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Mitigation of Power Quality Problems Associated with Solar PV Integration into Low Voltage Distribution Network in India

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Abstract*— The emergence of renewable power energy has opened a new horizon to the generation, transmission and distribution of electrical power. Higher electricity demand, reduction in non-renewable (fossil fuels) and increasing demands of renewable energy, the combination of solar photovoltaic (PV) generation in low voltage grid is increasing prominence in India. Many distributed energy resources are associated with the utility network or microgrids with the assistance of a power electronics interface to make a hybrid system in nature. However, power quality is affected by various internal and external factors of power system including non-linear loads or induction loads, changing load demands, faults and different weather patterns to deteriorate the performance system. This thesis focuses on power quality issues such as mismatch of voltage (Voltage dip) and poor power factor and possible solution of these PQ issues is addressed by FACTS device with two different energy storage devices. D-STATCOM is a part of FACTS device that has excellent voltage regulation capacity through reactive power compensation in hybrid power system. By voltage control topology, the proposed D-STATCOM can mitigate voltage dip and poor power factor problems during the addition of 11KVA rated extra load in hybrid power during specific time 0.1s to 0.3s interval. Furthermore, D-STATCOM with energy storage also provides active and reactive power compensation simultaneously and independently in 15KVA low voltage electrical distribution system integrates with 25KW Solar PV hybrid system. D-STATCOM with battery energy storage and capacitor to check the effectiveness of this combination for mitigation of these power quality problems through comparison of results. In this project, simulation tool, namely MATLAB/SIMULINK, is used to study the of power quality problems and mitigation device. From the simulation data shows that D-STATCOM with BESS is an effective solution of voltage sag & poor power factor between 0.1s to 0.3s and improve voltage profile at the desired stage and help to compensation of active & reactive power compared DSTATCOM with a capacitor. The future upgrade of the work is proposed as needs be to fill the gap.

***Keywords*— Power Quality, Low voltage electrical distribution system, Distribution static synchronous compensator, Point of common coupling, Battery energy storage system**

I. Introduction

Electric power distribution networks are extensive and are a key part of the infrastructure that supports commercial, residential and industrial facilities. These networks are always evolving, which is driven by a need for age-related renewal, application of clean and renewable sources of energy, power industry deregulation and increased or decreased demand. Besides, usage of solar photovoltaic generation is expanding in India and the government of India is offering numerous appropriations for sunlight-based power plants as a section National Solar Mission and helping approach administrative structure in numerous states. The primary points of interest of solar grid framework combination incorporate improved reliability of the grid and decrease transmission & distribution losses.

Furthermore, Solar PV systems are divided into two categories by on-grid applications and Off-grid applications. Off-grid solar power systems are independent and not connected to a utility grid and it supplies power to a remote load. “Grid-connected solar PV Systems have opposite nature. In a distribution system, Solar PV gives an improvement in the reduction of energy losses” [7]. Fig. 1 shows basic configuration of grid-connected Solar PV system in block manner. Power conditioning unit is considered as inverter which converts supply voltage DC to AC form and PV unit supplies electrical power to utility grid as well as local load. Numerous Valuable past studies have been performed to assess the potential effect of PV and have assessed the impact of DG [10] on the voltage profile along the LV distribution lines. The irradiance of solar and high penetration levels causes voltage regulation and poor power factor correction (power quality) issues in grid-connected Solar PV system. Most of the power quality problems happen in distribution systems due to non-linear loads or induction loads, changing load demands, faults and different weather patterns. Utility power companies, service providers & university students give interest in solving power quality issues and understanding the value of the project in future.

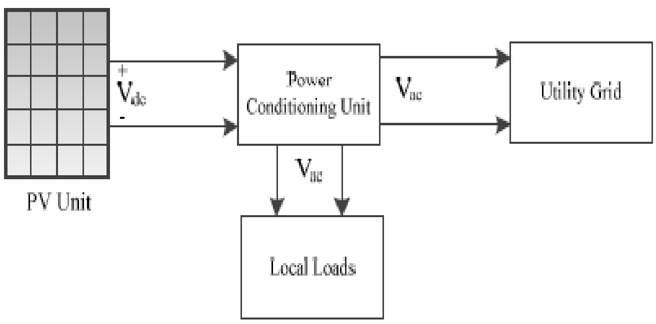


Fig.1. Grid connected Solar PV system [3]

The main aim of this research paper to mitigate voltage dip/swell & poor power factor in hybrid system through D-

STATCOM device [14] and check the evaluation of D-STATCOM with BESS. BESS system is also integrated with solar PV system for economical befits and saving energy in this research model as per point of view of many studies.

This research paper is organized in five sections: Overview of power quality issues is explained in section II, Proposed methodology and design parameters are presented in section III, Results and discussion part are described in section IV and conclusion presents in section V.

II. Overview of Power Quality Issues

Literatures[11] show analysis of power quality problems such as voltage unbalance, voltage sag ,voltage swell and poor power factor and harmonic distortion but literature survey [13] argued that when inductive load is connected for certain time period with low voltage based hybrid system at the time , higher possibility of voltage sag and poor power factor occurs in it and mitigation of it is considered through D-STATCOM device which is helping to alleviate the voltage profile and correct power factor because of its benefits in terms of functionality.

A. Voltage sag/dip

In this power quality issues, fluctuation of voltage means voltage signal has Changed in signification percentage of rated voltage while increasing demand for load with the existing system. By definition, a voltage dip is a reduction in the rms voltage in the range of 0.1 to 0.9 P.U. for a duration greater than half a mains cycle and less than 1 minute as shown in Fig. 2 [12].

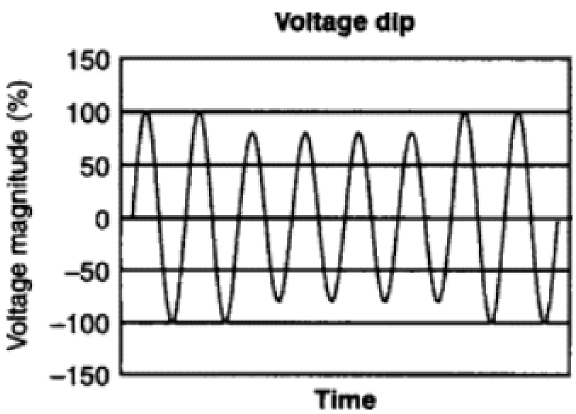


Fig. 2. Voltage sag/dip [5]

B. Poor Power factor

Power factor is a main part for efficient energy delivery in AC electrical system and it is measure of how effectively a specific load consumes electricity to produce work [1]. When solar PV is integrated with existing grid, mainly impacts on power factor because of inverter design, increasing inductive or capacitive load. Ideally, power factor is unity consider but in actual practice, power factor always less than 1 because of system reactance or non-liner load. Fig. 3 describe direction of active power and reactive power through four quadrants. Poor power factor means sudden drop of power factor whenever inductive load is integrated with low voltage system for certain time period. Main improvement of power can help to maximize current carrying capacity, improve voltage profile, reduce power loss, and lower electricity bills.

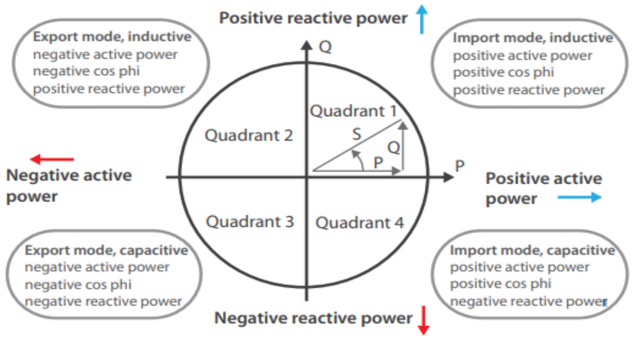


Fig. 3. Power factor through four quadrants [5]

III. METHODOLOGY & MODEL DESCRIPTION

A. Research Proposed methodology

Research project methodology of this work can be distinguished, and it is as appeared in the below steps:

1. Formulation of low voltage distribution grid-connected 25KW Solar PV hybrid power system model & apply research question on above hybrid system for addressing the power quality problems.
2. Development of proposed D-STATCOM and check functionality validation before integrating with hybrid system and integrate with formulated hybrid system.
3. To propose and develop the D-STATCOM with battery energy storage system as DC Source and integrate with hybrid system for mitigation above PQ issue.
4. To check effectiveness of D-STATCOM through capacitor & BESS configuration and finalize configuration

B. Model Description

In this heading, design parameters of model are presented in tabular form and explain MATLAB/Simulink model of research project with enough data in sequence.

1. **Low voltage (415V) AC hybrid system**: In hybrid system, 15 KVA low voltage distribution system relates to 25KW solar PV system. PCC bus is placed in LV network to measure and alleviate PQ issues. Fig. 4 shows hybrid configuration of LV network under 415V, three-phase AC supply and 50Hz frequency. LV Network has no upstream network in this configuration.

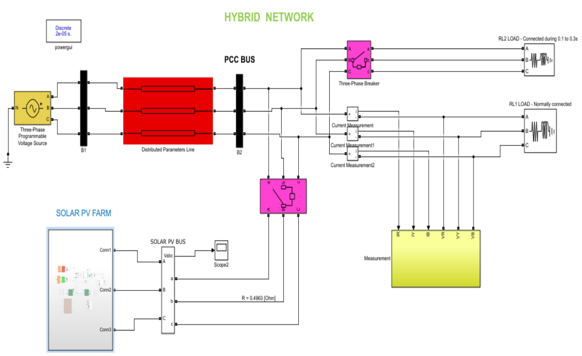


Fig. 4. Hybrid network

Design Parameters of Hybrid network:

TABLE I. HYBRID NETWORK

Parameters	*Value*
System voltage & frequency	415V & 50Hz
Three phase loads (in power rating)	RL1 = 15KVA & RL2 = 11KVA
Solar PV array	26KW (13KW each- 2 no)
Boost converter rating	330V-530V DC, 2kHz
Inverter	30-35KVA, 3 legs
Filter choke	0.00215H
Filter capacitance	550 µF

2. **Principle & modelling of D-STATCOM**: A Distribution level static synchronous compensator (D-STATCOM) is a shunt connected flexible AC transmission system (FACTS) controller used for power quality in the distribution level or at the medium voltage level **[4]**.D-STATCOM is more reliable techniques for improving voltage related problems such as voltage unbalance, rise, and drop. DSTATCOM is also providing compensation of harmonics and reactive power for the electrical grid. DSTATCOM provides a better solution for the enhancement of voltage profile and reduction of unbalance as compared to the DVR. The D-STATCOM regulates bus voltage by absorbing or generating reactive power. This reactive power transfer is done through the leakage reactance of the coupling transformer by generating a secondary voltage in phase with the primary voltage which is provided by a voltage sourced converter. When the secondary voltage is lower than the bus voltage, the D-STATCOM acts as an inductance & absorbing reactive power and it acts as capacitor & generating reactive power in opposite case. Fig. 5 shows basic configuration of D-STATCOM.

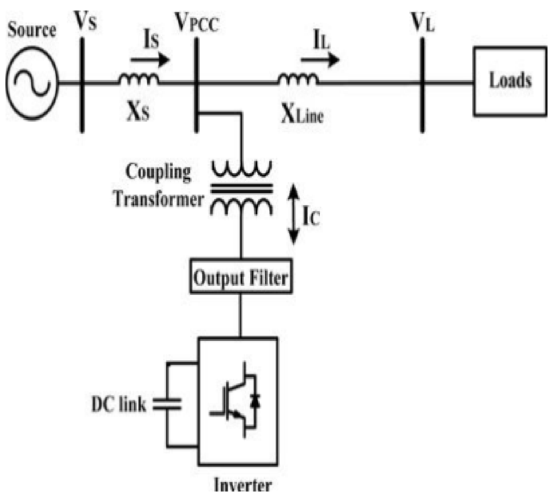


Fig. 5. Basic configuration of D-STATCOM [6]

- **Voltage source converter:** Voltage source converter is power electronics device, which can generate a sinusoidal voltage with any required magnitude, **frequency and phase angle**. It converts voltage from DC to AC. It combines switching elements and DC storage device for getting sinusoidal voltage.
- **DC link & energy storage:** A DC link voltage is provided by energy storage device such as capacitor or battery to voltage source converter. DC bud voltage value depends on PCC voltage and its must be higher than amplitude of the AC mains voltage for successful PWM control of VSC of D-STATCOM.
- **Transformer:** It provides isolation between inverts to PCC bus and it prevents the DC storage capacitor from being short circulated through switches
- **Output filter:** It provides pure sinusoidal voltage and it is designed by four parameters: resonant frequency, harmonic distortion rate, reactive power compensation, and inductance voltage drop. Fig. 6 demonstrates modelling of D-STATCOM device [15] and Fig. 7 shows control part in MATLAB [2] & suitable design parameters are considered as per requirement.

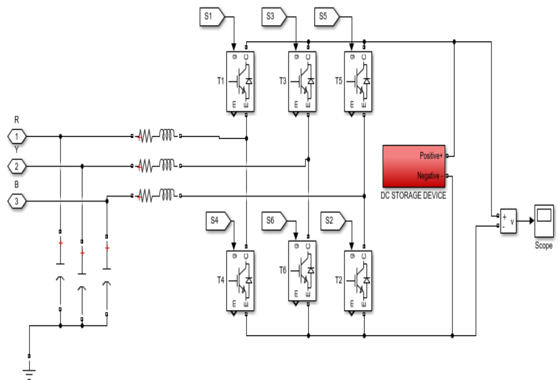
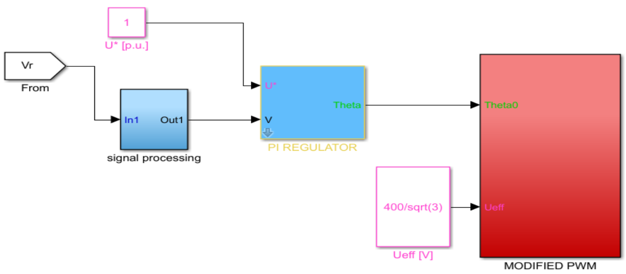
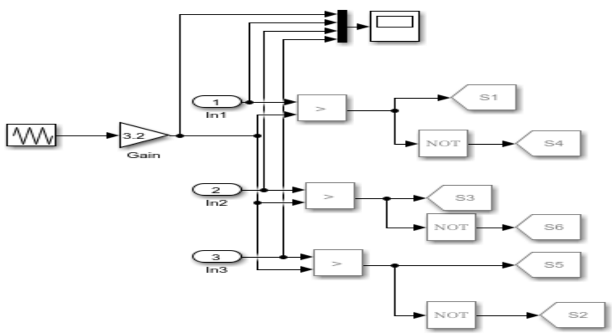


Fig. 6. Modelling of D-STATCOM in MATLAB



(a) Phase-locked loop



(b) switching sequences of six switches

Fig. 7. Control circuit of D-STATCOM

Design Parameters of D-STATCOM:

TABLE II. D-STATCOM PARAMETERS

Parameters	***Value***
Operating voltage & frequency	3 phases, 415V,50Hz
Voltage source converter	6 pulse type, 3 legs, 16KVA,
DC bus voltage	650V
DC bus capacitance	750 µF
Filter choke	4.8-5µH
Proportional gain	0.192
Integral gain	0.075
KVAR rating	25 KVAR

3. **Battery energy storage system :** BESS system [8] consists of number of series-parallel combination of battery as per requirement of desired voltage. 48V, 200Ah rated 12 numbers of battery in series combination provides 650V DC voltage to inverter via boost converter & 550 µF charge holding capacitor. Battery energy storage system provides DC suppy to DC Bus for input of inverter [17] &18].

IV. SIMULATION MODEL & RESULTS

In this chapter, need to present the outcome form the test cases which is derived from the Projected methodology in methodology chapter and to verify the desirable result to get the objective of research project.

A. Simulation model

Fig. 8 illustrate whole simulation model of this research project which corresponds to system configuration illustrated in fig.5 in terms of D-STATCOM, source & load. From Fig. 8, 15KVA LV network is connected with 25KW Solar farm through three-phase circuit breaker. Voltage sag/ dip is created through 11 KVA load which is connected through breaker with low voltage distribution system. D-STATCOM is connected through M1 bus & it operates whenever system causes unbalance or sudden fault in balance system. All test results are measured with respect to PCC bus M2. Value of voltage across PCC bus is considered in per unit quantity for preciseness in result.

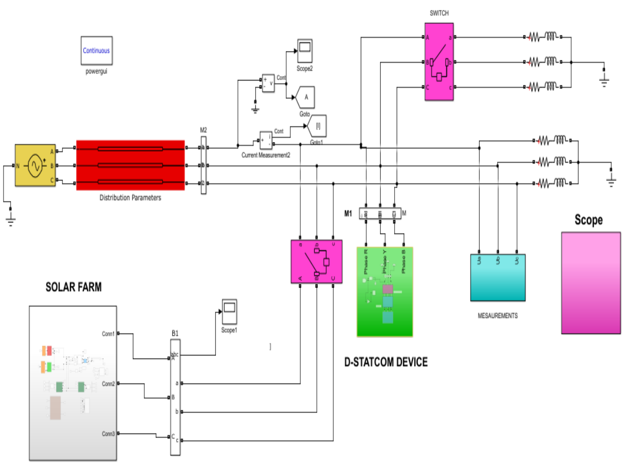


Fig. 8. Simulation Model

B. Simulation results & Discussion

The results can be divided into four parts for better clarification.

(1) Nature of Voltage profile & power factor when LV hybrid system is balanced

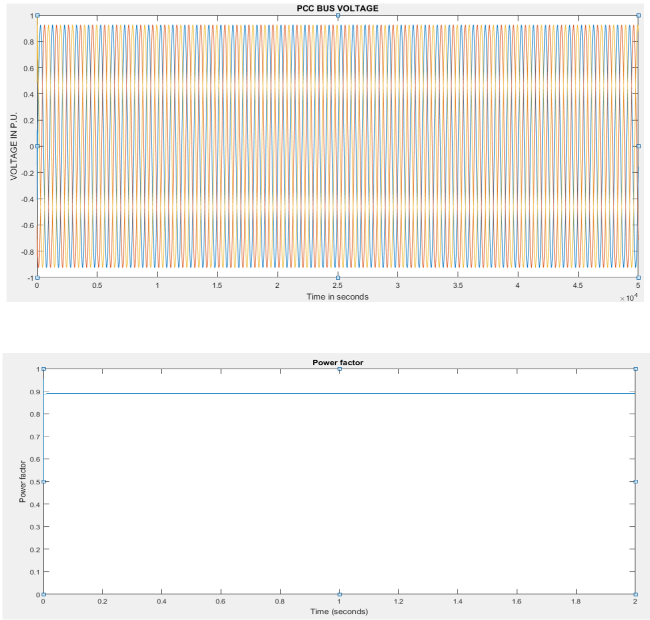


Fig. 9. Waveform of voltage profile & power factor at PCC in case of balanced hybrid system

(2) Nature of Voltage profile & power factor when LV hybrid system is unbalanced due to addition inductive load for specific period 0.1s to 0.3s

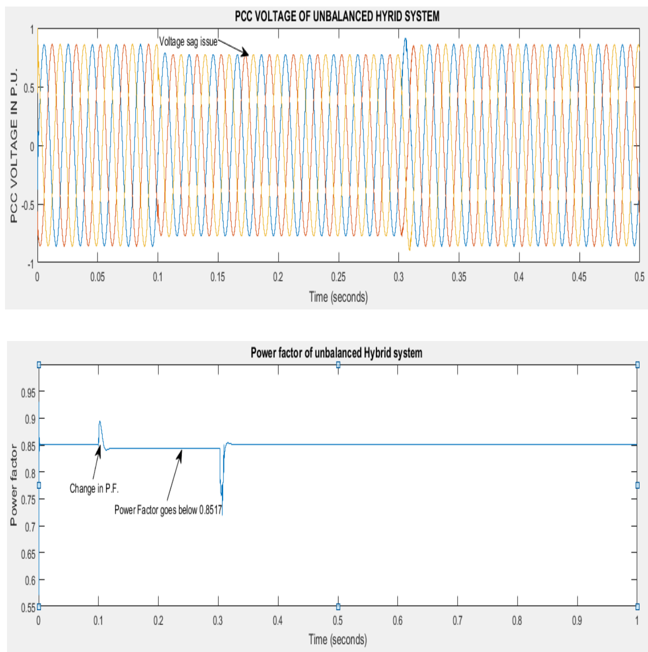


Fig. 10. Waveform of voltage profile & power factor at PCC in case of un-balanced hybrid system

Fig. 9 illustrates the voltage profile and system power factor whenever Hybrid system is in stable condition. At that time, PCC bus voltage 0.96 per unit and system power factor 0.889. While low voltage-based hybrid, system is added with extra load 11KVA, Fig. 10 comes in picture. Due to addition of load to LV network, it is unbalanced and can see the effect on voltage profile and power factor. PCC bus voltage decreases from 0.96 to 0.79 per unit between 0.1-0.3s and system power factor 5% reduced from original. These power quality problems are solved by D-STATCOM device which is explained in Fig. 11 & Fig. 12.

(3) Nature of Voltage profile & power factor during operation of D-STATCOM

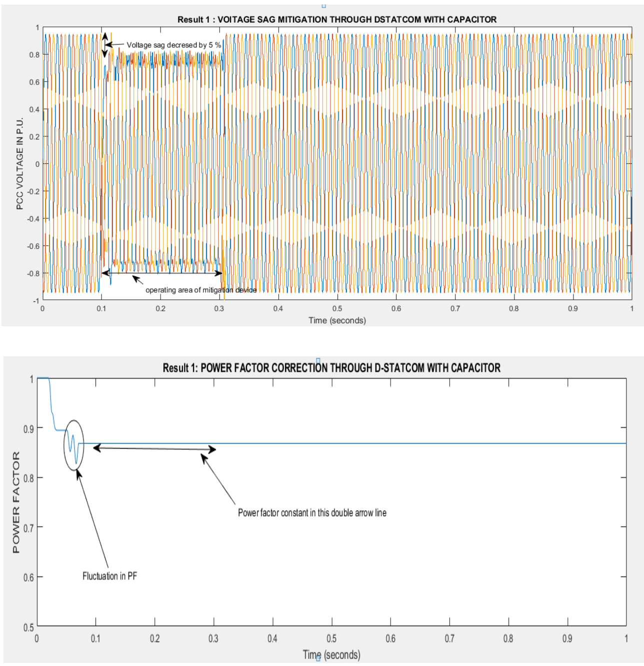


Fig. 11. Simulation Waveform of voltage profile & power factor with D-STATCOM

(4) Nature of Voltage profile & power factor during operation of D-STATCOM with BESS

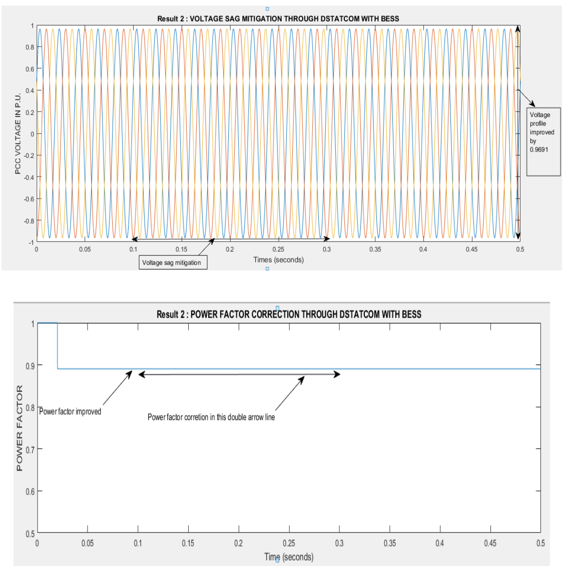


Fig. 12. Simulation Waveform of voltage profile & power factor with D-STATCOM+BESS

Here D-STATCOM device is coupled with PCC bus for compensation of voltage and improve power factor. Fig. 12 shows that when D-STATCOM device operates, voltage sad/dip issues are alleviated in hybrid system. Voltage profile improved from 0.79 to 0.83 per unit between 0.1-0.3s and system power factor is almost same 0.88. BESS as DC storage is applied with D-STATCOM help to achieve desire voltage profile and system power factor and compensate active and reactive power of hybrid network. Voltage Profile from 0.79 to 0.9691 per unit & power factor from 0.8534 to 0.8906 are upgraded between 0 to 0.5s which demonstrates compensation of active and reactive power. Overall, BESS configuration is efficient for improving voltage profile through results and terminology. In future, the effectiveness of BESS will be evaluated by the fuel cell to resume this study as per pieces of literature [16] recommendations.

V. Conclusion

Grid-connected solar PV approach is the outcome of future trend in transformation of grid that promotes renewable energies and they have presented difficulties in the steadiness and security at distribution level as Power quality problems. To investigate different type of power quality problems but this study considered those power quality issues which have high level of occurrence in the LV system. The power quality issues were fundamentally investigated and exhibited right in this research project, as mismatch of voltage profile (voltage sag/dip) and poor power, through modelling tested hybrid power system. Reason for choosing PV sourced hybrid system in this study increase potential of renewable energy that can be built up in India as well as worldwide. Compensation of power is one of the effective methods that can lighten the voltage issues raised and this research study gives contribution in in-depth investigation on its viability in terms of voltage regulation and power factor. This research study proposed D-STATCOM work as the reactive power compensator device to alleviate the profile of voltage and correct power factor in developed PV connected low voltage distribution network because of its benefits in terms of functionality. Control algorithm of D-STATCOM is followed through a pulse width modulation technique to achieve 15-30% increase in rated voltage. An Investigation is broadened the examination work further by battery energy storage system and capacitor which are integrated with D-STATCOM. From the simulation data, DSTATCOM with BESS configuration increase voltage profile 17.91 % and also do 1% real power compensation & 14& reactive power compensation to improve voltage profile. Enhancement of D-STATCOM with BESS give better flexibility for distribution system when compare with Capacitor system in the aspect of increasing eco-friendly solution.

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