A Probe into Reactive Power Management in Renewable Energy System using Facts Devices

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Abstract: In the modern era, most of the utility grid is connected with Renewable Energy resources (RERs). In addition to this, many power electronic converters and reactive power compensating devices are also incorporated into the existing grid. This makes the system complicated. Penetration of renewable energy resources affect many power system parameters like grid stability, quality of power, reactive power balance and Sufficient energy utilization. However, the Distributed Generation (DG) towards the power electronic interface creates some critical power quality events such as reactive power management, harmonics and voltage profile which makes the distributed system become a polluted one. This paper depicts the review of modelling and incorporation of various reactive power compensating devices like TCSC, SVC and STATCOM into RES. Power generation model of solar, wind and fuel farm is discussed in this paper. Reactive power compensating devices and its location and sizing are important for the stable and secure operation of the electric grid. Consequently, power quality issues, real-time interconnection issues and policies related to reactive power management are in this paper.

Keywords: Reactive power management, Renewable Energy Resources, Distributed Generation, Power Quality, FACTS devices.

I. INTRODUCTION

In the last two decades of the 20th century, a spacious development in the knowledge domain of renewable energy sources have accelerated, which is attributable to negative impression on the conventional energy sources. It evidently leads to a viable interest to connect various types of equipment to distribution networks. The hiking demand for de-carbonized energy supply leads to generate more distribution networks. The designated Distributed Generation (DG) covers all the application of small generators that range from 15kW to 10kW dispersed all over in the power system [1]. Current DG power sources comprise of hydropower, wind, photovoltaics (PV), fuel cell, diesel and gas turbines. Renewable and other generators are located downstream in a distribution network. The concept of integrating small variable nature sources with Battery Energy Storage Systems (BESS) and governable loads into flexible substances that are termed as microgrids (MGs) [2].

Apparently, distribution energies aid for both the customers and the utilities. When customers use the DGs, the power quality and reliability can surge. There will be few outages and so the efficiency in using the energy can be improved. The energy cost will be less. Furthermore, the emission of greenhouse gases can be compressed notably. When the utilities use the DGs, the system capacity will be piloted and the depletion will be less. The voltage profile management will be improved. Reactive power can be guided in a superior way. The customer-value relation will be improved [3].

Additionally, renewable energy resources have continued their instant growth in recent years. Renewable energy resources are positioned as a magnificent solution to fossil fuel depletion. The materializing application of renewable energy sources and distribution networks in microgrid initiated new dares concerning the voltage stabilization, power quality and the efficient reactive power management. Wind and Solar energy are the major credits of renewable energy resources for power generation and are swelling at a rapid rate for the last two-three decades. Ministry of New and Renewable Energy (MNRE), Government of India is steering to achieve 20000 MW grid collaborative powers via solar and 38500 MW from wind by 2022. A wide literature review has led to the enhancement of power quality events. This is due to the incorporation of renewable energy resources in the power grid depicted in [4].

Moreover, in power system the electrical energy generation, transmission, distribution and the utilization are in the form of alternate current (AC). The modern daily life needs inductive loads more than other loads like reactive and capacitive. Each inductive load requires reactive power with lagging power factor. There is a plethora of different methods to provide Reactive Power Management such as voltage sags and swells that are mitigated for the performance of the Distributed Generation (DG). Reactive power management or VAR management oversee the coordination of the reactive power of the AC system execution. The major aspects of RPC are voltage support as well as load management. Voltage support deals with the voltage maintenance of the transmission /distribution line of the power system. Load management deals with power factor performance to balance the real power. Reactive power is effectively controlled in both cases. In fact, in the last few years, tremendous changes have occurred in the modification of the custom power devices. Among these, the visible one has occurred in FACTS (Flexible AC Transmission System) devices. The custom power devices have a dynamic role in reactive power management in the power system. FACTS devices hike the aggressive concert of the system by maintaining voltage stabilization as well as the power quality mitigation [5].

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On the whole, this paper depicts the review of reactive power management, using FACTS devices in distributed generation environment and is also concerned with the power quality issues. It also deals with the modelling of the renewable energy system in reactive power management.

II. REACTIVE POWER RENUMERATION: STATE OF THE ART REVIEW

Traditionally, mechanically or fixed switched inductors or capacitors and rotating synchronous condensers have been used for reactive power management. The switched reactive power managements, both shunt capacitors and shunt reactors, are used for control of voltage stability in the steady-state system. Series and shunt VAR management are treated to alter the natural electrical traits of AC power systems. Series management adapts the distribution or transmission system constraints, although shunt management performs the equivalent impedance of the load [6]. Reactive power management desires additional equipment, techniques and charge for installation and authorization. The trigger in reactive power entails additional short-term energy storage (inductors or capacitors).

In general, Static Var Compensators (SVCs) using thyristor-controlled reactors (TCRs) and thyristor-switched capacitors (TSCs) absorb and deliver the desired reactive power, respectively, that has been developed recently. With the help of self-commutated Pulse Width Modulation (PWM), converters with an apt regulator outline permits the execution of static compensators capable of generating or absorbing reactive current components with a time response faster than the fundamental power network cycle. However, the application of thyristor-controlled devices rectifies the limitations of rotating machines and DC controlled devices with fast response time, lower loss and less maintains.

Based on the practice of reliable high-speed power electronics, powerful analytical tools, advanced control and microcomputer technologies and flexible AC transmission systems (FACTS) have been established. These represent a new concept for the operation of power transmission systems. The progress in Flexible AC Transmission System (FACTS) technology deliver the reactive power management dynamically. FACTS devices are the powerful devices for power quality events.

In short, this work delineates a state of art based on intense studies by various authors on the problems of reactive power management in Distributed Generation (DG). On the other hand, many authors have proposed resolutions to single/multiple objective functions [7], curtail power losses, advance power factor, enhance voltage profiles, discharge capacity in lines and equipment, guarantee voltage stability and mitigate harmonics.

Table 1 Reactive Power Management

Taxonomy of Compensation	Devices	Features
Thyristor switched management	TCR, SVC	Lower losses, fast response time, less maintenance requirement, cost, heat dissipation
FACTS based management	FACTS devices	Lower loss, less switching losses, high cost, fast response
Dynamic reactive management	Synchronous condenser	Noisy operation, rotational losses, bulk size
Switched power management	Shunt reactors, Shunt capacitors	Resonance with nearby loads, bulk size, switching transients

III. REACTIVE POWER MANAGEMENT IN DISTRIBUTED SYSTEM

Generally, the main aspiration of distribution grids is to ensure the conveyance of electric energy for the client with essential degree of efficiency, reliability and quality which involves minimizing energy losses and improving conveyance progressions [8]. Furthermore, it investigates a particular tactic that high spots the impacts of the assembly of reactive power sources, that may serve as the resolution for voltage control in a medium voltage distribution network. Moreover, reactive power management is one of the well-recognized approaches because of its involvement to the demotion of energy losses. Besides other benefits; for instance, voltage profile and improvement of the voltage stability, power factor enhancement, surge of the operation capacity of lines and transport and gadgets of the grid, all of them are subjected to different operating restrictions. The motive of this research is to reveal the need to respond in a comprehensive and competent way. It seeks to regulate electric variables that are impacted by reactive power management and needed by the distribution system loads that is predominantly inductive in nature.

A. Analysis of Topologies that Intrude in Reactive Power Management in Distributed Generation

The electricity distribution grids are the carriers of energy from substations to distribution transformers in the medium voltage. The transference of electrical energy with quality and efficiency in distribution grids is a multiplex process. It is established in several measures, because these systems are extant in different types of grid topologies, multiple connections, different loads with different natures, absence of lines in transpositions, different construction and configuration characteristics, many points of union or binds in synchronicity with the plants and animals.

B. Energy and Loss of Power Distribution Generation

The Joule effect enumerates that the circulation of electric currents in electric conductors are due to the effect of heating electric subjects which link both energy and power loss in the system. In stiffed distribution systems, the reactive power drifts are expended in the grid.

Active power loss represented as below:

$$\Delta P = \sum_{i=1}^{n} I_i^2 * R_i \quad (1)$$

Where,

n = The quantity of nodes in the system

I_i = The current rate at the node i

R_i= The resistance at the node i

Reactive power in the system can be represented as

$$Q_i = \sqrt{3} * V_i * I_i * \sin\varphi_i \quad (2)$$

Where

V_i = The voltage at the node i

I_i= The current rate at the node i

$\emptyset_i$= The angle amid voltage as well as current at the node i.

Power factor can be deliberated as [20]

$$PF = \cos\emptyset_i = \frac{P_i}{S_i} = \frac{P_i}{V_i * I_i} \quad (3)$$

Where

PF and cos $\emptyset_i$ = The standard basic marks for nomenclature the power factor,

P_i= The active power/ real power rate at the node i

V_i = The voltage rate at the node i

S_i= The apparent power rate at the node i

I_i= The current rate at the node i

C. Performance in Voltage Profile

The key aspect discussed in this work, establishes the stability and reliability of voltage especially medium voltage in distribution system as one of the principal contests faced by energy distribution companies. Energy must reach customers with quality standards that demand constant enhancement, to sustain the degree of steady voltages within the topologies ruled by the canons, recognized in each republic as per the different voltage ranges [9]. Static reactive power compensators can preserve a prescheduled stable voltage profile level. Furthermore, if the voltage in the coupled node is more, the compensator performs in an inductive mode and absorbs reactive power of the load. Hence, the voltage becomes less and with the compensator behavior changing to the capacitive mode to release reactive power.

IV. REACTIVE POWER MANAGEMENT TECHNIQUES IN RENEWABLE ENERGY SYSTEM: A REVIEW

A. Control Methods

Many advanced control procedures have been used for boosting the quality of power in the renewable energy system. Reactive and active power/frequency droop control was principally utilized for the power control in the renewable energy system. The (P/f-Q/V) droop control was prolonged from a traditional grid to short voltage grids emphasized in [10]. An enhanced (P/f-Q/V) droop controller was employed to recompense for the disparity load environment suggested in [11]. A novel Adaptive Notch Filtering (ANF) tactic was applied without PLL to deliver voltage regulation and reactive power control proposed in [12]. It is established that fuzzy found models are broadly used in current years for site estimation, for mounting of photovoltaic/wind farms, power point tracking in solar photovoltaic/wind and optimization among inconsistent criteria discussed in [13].

The LF regulator loop was anticipated for a Fuel cell without support of the RESs discussed in [14]. The Energy Management Unit (EMU) strategy grounded on the MEPT and LF control loops established the fueling tariffs for the fuel cell demonstrated in [15]. HFC (High-frequency component.) and LFC (Low-frequency component) Control is used for wind/load variations. Subsequently, an enhanced droop control method through online virtual impedance adjustment is presented in [16]. Furthermore, power sharing control strategies of DG units are based on communication embrace concentrated control debated in [17]. In [18], master/slave control and distributed control is considered. Integrated control strategies denote the hierarchical structures which generally comprise of primary, secondary, and tertiary controls analyzed in [19]. A direct voltage sensitivity analysis method is proposed in [20] and [21]. Reactive power management via combined control of electronic power processors is proposed in [22]. Q/V-P/f control is modified to comply with passive and active nature of DG sources illustrated in [23]. Instantaneous P-Q theory for reactive power management is presented in [24]. RPA (Reactive power allocation) tactic founded on phasor analysis for P-Q management is specified in [25].

In addition to reactive power management, harmonic management using droop control is presented in [26]. Single-point reactive power control method described in [27]; P-Q control using Finite Hybrid Automata (FHA) counting droop control, designed for switch-mode microgrids is discussed in [28]. A Modified One-Cycle-Control and an Autonomous Control of Current- and Voltage Controlled DG Interface Inverters is sketched in [29]. Network Partition-Based Zonal Voltage Control and An Improved Hybrid Modulation Method is presented in [30]. Phase Angle Control and decentralized control method is discussed in [31]. A Novel Fourth-Order Generalized Integrator Based Control Scheme and A generalized passivity-based control approach shows the reactive power management in a distribution system. Implementing dynamic evolution control approach and Passivity-based control projected to improve reactive power sharing is represented in [32].

B. Algorithms

In general, a list of algorithms has been used for reactive power management such as MPPT algorithm, Affine Projection-Like Algorithm, flower pollination algorithm and Dynamic Consensus Algorithm, hybrid evolutionary algorithm, power flow analysis using improved impedance matrix-based algorithm. In [33], performance optimization for mine blast algorithm is investigated.

Coordinated control of distributed generation system with improved generalized enhanced phase locked loop control algorithm and IVCA (Improved Virtual Capacitor Algorithm) is explained in [34].

There are various algorithms for reactive power management in distribution system, namely, Back-Propagation Algorithm used for Autonomous Wind–DG Microgrid, SOGI (second-order generalized integrator) control algorithm, water cycle algorithm used for optimal allocation and sizing of multiple DG and capacitor banks considering load variations, Anti-hebbian control algorithm, Reactive Power Optimization for Distribution Network Based on Distributed Random Gradient-Free Algorithm, Reinforcement Learning Algorithm for Enhancing Power Quality in Microgrids With a New Online Control Strategy for DSTATCOM, Multi-Objective Control Algorithm for Hydro SPV Generation-Based Dual Mode Reconfigurable System and Small, EKF algorithm for Volt/Var Control on a distribution grid with renewable penetration- all which are described and discussed in [35]

C. Devices for Management

The performance of power systems declines with the size, the loading and the complexity of the networks. The power quality performance in the RES depends on the mitigation techniques (reactive power, providing harmonic and unbalanced management). The existing solutions for reactive power managements lie in the usage of capacitor, application of TSC as well as TSR devices, LC filters. Despite of its advantages, these solutions have the problems like ampleness, fixed managements and resonance. Best solution for reactive power management is power electronics-based FACTS (Flexible AC Transmission System) devices. Performance of FACTS Devices on a Power System (Large Wind Farm) is explained in [36] in detail.

In fact, a static VAR compensator (or SVC) is an electrical apparatus for providing blistering reactive power on high-voltage electricity distribution networks. Power-quality events and the requirement for reactive-power management in the grid integration of wind power is described in [37]. A critical review of voltage and reactive power management of wind farms explains the use of STATCOM for dealing reactive power requirements of wind farms, consisting of application of SVC techniques for determining the issue of voltage and reactive power necessities, application of DVR, capacitor banks, SDBR (small series dynamic braking resistor) and supplementary devices.

To govern voltage/reactive power management, countless tactics used by different researcher are evaluated. On the whole, the strategies used by researchers are STATCOM, SVC, DVR, OLTC, SDBR, FACTS Devices, UPFC or UPQC or in combination with another device. Solid state transformer (SST) is one of the most rapidly developing technologies for renewable energy integration. SST (Solid state transformer) improve power qualities that compensates reactive power. Renewable energy system with wireless technology using ZigBee devices are planned and suggested for active-reactive power control and coordination.

Furthermore, multi-function amenities like constant frequency United Power Quality Conditioner Based on Supercapacitor [38], universal power line manager consisting of UPQC, UPFC and matrix converter has been suggested for diminution of different power quality events. VAR compensator is practiced widely, parallelly functioning as the wind/hydro microgrid along with Integrated Brushless Starter Generator. STATCOM as a custom power device (CPD), Bipolar AC/ AC Converter with Matrix Choppers based UPFC topology, SVC in MV grids with TCR and TSC are advised for reactive power management and voltage fluctuation mitigation in Renewable energy system.

Power quality events in conventional grid-connected with renewable energy resources can be explained with the incorporation of FACTS devices. UPQC can be used in Renewable energy system for voltage sag/swell mitigation, supply/load disturbance management. In grid-connected mode, RPC is contributed by UPQC as proposed in [39].

For example, table 1 shows the review of FACTS controllers. The table, a group of different constraints are used, such as devices and techniques (methods and different class of FACTS devices), decision variables (DG site, DG size, FACTS site and FACTS size), objectives (Test system, stability, VS (voltage stability), power quality, economics, LC (loss criticism), reliability) and the test system such as IEEE-33, IEEE-69, IEEE-9 and so on.

V. BIBLIOGRAPHICAL REVISION

For the investigation of the performance of the particles encompassed in the issue of optimization of reactive power enhancement, a comprehensive bibliographical review is made taking into report many oblique libraries, including ScienceDirect, IEEE Xplore, Scopus, Taylor and Francis among others. This bibliographic review objectives aim at relating the intellectual optimization strategies handled by discrete scriveners, to solve the management problems. With this outcome, the comparisons are established amid multi objective proposals, on the report of considerable distribution generation milieu. The number of variables intrude in each of the anticipated mathematical models. The bibliographic review encompasses the most current and innovative articles of the discipline and are revealed in a number of references- implementation of prominent energy saving estimation for Volt/VAr control of systematized distribution system. Scientific journals are scrutinized in [40-43].

Fig.1 illustrates the behavior given by the authors according to the theme, to solve the problem of reactive power management in distribution generation, based on apt reactive power management. It can be seen that the most painstaking variable is: reactive power management.

A. FACTS Devices in Terms of Objective Functions

The definition of the objective function defined in [44] and the scope of the objective functions are increasing day by day in the research arena. Table 2 illustrates the Review of FACTS controllers Techniques via Genetic Algorithm (GA) with different bus system, in which various constraints which are co-related to the optimization of reactive power management.

Table 2. Review of FACTS controllers Techniques

Year	Devices and techniques		Decision variables				Objectives						Test system
	methods	Type of FACTS	DG spot	DG range	FACTS spot	FACTS range	Economics analysis	LC	Reliability analysis	Stability analysis	VS	Power quality	
2015	F-ACO	DSTATCOM	✓	✓	✓	✓			✓	✓			IEEE 33
2015	BAT-A	DSTATCOM			✓	✓	✓						IEEE 33 IEEE 69
2015	ICSO	DSTATCOM	✓	✓	✓	✓			✓			✓	IEEE 69
2015	IM	DSTATCOM			✓	✓	✓						IEEE 33
2015	BFOA	DSTATCOM	✓	✓	✓	✓	✓						IEEE 33 IEEE 69
2016	IM	STATCOM			✓	✓				✓			8 BUS RADIALS
2016	PSO	STATCOM			✓	✓				✓			15 BUS
2016	IM	UPFC, DSTATCOM			✓	✓	✓						IEEE 33 IEEE 69
2016	PSO	DSTATCOM	✓	✓	✓	✓	✓						IEEE 118
2016	DEA	DSTATCOM			✓	✓				✓			IEEE 69
2016	IM	DSTATCOM			✓	✓	✓		✓	✓			UK-38 BUS
2016	PeSO	DSTATCOM	✓	✓	✓	✓							IEEE 57
2016	DICA-NM	DSTATCOM			✓	✓	✓						IEEE 33 BUS DARIAL
2017	MSFLA	DSTATCOM	✓	✓	✓	✓	✓						IEEE 33
2017	CSA	DSTATCOM	✓	✓	✓	✓	✓						IEEE 12 IEEE 34 IEEE 69
2017	ICA	DSTATCOM			✓	✓	✓						IEEE 33 IEEE 69
2017	F-GA	DSTATCOM			✓	✓	✓		✓				IEEE 33 IEEE 69
2017	IM & VA	DSTATCOM			✓	✓	✓			✓		✓	25 BUS
2017	DLTBO	DSTATCOM	✓	✓	✓	✓			✓				IEEE 33 IEEE 9
2017	IM	DSTATCOM	✓	✓	✓	✓				✓			IEEE 33

The key parameters of the objective functions are listed below:

- Uniformity/Non-uniformity Constraints
- Optimal location of the test bus
- Assessment
- Criterion affected

Another key point obtained in table.2, it is inferred that DSTATCOM has been used to boost the appraisal of system by influencing a number of constraints like, dropping active and reactive power loss, attenuating generation cost, elaborating voltage stability by decreasing Lindex, controlling the active power flow, improving total transfer Capability (TTC), improvement of stability margin (SM) etc.

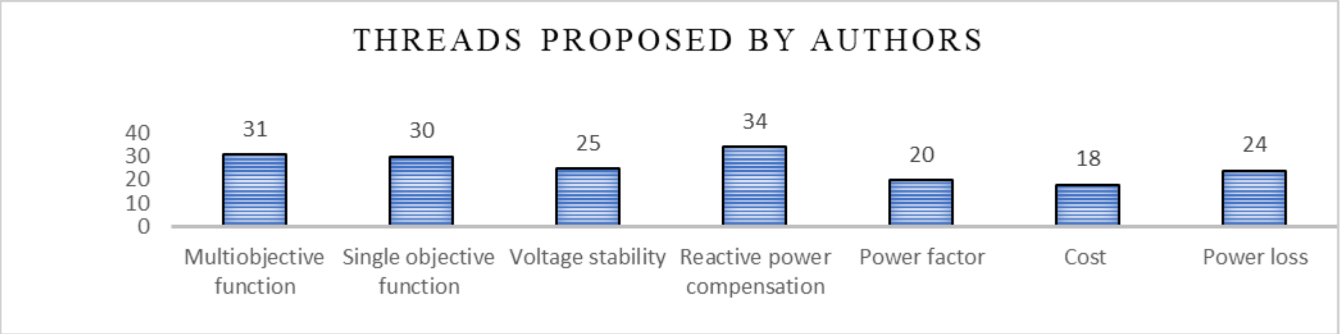

Fig 1. Graphical representation of Threads proposed by authors.

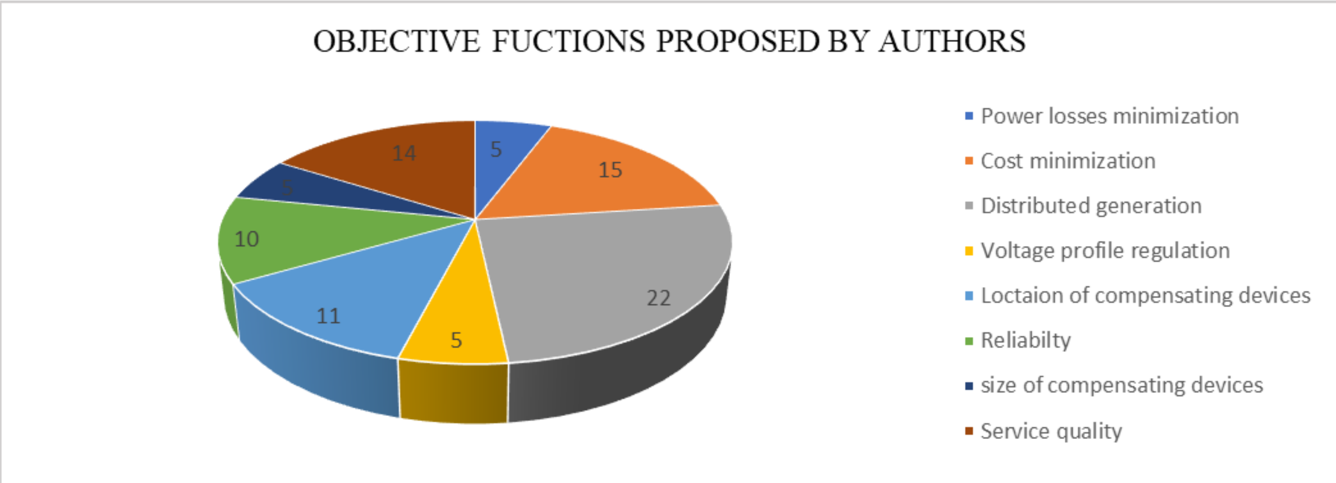

Fig.2 Graphical representation of objective functions proposed by authors

VI. PQ Events in Electrical Power System: A Survey

Power quality (PQ) events eventually abide as a consumer-driven issue, with the customer`s point of reference grabbing utmost superiority. The subsequent definition of a power quality problem is used in "Any power problem manifested in voltage, current, or frequency deviations that result in failure or misoperation of customer equipment" [45]. When the quality of power decreases, the power loss increases. Recently, the power quality issues are more complex in all levels of production, transportation, and distribution systems. Both end users and utilities are affected by the power quality issues. Many of the new devices are very sensitive and sometimes do not operate properly with minute variations or disruptions when the electrical supply occurs. Some examples of problems that occur due to power quality issues are overheating of electrical distribution systems, power supply problems, data errors, automatic reset, equipment Failure, UPS alarm, and Software Corruption.

However, for the proper functioning of electronic devices, it requires an optimum voltage within the consistent range. The commonly used power quality events are voltage sags, voltage unbalance, harmonics, transients and flicker. Even though the internal factors like surge, and sag affect the quality of power, the power quality problems are also affected by external events like lightning strikes. Because of the enhanced use of critical loads, there develop asymmetrical voltages and harmonics in power electronic (20%) and PV systems equipment (18%) respectively. Among these events, voltage dip account for the peak percentage of loss, about 31% shortlisted to voltage dip. The bottommost percentage is voltage transients by 8%. Figure 7 exhibits the distribution of various power quality issues in percentage.

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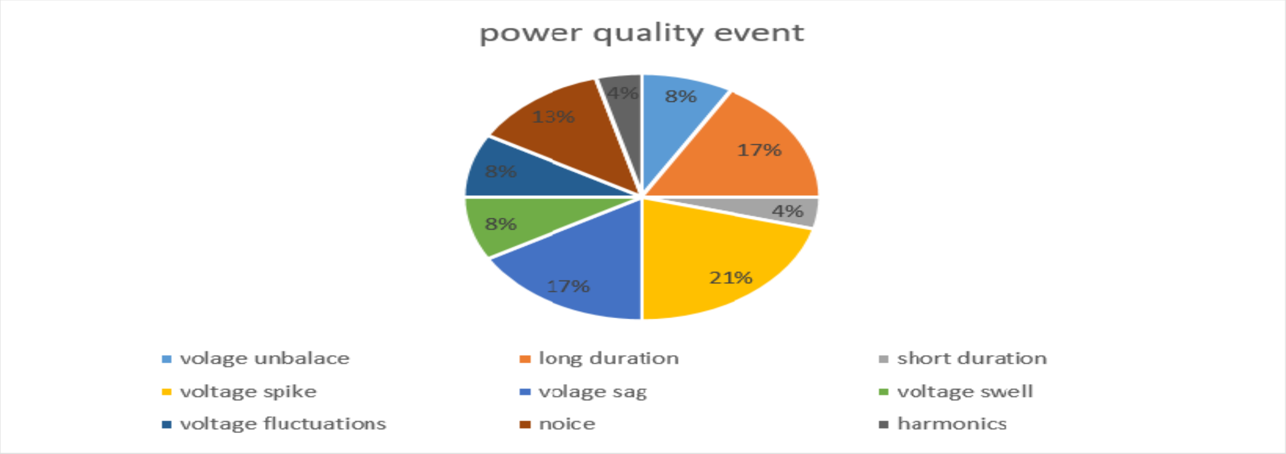

Fig. 3. Distribution of power quality events.

VII. CONCLUSION

This paper portrays a comprehensive overview of the Reactive Power Compensating devices in renewable energy resource environment. In fact, renewable energy becomes a major grantor to our modern society, but their integration to power grid creates significant technical challenges in the power system. With the integration of such renewable energy resources with the existing power system network, reactive power management is a challenging task. In larger Solar-PV generation and wind farms, there is a need of installation of reactive power management devices at high active power levels. Moreover, installation of RPC devices enhances grid stability, power quality, power system reliability and security. Integration of RPC has major influence and modifies the power flow, control strategies, and also has objective functions (single objective function) of the power system network and various control techniques. Selection of RPC device, optimal establishment location and ideal size of the devices should be based on the experience of power system operator by considering different optimization techniques. Complex optimization algorithms produce accurate solution with high speed. Since existing power system network demands proper reactive power management system, coordination among various algorithm, objective functions and various control techniques on these RPC devices contributes a major role in the power system network. Hence, the power system operators should take appropriate decision to maintain the uninterrupted operation of the power grid. The shunt devices are being extensively used for reactive power management and thereby for voltage control enhancement.

The first enhancement occurs in compensators SVCs that are reloaded by mechanically transferred devices in order to deliver additional exact and rigid control. The key benefaction of SVC is in its quick and effective vibes to the line voltage instabilities. Nevertheless, it was not competent enough across fast changing power quality events such as voltage sag and harmonics that required the enactment of more robust remunerators. The FACTS devices are amended to conquer this kind of solidity of events. Amidst, the first one was STATCOM listed in the shunt compensator group. Moreover, shunt devices and series management devices that are proficient to expand line impedance and stability are also considered in FACTS family.

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