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Power Quality Issues in Grid Tied Solar System and its Prevention

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***Abstract**: The present day demand due to the reduction of fossil fuel resources on a worldwide basis has enforced an urgent seek for alternative energy sources a well-acknowledged as renewable energy sources. In India the integration of solar PV generation in the utility grid is attainment high popularity. Consequently, the solar panel interfaced with the grid cause the power quality issues such as voltage regulation, flickers, harmonics etc. In this paper solar grid integration technology, challenges of integration & their mitigations techniques such as FACTS devise and power electronics are discussed. The key objective of this paper is to identify the problems associated with grid connected solar power system and the study of implementation of new projects of solar PV grid integration without repeating apparent challenges faced in prevailing plans and prepare data for scientists and researchers on feasibility of SPV grid integration.*

Keywords: Power Quality, Harmonics, Solar PV Energy, fossil fuel, voltage regulation, UPQC.

ABBREVIATIONS
THD – total harmonic distortion
SPV – solar photovoltaic
PQ – power quality
EBC – electronic boost converter
ESS – energy storage system
APFs – active power filters
MLI – multi level inverter
UPQC – unified power quality controller
VSI – voltage sources inverter
CSI – current source inverter
MPPT – maximum power point tracking

I. INTRODUCTION

Due to greenhouse gas emission and decrease of the usage of hydrocarbon deposit is currently the precept of the energy generation strategy transversely the world. The escalation in the contribution of PV power in the energy production is the recent progression owing to its reliability and price factor. Several nations are nowadays profound to invention the SPV energy-producing sources and have established goal-oriented objectives for SPV power generation in the approaching years [1]. Globally established capability for SPV has realized an exponential evolution, attainment about 290 GW at the completion of 2016. From the IRENA's 2017, presently China is the prominent producer of SPV pursued by Germany, Japan, and USA. The SPV energy is increased by 94 GW in 2018 (+ 24 percent). Asia sustained to govern global progression with 64 GW rise (nearly 70% of the worldwide expansion in 2018). Sustaining the tendency from preceding year, India, China, Japan and Korea enumerate for utmost of this. Additional major escalations existed in the Australia (+3.8 GW) USA (+8.4 GW), and Germany (+3.6 GW) [2], [3]. To restrict the Global warming calamity, the global warming should be kept to less than 1.5 centigrade degree above pre-industrial temperatures. For this goal, the global greenhouse gas emissions should be miniaturized, and by 2050, these emissions should be decreased worldwide by 80% from their 1990 levels. At present, the world annual power consumption is 10 terawatts (TW) and by 2050 this amount will be nearby 30 TW[4] . SPV systems can enrich the operation of electrical power systems by reducing the energy losses, improving the voltage profile of distribution feeders and maintenance costs. Nevertheless, in comparison with other RES (renewable energy sources) , SPV systems face various key issues, such as harmonic pollution, feeders overburdening, higher cost, lower reliability, low efficiency, which obstruct their extensive use. Furthermore, variations in solar irradiation can cause voltage flicker and power fluctuation, ensuing in contrary effects on highly penetrated SPV systems in the energy system [5]–[7]. In distribution systems (DGs) utility exercised because of the higher penetration level of SPV system by means of it may affects the voltage regulation, stability, Increased Reactive power, Islanding detection difficulty and power-quality (PQ) problems. Nonetheless, the non-linear loads at PCC generate harmonic currents and excess use of power electronics equipment, which may disturb the PQ of the systems. This produces distorting effect on generation and transmission sideways and furthermore load current and voltage harmonics can create a severe PQ concerns in the energy network [8]–[10]Due the harmonics problem of malfunctioning of control unit and protective relays are encountered. The SAPF have been realized as supreme efficient solution for harmonics problems. In recent times, fuzzy control schemes have engendered a boundless concentration in certain field of power electronics. The fuzzy control schemes has more advantages in place of the PI controller like as: it can work with imprecise inputs; it does not require an perfect mathematical model; and it has ability to handle the non-linearity etc. [11], [12]. Conventionally passive filters technologies were used for harmonic reduction, but owing to some limitations of resonance that can recompense particular harmonic at an interval.

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Nowadays there is leading power electronics strategies implemented for different current control schemes which is used in APFs. Shunt APF having inverter technology like as current source inverter and voltage sources inverter. Presently there are numerous current control approaches used in APFs such as fuzzy logic, dead beat control, Hysteresis current control technique, and direct control scheme are needed for pulse width modulation generation [10],[13]. This paper concerns with the power qualities issues associated to SPV linked to the utility grid and the effect of poor P Q and to learning the mitigation of PQ problems in grid tied SPV systems.

II. GRID TIED SOLAR PV SYSTEMS

In the modern years, SPV power into utility grid has been growing at an enormous proportion. The grid tied solar systems is consistently connected over the 3 phase inverter since the SPV array supplies only DC power. The EBC is used that boost the voltage levels arriving from the solar array. An MPPT technique is used to track the extreme power from the SPV panels. The boost converter duty cycle is determined by the MPPT technique which usually lies in between 0 to 1[14]–[17]. An Inverter is convenient in changing DC to AC power for various applications. Grid tied inverters, based on construction; i.e. module type, string type, central type and multiple string type. The central type of inverter is usually needed for low the voltage operations for the reason that of its better control and simplicity. MLI is an appropriate resolution for grid-tied SPV systems due to its less switching losses and improved efficiency. The cascaded H-bridge schemes of MLI family demonstrates the better working performance in several real-world applications like compensators, STATCOM, grid-connected etc. [18], [19]. Schematic illustration of complete design of grid-tied SPV system is presented in Fig.1. All the components such as PV panel, DC to DC converter, MPPT, inverter schemes and control approaches ought to to be functioned in synchronism to improve the inclusive efficiency of the whole systems.

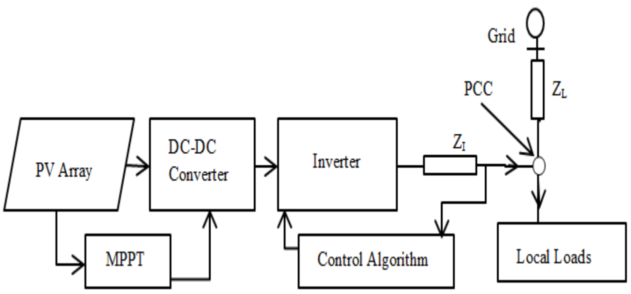

Fig.1. Schematic diagram of grid-connected solar PV system

III. DEMANDS FOR GRID TIED PHTOVOLTAIC SYSTEM

The requirement for the grid tied SPV system based on electronics converters system can be described at various levels as revealed in Fig.2. At the SPV side, the power output of the solar strings must be magnified and sustained suitable value for voltage of the DC link for inverter system. Furthermore, for safety the SPV string observing and analysis be required to enhancing at the solar side and on the utility grid side, the output current THD should be achieved lower than 5% [20]. The large-scale greater power ratings SPV systems must not disturb the utility grid frequency and voltage via providing frequency regulation. Subsequently the power capability per capita generating unit is comparative squat nonetheless the power cost is comparatively higher; at present constantly substantial challenges for greater efficiency in order to diminish the SPV power cost. In case of efficiency, the PE system consider for the utmost power losses in whole SPV system. Lastly, for the reason that of revelation, the SPV converter system (PE system) necessity be greater temperature unaffected, that is also advantageous for the performance of reliability [21]–[23]. As presented in Fig. 2, evolving the forecasting, islanding protection & technologies of communication is essential to development of the future SPV systems into a combined power utility grid.

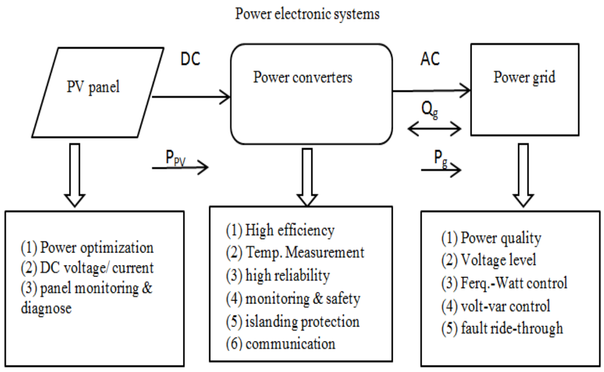

Fig.2. challenges for a grid tied SPV system.

IV. POWER QUALITY CONCERNS

The integration of SPV distributed generation (DG) in energy systems can relieve overloading in transmission or distribution lines support the general grid requirement and provide peak shaving. Nevertheless, improper coordination, installation and location may disturb the quality of power systems. When integrating distribution system, the inverter structured the heart of SPV grid tied system and is liable for PQ generated into the grid. Although it handles the significant operating parameters such as frequency range and voltage, it also disturbs the SPV power quality that is introduced into the utility grid. There are some PQ problems are:

Flickers*:* these are fast fluctuation of the voltage that is injected in the loads. These voltage variations are caused by monotonous load linking and discontinuous current concentration [24].

Harmonics: The greater frequency harmonic contents in the energy system can disturb the utility grid voltage and current excessively. Owing to the impedances of the energy system, voltage harmonic contents can generate current harmonics contents. The grid current harmonic components are originated through the loads supplied with PE appliance that consume higher frequency current contents. The voltage harmonic contents are created ordinarily by means of the switching of PE devices. Voltage harmonics contents can besides be originated owing to harmonic contents at lower frequency as comparisons of bus regulator cut off frequency or due to regulator malfunctioning.

Voltage Dips and Over Voltages: in the low voltage utility grid system over voltage may be produced by environmental phenomena and faults on the utility system. Owing to the abridged expansion of power the utility network, these measures can be minimized by prudently planning and establishing the power network.

V. POWER QUALITY MITTIGATION SCHEMES

A. Application of FACTs Device

FACTs devices and VSI type PE converters, using smooth dynamic reliable adaptive controllers, are developing as a power filtering equipment and stabilization to enhance the PQ. The fundamental approach of FACTs appliances is based consequent to the expenditure of high-voltage PE to regulate reactive & real flow of power and unified PE converters scheme with adaptive fast control schemes are required to linked ac-dc RES and emerging smart grids. The basic concepts of these are:

1) Introducing the ac components in parallel or series with the power system network to generate superimposed flow of voltages or current.

2) Supplying localize capacitive or reactive current in electric system at the bus bar for control of flow of reactive power.

These are dynamic flow controller (DFC), SVC, TCSC, UPFC, and STATCOM.

STATCOM is a PE scheme whose elementary concept is absorption or injection of reactive current on point of common coupling. The STATCOM system is a PE inverter using DC link capacitor primarily system implemented for reactive power reimbursement towards the load side. It obtains control signals that are produced by means of adaptive Icosφ techniques [25]. The Icosφ approach is used to reimburse harmonic contents, unbalance impacts in a unbalanced or balanced 3-phase load/source [26].

The units amplitudes source voltage of phase to ground of phase a, b and c is given as:

$V_a = 1 \times \sin(\omega t)$ (1)

$V_b = 1 \times \sin(\omega t + 120)$ (2)

$V_c = 1 \times \sin(\omega t - 120)$ (3)

The reference source currents for all phases given as:

$I_{sa} = K|I_{sa}| \times V_a = K|I_{sa}| \times \sin(\omega t)$ (4)

$I_{sb} = K|I_{sb}| \times V_b = K|I_{sa}| \times \sin(\omega t + 120)$ (5)

$I_{sc} = K|I_{sc}| \times V_c = K|I_{sa}| \times \sin(\omega t - 120)$ (6)

K is the load factor of the system.

It decides the total real power which can be delivered by means of the grid/source. The STATCOM are concluded all excellent useful characteristics, cost saving, more rapid attainment, reduced proportions, and the capability to deliver the reactive and active power. The STATCOM may also be required to boost transient situations, control voltage flickers along with voltage fluctuations of system [25].The arrangement of STATCOM linked with photovoltaic energy source is displayed in Fig.3.

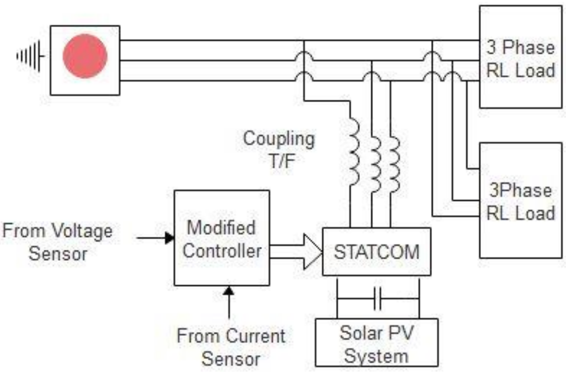

Fig.3. illustrative diagram of a grid tied SPV system using STATCOM.

A Static transfer switch (STS) is used to mitigating interruptions and voltage dips [27]. A Static VAR compensator (SVC) provides control of AC voltage through production and consumption of the reactive power using passive elements of PE. The capability to consume differences in the reactive power creates the SVC appropriate for flicker lessening to certain point. It is ordinarily constituted by means of some of thyristor switched capacitor divisions and one thyristor controllable reactor. By this prearrangement, the SVC can produce unremittingly volatile reactive power in an indicated range & the TCR size is restricted to TSC one branch rating. Nonetheless, the capability of SVC on the way to diminish flicker is restricted through its lower speed response [28]. UPQC is a combination of the shunt and series APFs coupled alongside. The series constituents recompense turbulences of the supply side such as voltage swells, harmonics, flicker and voltage instability. The UPQC aims to delivers voltage to sustain the load voltages electrical network. The shunt component diminishes the problems such as load unbalance, reduced power factor and load currents harmonic contents. For balanced sinusoids source current in-phase with the source voltages a current component is injected in to the system [29]. Fig. 4 demonstrates the primary arrangement of UPQC using shunt and series APFs. A UPQC recompenses for alterations like as unbalanced load currents and the load voltages of a 3 phase systems.

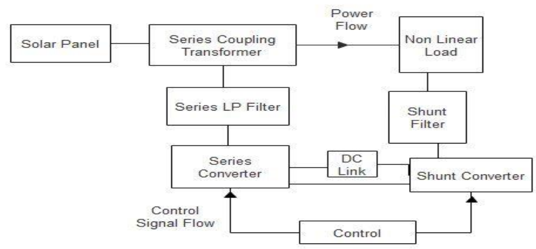

Fig.4. Principal Arrangement of UPQC

A UPQC equivalent circuit diagram is presented in Fig. 5. A 3-phase system that is unbalanced comprises of zero, positive and negative sequence fundamental and harmonic constituents.

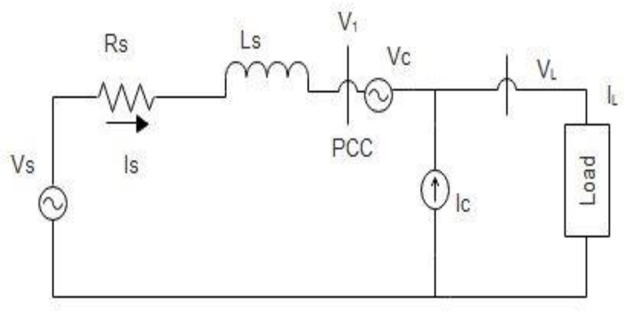

Fig.5. UPQC equivalent circuit diagram

The equation of system voltage can be articulated as:

$V_a(t) = V_{s0}(t) + V_{s+}(t) + V_{s-}(t) + \sum V_{sh}(t)$ (7)

Here subscripts 0, + and – signifies zero, positive and negative sequence components correspondingly. The component of voltage compensated by the series converter is given as:

$V_c(t) = V_L(t) - V_s(t)$ (8)

The equation of load current with distortion can be stated as:

$I_L(t) = I_{L0}(t) + I_{L+}(t) + I_{L-}(t) + \sum I_{Lh}(t)$ (9)

The PE shunt converter offers reimbursement on the load side harmonic currents on the way to diminish distortion of voltage. The component of voltage compensated by the series converter is given as:

$I_c(t) = I_L(t) - I_s(t)$ (10)

Equation (8) and equation (10) enact the elementary ideologies of an ideal UPQC.

Transient voltage surge suppressor offers the elementary configuration to diminish PQ concerns. It is provides an interface amid sensitive load and power load. TVSS comprise of an element with a nonlinear resistance to confine the excessive line voltage and compresses transient voltage on the way to a secure level [30].

IT known as isolation transformer are principally used to segregate sensitive loads from noise and transients. The grounded shield placed betwixt the primary and the secondary is the key component of IT which is prepared by nonmagnetic foil. The interruption from source side is transferred by means of the capacitance among the primary & shield. Formerly it conducts an unneeded interruption to ground. The isolation transformer can also reduce the harmonics contents and improve the voltage of neutral to ground [31]. On the contrary, some of the key drawbacks of the IT is that it cannot reduce the voltage fluctuation from the systems[32] . A DVR known as dynamic voltage restorer contains of the voltage source linked in series by means of the load. At the load terminals the output voltage is constant by using a step up transformer. A DVR is highly efficient to diminish some significant power quality concerns like as voltage swells and sag [33].

There are numerous other mitigation procedures such as: active conditioner, equipment damaging, true RMS metering, total rewire, dedicated circuits, passive filters, TN-S rewiring and meshed earth upsized neutral etc.

B. With Application of Series Active Power Filter

The main objective of establishing the SPV system on PCC is to generate active power and to upgrade the operation of power system network. Nevertheless, to avoid the supplementary power cost of systems circuit, numerous SPV-fed grid tied technologies linked the solar inverter by means of the extra performance of SAPF, along with the reactive power support. The Photovoltaic inverter consume the active power generated from the SPV power network and to refine the load side current harmonics contents the compensating current is injected into the grid [34]–[37]. In addition, the APFs are familiarized in the SPV system to recover current harmonic distortions and enrich the reliability, efficiency of the system [38], [39]. Currently, the multilevel-multifunctional inverter (ML-MFI) has developed the new popular approaches implemented in the SPV grid-tied energy power networks. The ML-MFI generates the output waveform in steps with lower THD at higher DC voltage. It controls the grid current harmonic and voltage at PCC [40], [41]. Circuit configuration of APF technology is shown in Fig.6 to Fig.8.

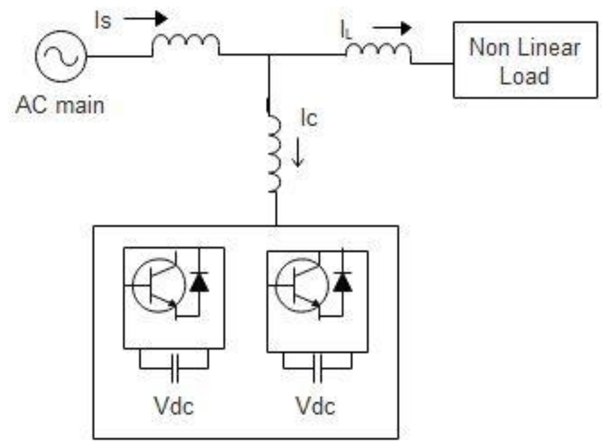

Fig.6. Shunt APF

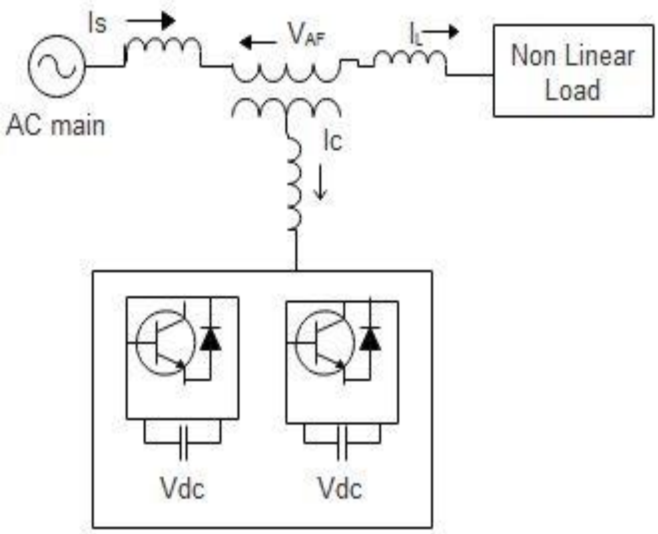

Fig.7. Series APF

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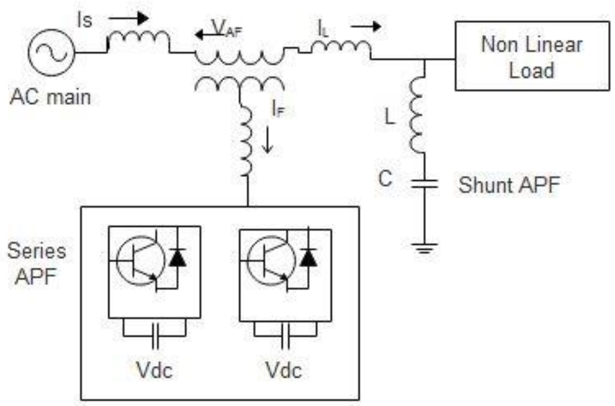

Fig.8. Hybrid APF

It also controls transient operation in among the SPV generator to the grid at the time of the active power filter (APF) operation. The ML-MFI technology is more advantageous in higher rated large SPV systems for the reason that of lower electromagnetic interference outputs, lesser harmonic and low power dissipation [42]–[44]. Comparison of different APF technology is shown in Table 1.

Table-1: Comparison of APF technology

Specific Considerations	APF Technologies		
	Series APF	Shunt APF	Hybrid APF
APFs functions as	VSI	CSI	Both the (CSI/VSI)
harmonics producing Loads	Diode rectifier using Capacitive Loads	diode/Thyristor rectifier using Inductive Loads	diode/Thyristor rectifier using Inductive Loads
Voltage harmonics	Mostly preferred	Not preferred	Generally preferred
Voltage sag and dips	Mostly preferred	Preferred	Generally preferred
Voltage flicker	Generally preferred	Mostly preferred	not preferred
Current harmonics	Not preferred	Generally preferred	Mostly preferred

Shunt APFs is the utmost leading and generous solution in contradiction of PQ issues with current harmonics and reactive power reimbursement. The APFs performance is determined by the control strategy and reference current finding methods. A signal of reference current is obtained by various harmonic load finding approaches, like as p–q theory, synchronous detection and principal positive sequence approaches [45]–[47].

By contradict systems of energy storage like as batteries, flywheels and super capacitors are there for prioritized to diminish the sporadic difficulty in renewable SPV power systems. Consequently, the ESS sustains the constant voltage using dropping voltage fluctuation in addition to preserving greater SPV efficiency [48]–[50].

In hybrid APF process, both the filters are systematized; such that a harmonics contents of lower order are removed by Shunt APFs action, while the harmonics contents of high frequency are eliminate by passive filter [51]. In recent times, numerous Hybrid APF schemes use several passive components and transformers are main tools to accomplish the filter size and cost of the system.

C. Control Techniques to Mitigate SPV Fluctuations

At lower SPV penetration levels, the PQ problem can be resolved at the local grid stage in the systems. Conversely, for higher SPV penetration levels control methods and grid components are needed to prevent PQ problems. These control approaches have to permit for controllable and stable output of the power and supply the appropriate power to the electrical network The control schemes should adjustment the SPV's instantaneous and "intermittent "power into a précised power which is meet the requirement of the grid. The purposes of control techniques are to reduce the grid code infringement, sustain the fluctuations and sustain the load [52]–[54].

- **Ramp Rate Control (RRC)**

The RRC scheme is implemented simply when the system power oscillation limit has been surpassed [55]. It amends the diverged ramp limit through the energy storage systems (ESS).The RRC is upgraded by means of SSC known as state of charge control, which upholds the flattening of decreasing & rising fluctuations [55], [56].

- **Moving Average Control**

The methods of moving average control needs preceding measured SPV power standards to maintain and calculate the average of power and also reimburses the difference from side to side the energy storage system. In this method SPV power fluctuation limit cannot control directly. The smoothed power injected in to the utility grid is acquired by computing the mean production significance with in a definite time frame [57], [58].

D. Control By using Multilevel Inverter

Inverter is the power electronics scheme that converts DC power to AC at needed frequency and output voltage level. It can be principally categorized into single level multi-level inverter. The fundamental concept of a MLI to attain higher power by using a series of power electronics switches with numerous low voltage dc sources to achieve the power conversion [59], [60]. The MLI scheme synthesizes the output voltage with lower harmonic distortion, consequently reducing filter necessities. In recent times H-Bridge MLI is used for upgrading of PQ owing to lesser cost and reduced switching losses [61].

VI. FUTURE SCOPE

The opportunities for future study in PQ concerns are countless. These comprise are specified as:

- A monitoring and mitigation scheme intended for voltage spike which is the additional topic that can be further examined. Appropriate detection and tracking approaches required to be established for that kind of very profligate fluctuating voltage.
- Complete study of PQ problems with hydro-power system requires to be examined. A widespread analysis on the PQ concerns along with their alleviation schemes required to be investigated additional systematically. Generally, non-controllable inconsistency of RES disturbs the systems that are use RE sources.

This inconsistency together with the power utility turbulences of grid side can be prospective future academic study topic.

- Supervising strategies for the voltage swell, interruptions, noise, etc. requires on the way to be established to identifying those concerns more precisely. The efficiencies of both methods time domain (TD) analysis & wavelet domain (WD) analysis can be compared for monitoring PQ problems.
- The integration between utility grids and micro grids can originate further PQ issues such as instability; loss etc. monitoring and mitigation of these difficulties also prerequisite to be studied.

VII. CONCLUSION

This article discusses the PQ problems for grid tied SPV systems based on RES. A detailed argument about quality of power concerns, their sources, and mitigation schemes have been described in the article. Discussion on approaches to monitor PQ, the appliances needed for that objective, and functions of custom power devices for preventing PQ issues has been presented. The techniques to improving power quality problems such as FACTs devices, active power filter, UPQC, multilevel inverter are discussed.

From this research article we found that the more severe PQ concerns are harmonic, fluctuation and voltage spikes. It has been found that the MLI is very effective for THD analysis and STATCOM may be a prospective choice owing to the benefits it propositions.

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