flow controller (DPFC) [56].

3.3 Power Converters

The power converters in power system can be designed to solve the PQ issues. The over voltage mitigation control scheme based converter and matrix converter is proposed to improve the voltage regulation in grid connected DGS under non linear load [1], [27]. In [5] the hysteresis current controlled inverter is proposed for better voltage regulation in PV connected grid system and Instantaneous symmetrical component theory (ISCT) Controlled Dual Voltage Source Inverter (DVSI) for unbalanced and non linear load [15].for fast and dynamic voltage regulation under dynamic load, PWM controlled VSI based DG interface is proposed [33].

Vector Controlled converter and Multi functional grid connected Inverter (MFGCI) are introduced to mitigate the harmonics in [20],[46]. GA based Space vector control of inverter and double tuned PI-R Controller is recommended to reduce harmonics in SOFC and DFIG connected grid respectively [25] [42] under non linear load. The multiple objective functions is achieved in [11] [23] by designing Multi level control strategy with hierarchical control structure and Fuzzy based Extinction Angle Control(EAC)-PWM converter with high penetration of DGs. In [16] [40], the harmonics mitigation and power factor correction in grid connected residential PV system and load is concentrate by recommending the ANR technique based VSI and Power Quality Enhancer (PQE) - Power factor correction (PFC) controller. Frequency and voltage control is proposed by controlling the local load based on droop characteristic in [37].

3.4 Energy Storage System

The PQ issues are also alleviated by interfacing energy storage system at PCC of distribution system. The voltage regulation is improved by introducing MPC to coordinate battery energy storage system (BESS) [6]. BESS also interfaced with DGs in presence of hybrid controller [18]. In [11] , the author suggested the BESS at PCC with STATCOM in weak utility grid. The superconducting magnate Energy Storage (SMES) with wind power plant is proposed for effective voltage regulation [57].

3.5 On Load Tap Changer

The on load tap changer (OLTC) is used in conjunction with automatic voltage controller (AVC) and line compensator device (LCD) to minimise the voltage variation in distribution network [9].

3.6 Hybrid Filters

Filters are used improve the power quality in the system. The filters which are controlled by hybrid control algorithm are called hybrid filters. The FACTS-DVS based Switched filter capacitor compensator is introduced in hybrid DG connected utility with non linear load in [8] [44]. The capacitor is placed optimally and sizing using PSO algorithm to improve voltage profile and power factor [17]. Shunt active power filter (SAPF) is proposed with a Hebbian control algorithm [12], PSO assisted Kalman filter (KF) [38] and Fuzzy Logic Controller based instantaneous p-q theory [52] to reduce the harmonics with reactive loads. Instantaneous real and reactive power control theory based Dual SAPF technology is proposed to reduce current harmonics in [49].

The voltage, power factor and harmonics of the system is handled by designing voltage flux oriented control (VFOC) algorithm based LCL filter under static loads [53]. Perturbation and observation (P & O) based MPPT PV System interconnects to utility through active filter to reduce harmonics is discussed in [24]. In [48], the author proposed hybrid power filter to mitigate PQ issues in distribution system.

3.7 Evaluation

The heuristic methods of locating and sizing of DG in power quality concern is more effective and give best results compare to other methods. The Facts devices like DSTATCOM, DVR, UPFC, UPQC, etc have main contribution in PQI and the performance can be increased by using hybrid control technology.

PQ issues due to integration of DG at PCC can be mitigated by using multi level and multi functional converter with a hybrid control technology for better tuning of parameters. Hybrid filters also plays a significant role in PQI but location of active filters in complex system using optimal techniques.

4. Contributions

The main contributions of reviewed paper in PQI with and without DGs, under various system and load condition are tabulated in Table II.

5. Future Ideas

1. New technique for ODGP. The accuracy level of finding ODGP to improve PQ in distribution system can be increased by developing a new method combining different technologies like PSO+GA, TS+ABC, PSO+FZ, FZ +GSA,GA+OPF, FZ+HA, GSA+ TS etc. The objective function can be also increased if properly planned. The ODGP for dynamic loads can be considered in finding ODGP for PQI.

2. Coordinated Planning. The optimal location of filters, DGs and CPDs are the major PQI methods in utility system. Therefore the placement of filters, DGs and CPDs are in coordination is essential. Such a coordinated planning will contribute more in PQI of distribution system. The meta- heuristic methods will be used to find the optimal location of all the above.

3. Prediction and Preventing PQ Issues. Introducing prediction tool with CPDs into the power system will help in avoiding PQ issues and takes the necessary action in maintaining the quality of power. The proposed technique can be implemented in transmission system but a challenging task to incorporate in distribution

   system. The complex calculation and data analysis should be done to train the prediction tool.

4. Hybrid BESS/SMES with voltage regulator. The voltage regulation will be better by developing a technique by combining hybrid controlled BESS/SMES and voltage regulation devices.

5. Reactive Power Support. The DG can be used for reactive power supporter in distribution system for preventing voltage sag in future.

6. The innovative control scheme for power converters is required to develop for efficient integration of renewable DGs to support the distribution system power quality.

7. Practical Implementation of all these techniques is also possible for benefit of the society.

TABLE II. CONTRIBUTION OF THE REVIEWED POWER QUALITY IMPROVEMENT WORKS

Published Year	Contribution	Reference
2018	The MPC based integration of BESS is introduced for voltage regulation without affecting the state of charge.	[6]
2018	AN ODGP is solved for the better voltage profile and to reduce losses by calculating voltage deviations.	[7]
	The FACTS-DVS/GP with various controllers are designed to improve voltage regulation in hybrid renewable Wind/micro hydro with smart AC grid	[8]
2018	The fuel cell based DSTATCOM controlled by iCosθ algorithm is proposed to control both real voltage & harmonics.	[54]

2018	For fast and dynamic reactive power compensation, an GTO-VSC based STATCOM is proposed.	[13]
	An active filters and P & O based MPPT-PV system is interconnected to improve PQ of distribution system.	[24]
2018	The voltage profile is improved using the GA based placement and sizing for high penetration of DG.	[32]
2018	The role of KF based PI Current controlled SAPF is compared with p-q theory in THD is evaluated.	[38]
2018	The Proposed PQE-PFC controller helps to reduce voltage THD in residential electrical grid.	[40]
	A Double tuned PI-R Controller used to reduce the THD and compared with conventional PI Controller.	[42]
2018	The mitigation of PQ issues is successfully achieved by introducing Hybrid fuzzy based UPQC.	[43]
2018	The RSC-MLI based DSTATCOM is designed to control reactive power and harmonics.	[50]
2018	A novel online control strategy based on RL algorithm for DSTATCOM is proposed to control reactive power and harmonics.	[51]
2017	The contribution of SAPF with anti-hebbian control algorithm in reducing harmonics compared with SRF based controlled algorithm.	[12]
2017	The contribution of STATCOM and BESS in improving the voltage profile at PCC during and post fault was simulated.	[14]
2017	The fuzzy based instantaneous p-q theory with SAF is introduced to control reactive power and harmonics.	[52]
2017	The VFOC with LCL filter is designed to improve the power quality of distribution system.	[53]
2017	Optimal location and allocation of DGs using WIPSO-GSA algorithm is proposed to improve voltage profile.	[31]
2017	A combination of PSO and Bat algorithm is carried out to find ODGP thereby PQ in IEEE 39 bus system.	[35]
2017	The Infinite inverter level based DSTATCOM is presented to reduce harmonics and voltage fluctuation.	[39]
2017	Source current harmonics are suppressed successfully by introducing Dual SAPF controlled by instantaneous real and reactive power control theory.	[49]
2016	The performance of SPI STATCOM is compared with conventional and multivariable STATCOM in PV connected grid.	[3]

2016	An ODGP is solved by using Exponential PSO with Reduced Search Space to improve voltage profile.	[55]
2015	An ISCT based DVSI is operated in two mode to compensate the reactive power and to balance the system.	[15]
2015	The ANR based VSI is proposed to improve PQ in Two stage -three phase solar PV interfaced grid.	[16]
2015	Voltage regulation and harmonics problem is solved by recommending ANFIS based UPQC.	[28]
2015	A simulink model of UPQC is designed to reduce the THD in PV connected system	[41]
2015	A MFGCI is designed operated in both forward and reverse power flow for PQI by reducing harmonics.	[46]
2015	A voltage sag and harmonics are reduced by proposing a fuzzy based PI controller UPQC in DFIG interfaced grid	[47]
2014	Plug and play pattern over voltage mitigation scheme is proposed for the system with high penetration of DGs.	[1]
2014	A DVR is designed to mitigate the voltage sag and swell in low voltage distribution system.	[2]
2014	An ODGP model is proposed based on PSO to improve voltage regulation in IEEE 30 bus system.	[4]
2014	The voltage regulation is improved by optimal placing and sizing of capacitor using PSO technique.	[17]
2014	The voltage sag and swell mitigated by controlling SOFC and battery using fuzzy controller.	[18]
2014	A better voltage regulation is provided by proposing PWM controlled DVR in MPPT Solar PV connected grid.	[19]
2014	The DG is interfaced through vector control power converter and also enhances the PQ by active power filtering.	[20]
2014	The PQ related problems in wind mill connected grid are mitigated by designing hybrid power filter.	[48]
2013	An voltage is regulated through an ODGP by sensitivity analysis	[10]
2013	The voltage regulation and THD concern, New control approach inverter as a solar DSTATCOM is proposed.	[21]
2013	DPFC is designed to reduce voltage and current harmonics and improve power quality in a matter of seconds.	[56]
2012	The UPFC is introduced in DFIG connected grid as solution for PQ issues.	[22]

2012	A PSO based DG placement and sizing to achieve voltage regulation is introduced in IEEE 30 bus system.	[34]
2012	A Lagrangian Relaxation technique is proposed and compared the contributions in PQI with PSO technique.	[36]
2011	Fuzzy based EA control, R-PWM and SPWM techniques are proposed to mitigate PQ issues in transient state.	[23]
2011	An ODGP using PSO and sensitivity analysis suggested for better voltage regulation and power flow.	[30]
2011	A Switched capacitor filter compensator controlled by dynamic tri loop error driven VSC improves the power quality of wind connected grid.	[44]
2010	An voltage regulation for static loads is provided by ODGP method based on GA.	[29]
2009	The PWM controlled VSI-based DG Interface is recommended for fast and dynamic voltage regulation at PCC.	[33]
2009	A novel way of controlling the load locally to control system voltage and frequency is proposed.	[37]
2009	Frequency and voltage is controlled by proposing a Pitch control and (SMES) technique.	[57]
2009	A combination of multi level inverter and decentralised load technique used to improve voltage profile and THD.	[11]
2008	The matrix converter with a Sub and super synchronous switching scheme is introduced in variable speed wind mill for better voltage regulation.	[27]

TABLE II *(Continued)*. CONTRIBUTION OF THE REVIEWED POWER QUALITY IMPROVEMENT WORKS

Published Year	Contribution	Reference
2008	Reactive power compensation is achieved by using OLTC with AVR and LCD in distribution system.	[9]
2008	The novel inverter control technique is introduced and tested in PSCAD to regulate voltage in PV connected grid.	[5]
2006	The fine tuning of inverter parameter is done by using GA based SVC method for harmonic reduction.	[25]
2006	The facts based compensator and PID controller is designed for voltage stabilization and PQ enhancement.	[26]

6. Conclusion

This paper presents detailed information of state-of-the-art techniques to improve the power quality of distribution system with and with DG environment. The major power quality issues (harmonics, voltage and frequency variations) are extensively reviewed and the mitigation techniques are classified into six: ODGP, CPD, Power converters, ESS, OLTC and Hybrid filters. The role of each and every method in mitigating PQ issues is tabulated. The future research ideas in power quality concern are summarised based on the literature survey.

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