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

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ABSTRACT

The Increased economic growth rate in India has resulted in increased energy needs at a very high pace. Managing the rapidly increasing energy needs is one of the major challenges 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. arise 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 industrialists.

KEYWORDS: *Custom power devices (CPD), Distributed generation (DG), Power quality (PQ), power converters, Optimization.*

I. INTRODUCTION

The power demand in the 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 plays a very crucial role. Supplying huge and continuous power is the biggest challenging task for the existing power system. In an attempt of supplying continuous power for the consumers, the distributed generation (dispersed generation, decentralized generation, and embedded generation) are introduced and it is integrated into 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. The Power generated by these distributed generations will be fed to the main grid through proper integration. The integration of DGs into the main grid imposes many problems on the grid. The integration of DG's, load fluctuation, sudden changes in loads, electronic equipment all are adverse 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 fulfill consumer demand. But the penetration point of DGs is selected by the customer that may inappropriate. Therefore, it adversely affects the 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 the steady-state stability of the power system for the consumer. In India, around 22% of the electricity produced is lost in the 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 provide 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 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 summarized the future scope on power quality issues and in section VI Conclusions are derived.

II. Study of Problem Formulation

A. General Problem Statement

The mitigation of power quality issues is a challenging and 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.

B. Objective function found in survey

The main objective functions considered by various authors in theliterature are as follows: 1) minimization of voltage fluctuation 2) Minimization 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) minimization of utilization cost. The objective functions of PQI methods can be single-objective or multi-objective which consisting of the above scenario.

C. System Condition

The distribution system can be more sensitive for various electrical variables such as voltage, reactive power, etc. Therefore, the analysis of system conditions also plays a major role in designing a system to enhance power quality. The reviewed paper having different system conditions 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.

D. 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.

E. Taxonomy

The details of the taxonomical survey based on PQ issues of literature regarding PQI in the distribution system based on objective function that has been addressed by different techniques is presented in Table 1. The power quality issues such as voltage sag, swell, harmonics, power factor & reactive power compensation were taken consideration to mitigate. The statistical data of most common cited power quality issues found in literature is shown in Fig 1 and voltage related issues are more popular compare to other PQ issues. A number of techniques have been proposed in the recent literature on PQI is reported in Fig 2. where a greater number of authors are working on OPDG, custom power devices and power converters.

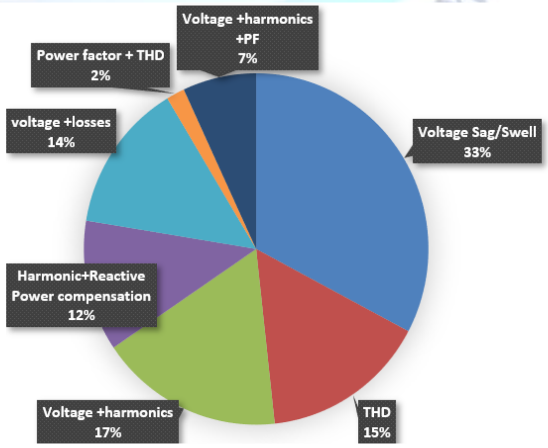

Fig 1. Power Quality Issues found in literature

Table 1: Taxonomy of the reviewed power qualityimprovement 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)
[4]	Voltage Profile	With and Without DGs	Linear load	Number, Location and sizing of DGs using PSO
[5]	Voltage Regulation	PV System interfaced Grid	Nonlinear 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.
[8]	Voltage regulation	Hybrid DG	Non-linear load	FACTS-DVS/GP based switched filter-Capacitor 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
[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)
[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
[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
[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
[55]	Voltage Profile	IEEE- 33, 69 bus system	Time varying load	Exponential PSO with Reduced Search Space
[12]	THD	With PMSM	Variable load	A Shunt Active Power Filter (SAPF) using Anti-Hebbian control algorithm.
[20]	Harmonics	DG connected grid	Non-linear loads	Vector Control Power Electronic interfaced DG
[25]	THD	SOFC connected Grid	Non-linear loads	The ANFIS uses GA for Space vector control of inverter.
[38]	Current Harmonics	Distribution system under Steady State	Dynamic load condition	PSO assisted Kalman filter (KF) based PI Current controlled Shunt active power filter
[41]	THD	Multiple PV System connected Grid	Non-linear load	Unified Power Quality Control (UPQC)
[46]	Harmonics	RES Connected grid	Non-linear load	Multi-functional grid connected Inverter (MFGCI).
[49]	Harmonics	DG Connected Grid	Non-linear loads	Dual SAPF controlled by instantaneous real and reactive power control theory
[42]	THD	DFIG Connected Grid	Non-linear loads	Double tuned PI-R Controller
[24]	Reactive power compensation	PV in Distribution network	Linear loads	P & O based MPPT PV System interconnects to utility through activefilter.
[3]	Voltage regulation + harmonics	Multi Machine System	Variable load	Synchronous PI Controller for STATCOM
[11]	Voltage profile+ harmonic	With High penetration of DGs	Multi load level	Multi-level control strategy with hierarchical control structure
[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).
[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.

[21]	Voltage dip/swell+ harmonics	IEEE 13 bus system	Unbalanced load	Solar-Dstatcom with a novel converter technology
[28]	Voltage Control +harmonics	Utility connected microgrid	Fuzzy load	ANFIS based Unified Power Quality Conditioner (UPQC).
[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
[15]	Voltage Regulation + Reliability	DG interfaced with grid	Unbalanced and Non-linear Load	Instantaneous symmetrical component theory (ISCT) Controlled Dual Voltage Source Inverter (DVSI)
[18]	Voltage Sag and swell + SOC	Utility with Unbalanced Condition	Mult-level Load	Fuzzy Controlled hybrid system consisting of Fuel cells and Battery.
[22]	Voltage Regulation + Real and Reactive power control	UPFC enabled Wind generated connected grid	Non-linear loads	UPFC
[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
[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
[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.
[54]	Voltage regulation + Harmonics	Distribution system without DG	Sensitive load	iCosθ Control Algorithm
[56]	Voltage & Current Compensation + harmonics	Distribution network without DG	Non-linear load	Distributed Power Flow Controller
[23]	Power factor+ THD	Single phase System	Non-linear	Fuzzy logic-based AC-AC converter
[37]	Frequency + Voltage Control	Multi DG connected System	Variable load	Decentralized Controllable loads
[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
[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.
[57]	Frequency+ voltage control	Grid connected WPGS	Non-linear load	Pitch control and superconducting magnate energy storage (SMES)
[58]	Reactive power Compensation + PF correction	Single phase System	RL & RC load	Electrical spring with capacitor
[53]	Voltage + Harmonics +PF	Distribution system	Static load	Voltage flux-oriented control (VFOC) Algorithm
[16]	Harmonics + Load balance+ power factor	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

	correction			technique.
[17]	Voltage Profile+ power losses + power factor	IEEE 30 bus system with 5 DGs	One level load	PSO based optimal capacitor placement and its sizing

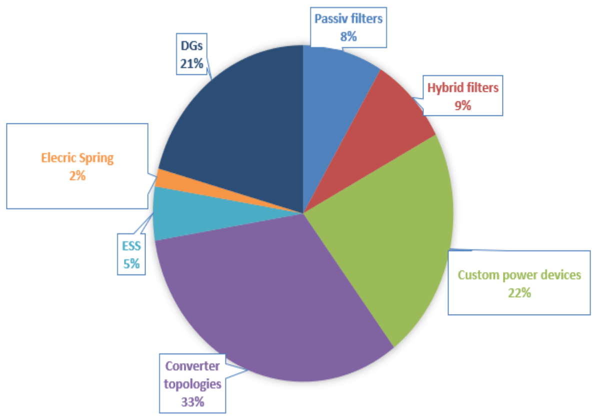

Fig 2. PQI Methods

III. PQI METHODS

This section provides the different techniques used in literature to solve PQ issues in distribution system under different load condition.

A. Placement of DGs

The optimal planning of DGs in the distribution system helps in improving the voltage compensation and also reduces the system power losses. Particle swarm optimization (PSO) techniques are applied to place DG in the 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].

B. Custom Power Devices (CPD)

Custom Power devices (CPD) play a crucial role in PQI of transmission and distribution systems. The Dynamic voltage restorer (DVR) is used to mitigate the voltage sag and swell in the distribution network [2]. The performance of DVR is improved by employing the 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 the 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 Nonlinear 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 to supply the varying load compensation [39], [50]. For high penetration of wind turbines, the hybrid DSTATCOM is proposed using artificial intelligence with an under load tap changer (ULTC) with variable load [45]. For a weak AC grid, the novel online control strategy with RL algorithm based DSTATCOM is designed to improve voltage regulation and to suppress harmonics under nonlinear load [51]. The THD was reduced to 5.25%, the unified power quality controller (UPQC) is connected in multiple PV unit integrated grid under nonlinear load [41]. The THD is reduced to 0.46% and also regulated the voltage at the point of common coupling (PCC) by using a hybrid fuzzy logic controller based in a 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 the DFIG connected grid. Along with the voltage regulation, voltage and current harmonics are reduced in DFIG using distributed power flow controller (DPFC) [56].

C. Power Converters

The power converters in the power system can be designed to solve the PQ issues. The overvoltage mitigation control scheme-based converter and matrix converter is proposed to improve the voltage regulation in grid-connected DGS under nonlinear 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 nonlinear 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 nonlinear load. The multiple objective functions is achieved in [11] [23] by designing a multi-level control strategy with a 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 a grid-connected residential PV system and load is concentrated 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].

D. Energy Storage System

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

E. Onload Tap Changer

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

F. Hybrid Filters

Filters are used to improve the power quality in the system. The filters which are controlled by a hybrid control algorithm are called hybrid filters. The FACTS-DVS based Switched filter capacitor compensator is introduced in hybrid DG connected utility with nonlinear load in [8] [44]. The capacitor is placed optimally and sizing using the PSO algorithm to improve the 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 are 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 the utility through an active filter to reduce harmonics is discussed in [24]. In [48], the author proposed a hybrid power filter to mitigate PQ issues in the distribution system.

G. Evaluation of PQI Methods

Passive filers are promising in suppressing PQ issues but design aspects are different for different system condition and need more protective devices with fine detuning. Therefore, it is upgraded with hybrid filter but it is costly compare to other methods. The traditional converters are lack in mitigating voltage and current harmonics of distribution system. Hence intelligent converter topologies are the promising solution for better voltage regulations and harmonic reduction. The optimizing DG location and size are the major key to enhance the capabilities of multi-functional DGs. Therefore, heuristic methods for optimal planning of different DG technologies is more effective in dealing with maximum PQ parameters and gives the best results compare to other methods. PQ issues due to the integration of DG at PCC can be mitigated by using a multi-level and multi-functional converter with a hybrid control technology for better tuning of parameters compare to voltage controller and current controller method. Even though D-Facts devices like DSTATCOM, DVR, UPFC, UPQC, etc have the main contribution in PQI but it focuses on few PQ issues and also the size, location and converter topologies are depending on system condition. Therefore, unique solution should be developed for optimal location and sizing. The converter topologies and mode of operation should be selected based on the nature of the system. The performance of CPD can be enhanced by designing suitable hybrid controllers and also by adding filters can reduce total harmonic distortion.

The response time of battery is large during transients hence super capacitors can be used which gives fast responses to the transients, also overcome the issues related to voltage, real and reactive compensation.

IV. Contributions

The main contributions of reviewed paper in PQI with and without DGs, under the various system and load conditions are tabulated in Table 2. From in-depth analysis of past and current trends in PQI methods, comparison between different PQI devices with their capabilities is tabulated in Table 3. The issues related bus voltage such as sag, swell, regulation can be solved by applying almost all the techniques. The passive filters are more effective in addressing more PQ issues and due to its limitation like need of protection and monitoring, depends on system condition requires advanced controlling devices. The passive filters are upgraded to hybrid filters to overcome the drawbacks and to mitigate maximum PQ issues. Nowadays, advanced converter topologies, Optimal planning of DGs and electric spring and energy

Table 2: Contribution of the reviewed power quality improvement works

Published Year	Contribution	Reference
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]
2008	The novel inverter control technique is introduced and tested in PSCAD to regulate voltage in PV connected grid.	[5]
2008	Reactive power compensation is achieved by using OLTC with AVR and LCD in distribution system.	[9]
2008	The matrix converter with a Sub and super synchronous switching scheme is introduced in variable speed wind mill for better voltage regulation.	[27]
2009	A combination of multi-level inverter and decentralized load technique used to improve voltage profile and THD.	[11]
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]
2010	An voltage regulation for static loads is provided by ODGP method based on GA.	[29]
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]
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]
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]
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	A combination of ANFIS based STATCOM ,ULTC transformer and three phase harmonic filter is designed for PQ issues	[45]
2014	The PQ related problems in wind mill connected grid are mitigated by designing hybrid power filter.	[48]
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]
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]
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]
	An active filters and P & O based MPPT-PV system is interconnected to improve PQ of distribution system.	[24]
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]
	A Double tuned PI-R Controller used to reduce the THD and compared with conventional PI Controller.	[42]
2017	Source current harmonics are suppressed successfully by introducing Dual SAPF controlled by instantaneous real and reactive power control theory.	[49]
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]
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]
2018	For fast and dynamic reactive power compensation, an GTO-VSC based STATCOM is proposed.	[13]
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]
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]
2018	The fuel cell based DSTATCOM controlled by iCosθ algorithm is proposed to control both real voltage & harmonics.	[54]

storage system plays major role in presence of renewables and integration of multi-functional DGs is more promising compare to custom power devices like DVR, DSTATCOM, UPQC. The multilevel converter topologies combined with intelligent method will enhance the capabilities of custom power devices and DGs. On the other hand, size and location of these devices also matter to avail maximum benefits. Even though the hybrid filters are more effective but it is not economical to use throughout the grid.

V. FUTURE IDEAS

Literature offers no clear and current methodology to mitigate all the power quality issues. There is need of some cost-effective novel methods for this problem. Most of the analysis is carried out by considering load is linear, non-linear and constant but practically load is variable with respect to time. By considering all the research gap found in literature, some of the methods are proposed which can successfully fill the gaps.

Table 3: PQI Devices and their competences

PQI devices	Voltage Sag/swell	Harmonic Compensation	Selective harmonic compensation	PF correction	Load balancing	Loss reduction	P compensation	Q Compensation
Passive Filters		*	*	*	*	*		*
Hybrid filters	*	*	*	*	*	*	*	*
Custom Power devices	*	*						*
Power converters	*	*		*				*
ESS	*						*	
Electrical Spring	*						*	*
DGs	*		*	*		*	*	*

i. *A new technique for ODGP:* The accuracy level of finding ODGP to improve PQ in the 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.

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

iii. *Prediction and Preventing PQ Issues:*Introducing a 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 the 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.

iv. *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.

v. *Reactive Power Support:* The DG with an efficient control algorithm can be used for reactive power support in the distributionsystem for preventing voltage sag in the future.

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

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

VI. Conclusion

This paper presents detailed information on state-of-the-art techniques to improve the power quality of the distribution system with and with the DG environment. The major power quality issues (voltage and current 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 contribution of PQI devices and their capabilities are tabulated. Based on the key gap identification, the future research ideas in power quality concern are summarized.

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