INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH IN ENGINEERING AND MANAGEMENT (IJSREM)
VOLUME: 06 ISSUE: 07 | JULY - 2022 IMPACT FACTOR: 7.185 ISSN: 2582-3930

Power Quality Assessment & Mitigation of Grid Integrated PV System in Distribution Network

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***Abstract*— the need for electrical energy has become increasingly important. With the advancement of technology, computer and telecommunication networks, railway networks, banking, post offices, and life support systems are only a few examples of applications that cannot function without electricity. At the same time these applications demand qualitative energy. Thus, this Paper Presents the Integration of PV (renewable sources) into the existing grid to meet rising demand of electricity without stress on conventional power plant. Thereby, reducing greenhouse gases emissions to environment and this paper also presents D-STATCOM model to mitigate major power quality issues like Voltage Sag & Swell. In This paper, the design and performance of the D-STATCOM Control strategy were examined and simulated in this work utilizing the MATLAB Simulink environment.**

Keywords—Integration of Photovoltaic (PV), Voltage Sag & Swell, Phase Locked Loop (PLL), Voltage Source Inverter (VSI), Dynamic Voltage Restorer (DVR), D-STATCOM.

I. INTRODUCTION

Renewable energy sources are Environmental friendly in the production of Electricity to meet increasing demand. PV is a renewable energy source is used to offer electricityto use rs in a dependable, secure& sustainable manner, as well as to me et the world's rising energy demand [11].Electricity Producing using PV system is an important substitute to reduce stress on conventional fossil Fuels and The ideal generation capacity mix for 2019–20 and 2029–30 is described in a CEA draft report [12] depicted in fig.1.it is the reliable technique plays an important role in CO_2 emission mitigations. Although the initial cost of PV System is relatively high but running cost is very low hence it's economic.

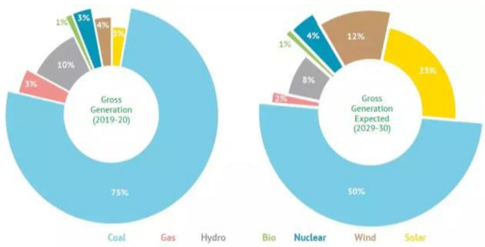

Fig.1: CEA Draft Report on optimal Generation Capacity Mix for **2019-20** & **2029-30.**

The several studies reported that although renewable energy sources have many advantages, the grid's power quality is impacted by the addition of renewable energy sources. This is mostly because renewable energy sources are intermittent nature. The major power quality issues identified are synchronization issues (voltage sag, voltage swell, and harmonics) and intermittent power flow etc.

A review of numerous studies published over the past few years has been provided in order to study power quality issues & mitigation methods. It is necessary to meet energy needs by integrating renewable resources like PV, Wind into power system to minimize environmental impact & stress on conventional power plant discussed in paper [1-2] presents integration of PV & Wind energy into existing gird affects the quality of power at Point of common coupling (PCC) of a distribution system due to intermittent nature of source available or increasing Utilization of Power Electronics Devices (i.e., Non-Linear Loads) (or) due to faults occurring in System [3,4], generates significant power quality problems like harmonics, voltage sag, and voltage swell [3]. Diverse software's tools are used to examine different power quality issues and mitigation strategies, power quality parameters and measurement equipment, international standards and regulations, major challenges, and solutions to power quality issues discussed in [5-6]. In [7-13] authors presents about power quality issues & different Mitigation techniques & its basic configurations, operating principle and control strategies in general.

The layout of this paper is as follows: In section IV Integration of Grid Connected PV system are discussed. Section V discusses the Power Quality Issues & Mitigation techniques for improving the power Quality at Point of Common Coupling (PCC) of a Distribution System. In section VI Simulink Models of Gird Connected PV System with existing gird and Control Strategy of D-STATCOM are simulated and results are discussed and finally Section VII Concludes the proposed work with results.

II. PROBLEM STATEMENT

The rising demand of electricity stress on conventional power plant increases the emission of green house gases (GHG) to environment causes global warming. The integration of renewable sources into the existing grid to accommodated rising demand but affects the power quality of the grid is mainly due to the intermittent nature of the renewable sources available and in the distribution network due to Non-Linear loads or due to faults occurring. To meet customer's satisfaction electricity company need to provide a reliable and good quality of supply, thus to mitigate power quality issues by finding best suitable and optimal technique to enhancing quality of power at Grid or Point of Common Coupling (PCC).

III. METHODOLOGY

Power Quality investigation and mitigation of grid integrated PV system in distribution network. Integration of PV System into Grid and A study on power quality issues such voltage sag and voltage swell was performed along with the integration of

PV systems into the grid. Hence, this project chooses the methodology of electrical systems simulation. MATLAB/SIMULINK software is used to model the renewable energy system that is incorporated into the main grid and D-STATCOM was modeled to reduce the voltage fluctuations and harmonics. It needs to be analyzed that within the limit specified by IEEE Standard, D-STATCOM was able to eliminate voltage fluctuations and harmonics.

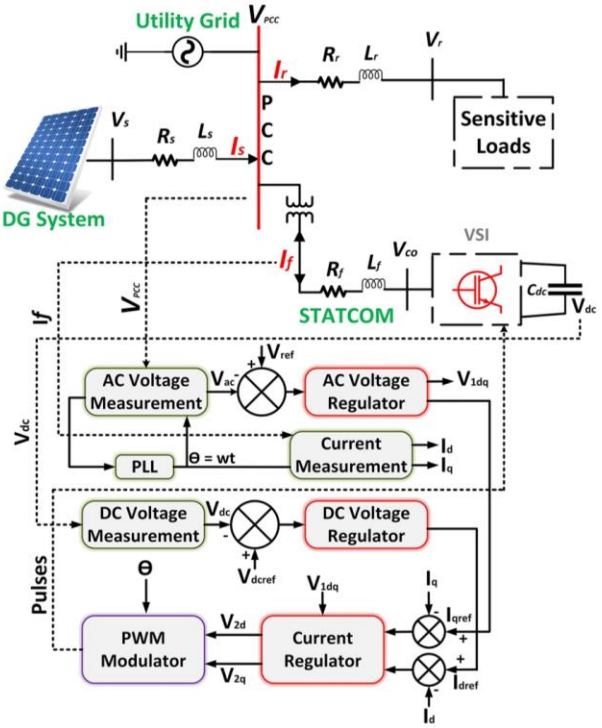

Fig.2: PV Integration wth Utilty grid at PCC in Distribution network with D-STATCOM.

IV. GRID INTEGRATION OF PV SYSTEM

Grid-connected PV systems (GCPV) are intended to run simultaneously with the conventional utility grid. PV array, DC-DC buck/boost converter, DC-AC inverter, filter etc. are the main parts of a GCPV system.

The output voltage of the DC from solar panels is converted into the AC system by the inverter. PV system connected to the grid to create the best and most energy possible from PV arrays, a maximum power point tracker (MPPT) is typically connected to a DC-DC converter as depicted in fig.3.

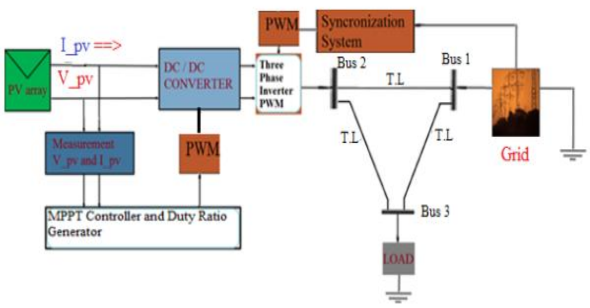

Fig.3: Schematic representation of Grid Connected PV (GCPV) System.

A. Mathematical Modeling of PV.

The influence of temperature, solar radiation, diode quality factor, and series resistance is evaluated. The effects of physical characteristics such as diode quality factor, series resistance Rs, shunt resistance Rsh, and saturation current, as well as environmental factors such as temperature and solar insolation are considered.

Fig.4 (a) & (b) depicts equivalent circuit of a PV cell and a PV array. The cell photocurrent is represented by the current source Iph. The intrinsic shunt and series resistances of the cell are designated as Rsh and Rs, respectively. They may be ignored in order to simplify the analysis because Rsh>>RS typically. Practically speaking, PV cells are arranged into bigger units called PV modules, and these modules are linked together in series or parallel to create PV arrays, which are used to produce energy in PV production systems.

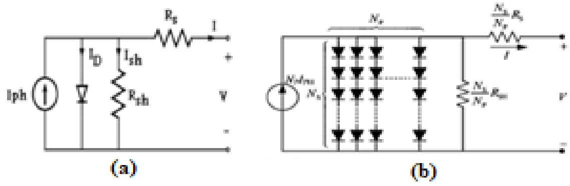

Fig.4: Equivalent Circuit of PV Cell and PV Module (array).

- Module photo-current Iph, represents the voltage-current characteristic of a solar cell.

$$I_{ph} = [I_{sc} + K_i(T - 298)] \times Ir/1000 \quad (1)$$

Where,

Iph & Isc: photo-current & short circuit current (Amp)

Ki: short-circuit current of cell at 25 °C and 1000 W/m2;

T&Ir: Operating temperature (K) & sun irradiation (W/m2).

- Module reverse saturation current (Irs) is,

$$I_{rs} = I_{sc}/[\exp(qV_{OC}/N_S knT) - 1] \quad (2)$$

Where,
q = 1.6 1019C for the electron charge.
Voc: open circuit voltage (in Volts)
Ns: number of cells linked in series
n: Ideality factor of the diode.
k== 1.3805 × 10^{-23} J/K for Boltzmann's constant.

- The module saturation current I_o varies with the cell temperature is,

$$I_O = I_{rs}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{q \times E_{go}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] \quad (3)$$

The band gap energy of the semiconductor, Eg0, is equal to 1.1 eV where, Tr: nominal temperature = 298.15 K

- The current output of PV module is:

$$I = N_P \times I_{ph} - N_P \times I_O \times \left[\exp\left(\frac{V/N_S + I \times R_s/N_P}{n \times V_t}\right) - 1\right] - I_{sh} \quad (4)$$

With

$$V_t = \frac{k \times T}{q} \quad (5)$$

And

$$I_{sh} = \frac{V \times N_P/N_S + I \times R_S}{R_{sh}} \quad (6)$$

Where,
N_p: the total number of parallel PV Module.
Rs & Rsh: series resistance (Ω) & shunt resistance (Ω)
V_t: Diode Thermal Voltage (Volts).

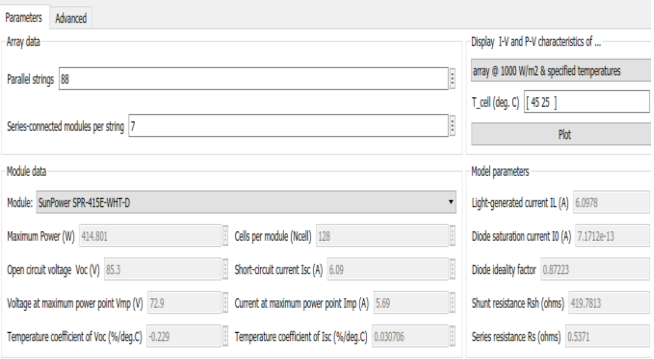

Fig.5: Specific of PV Module [Sun Power SPR-415E-WHT-D].

B. MPPT Technques.

Maximum power supplied by the photovoltaic panels is not always stable and fixed in the same operating point. To extract the maximum power, it is necessary to implement an MPPT algorithm. Different Methods of MPPT Techniques are varying in complexity; cost, and speed of convergence, sensors required, hardware implementation, and effectiveness are listed in table below.

Technique	P&O	IC	CV	OCV	SCC	RCC
Sensed parameters	V&I	V&I	V	V	I	V&I
Tracking speed	Slow	Slow	Slow	Slow	Slow	Fast
Tracking accuracy	Medium	Medium	Low	Low	Medium	High
Control strategy	Direct control (sampling method)	Direct control (sampling method)	Indirect control	Indirect control	Indirect control	Indirect control
Complexity level	Simple	Complex	Simple	Simple	Simple	Complex
Stability	No	Yes	No	No	No	Very stable
Parameter tuning	No	No	Yes	Yes	Yes	Yes
Ability to track under PSCs	No	No	No	No	No	Yes
Efficiency	97.8 %	98.5%	72.8%	92.4%	93.4%	96.4%
Cost	Affordable	Expansive	INEX	INEX	INEX	Expansive

Table.1: Comparison of Different MPPT techniques Algorithm.

P&O and Incremental Conductance MPPT Techniques Algorithms are direct control method hence extensively used to track Maximum Power (MPP) from Solar Panel with affordable cost. Incremental Conductance as almost same efficiency as compared to P&O but Incremental Conductance control is more complex. Thus, P&O Algorithm used in this Project are discussed in detailed.

- *Perturbation and Observation (P & O) Method*:

It is simple to implement the Perturb and Observe algorithm i n both analogue and digital circuits,& it does not require prior k nowledge of the PV generator characteristics (such as solar inten sity and temperature).Even if solar irradiance & cell temperature are constant, it disturb's the system's operating point, causing th e PV array terminal voltage to oscillate around the MPP voltage. Because of the balance between performance and simplicity, it is a straightforward, simple technique hence, that is quite popular.

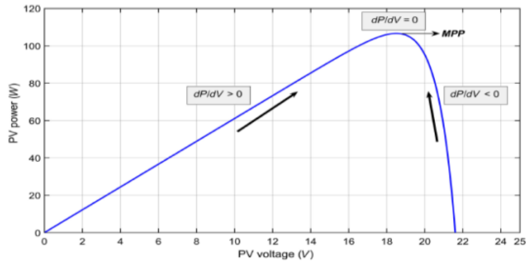

Fig.6: P-V Characteristics of PV System.

Case 1: Delta P>0 Delta V < 0		Case 2: Delta P>0 Delta V > 0	
Power increases, Voltage decreases	Delta D Subtracted	Power increases, Voltage increases	Delta D Added
Case 3: Delta P<0 Delta V < 0		Case 4: Delta P<0 Delta V >0	
Power decreases, Voltage decreases	Delta D Added	Power decreases, Voltage increases	Delta D Subtracted

Table.2: Operation of P & O MPPT Algorithm to adjust duty cycle for tracking MPP.

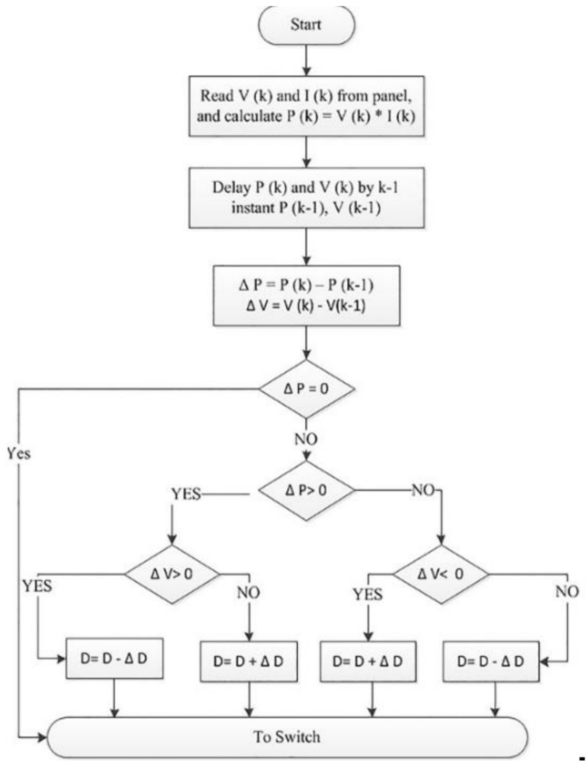

Fig.7: Flow Chart for P& O Algorithm.

C. Designing of PV Components.

- *PV Array*

The module used for 250 KW GCPV is *Sun Power SPR-415E-WHT-D* PV array. Table.3 provides the PV module's specifications.

SI. NO.	*Model: Sun Power SPR-415E-WHT-D*	
	Parameter	**Value**
1.	Maximum Power (P_{max})	414.80 Watt
2.	Voltage at P_{max} (V_{max})	72.9 Volts
3.	Current at P_{max} (I_{max})	5.69 Amp
4.	Short Circuit Current (I_{SC})	6.09 Amp

5.	Open Circuit Voltage (V_{OC})	85.3 Volts
6.	Number of Cells per Module (Connected in Parallel)	88

Table.3: Specification of PV Module.

The PV array for the proposed models is intended to provide 250kW (array power) at a maximum irradiation of 1000 W/m2 and a constant temperature of 25°C. The maximum power (Pmp), the maximum voltage (Vmp) and maximum current (imp) of the PV system is 414.80 W, 72.9 V and 5.69 A respectively. The string voltage ($Vstring$) is 510 V. The number of modules, string power and number of strings of the PV system can be calculated using the following equations.

Equations	Calculated Values
$Number\ of\ Modules = \frac{V_{string}}{V_{MP}}$	88 Modules
$String\ Power = No.of\ Modules * Max.\ Power$	36.502 KW
$Number\ of\ Modules = \frac{Array\ Power}{String\ Power}$	7 Strings

- *Inverter and Filter Design*

SI. NO.	*Parameters of Inverter*		
	Parameter	**Equations**	**Value**
1	Inverter power (P)	--	50 KW
2.	Base Voltage ($Vbase$)	--	415 V
3.	Base Power ($Pbase$)	$P_{base} = \frac{V_{base}^2}{P}$	3.4445 W
4.	Switching frequency, (fs)	$fs = 99 * f$	4950 Hz
5.	Sampling time (Ts)	$Ts = \frac{1}{fs * 100}$	2.02×10^{-6} sec
6.	Resistance in RL branch (R)	$R = 1.5 * 10^{-3} * P_{base}$	0.0052 Ω
7.	Inductor value in RL branch (L)	$L = \frac{(0.15 * P_{base})}{(2 * pi * f)}$	0.0016 H
8.	Capacitive reactive power (Q_C)	$Q_C = 0.1 * P$	5000 W
9.	Active power (P_C)	$P_C = \frac{Q_C}{50}$	100 W

Table.4: Calculated Parameters of PV Inverter.

D. Phase Locked Loop (LOOP).

A phase-locked loop is a closed-loop feedback control circuit that is responsive to both frequency and phase. In addition to synchronizing the output and input frequencies, a PLL assists in establishing the input-output phase connection to generate the appropriate control voltage. As a result, it helps a circuit achieve frequency and phase lock.

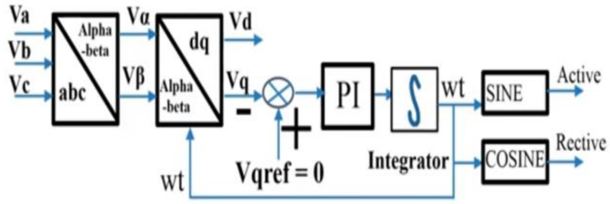

Fig.7: Closed Loop PLL Circuit to Measure 'wt'.

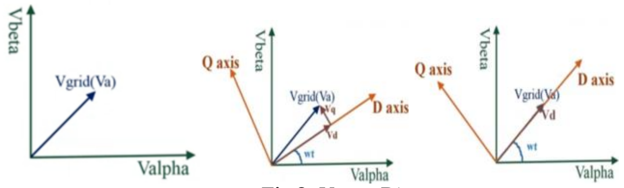

Fig.8: Vector Diagram.

V. POWER QUALITY ISSUES AND MITIGATION TECHNIQUES

A. Power Quality Issues.

Power Quality has gained its importance in recent years as it plays a vital role in supplying electricity effectively to its end user. IEEE defines power quality as "The Concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment."[3]

Power Quality is significant because customer pays for good quality power if power quality is poor, it breach of trust. Poor quality power damages consumer's equipments & affects equipments life, increases of system losses. The reliability of power supply's affected due to relay's operations, frequent faults and equipment failure.EPRI-2001study of typical PQ phenomena as shown in fig.9.

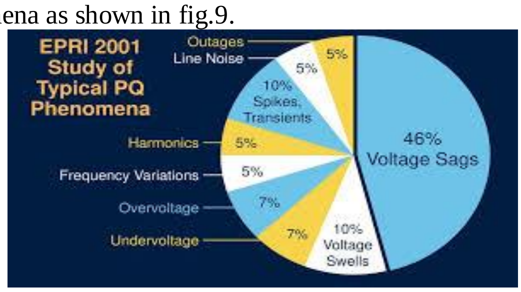

Fig.9: Major power Quality Problems (Source: EPRI-2001).

B. Mitigation Techniques for PQ Problems.

There are two ways to mitigate power quality problems - either from the customer side or from the utility side. Both load conditioning (on the customer's side) & line con ditioning (on the utility's side) perform effectively using custom power devices (CPD) to mitigate Multiple power quality issues related to utility distribution.

- *D-STATCOM*

A Voltage Source Converter (VSC)-based device called a Distribution Static Compensator is a D-Fact device that is shunt connected. It compensates for the reactive power and unbalance caused by various loads in the distribution system. The Performance of the D-STATCOM depends on Control Algorithm used for extracting there reference current components.

In Tehran, a ± 250 Kvar D-STATCOM was the first to be installed and D-STATCOM was built and deployed in Iran for a 1.6 MVA distribution Substation system.

a) Basic configuration of D-STATCOM

A shunt-connected device called D-STATCOM is used to control voltage by either generating or absorbing reactive power. Figure.12. depicts the schematic representation of a D-STATCOM. It includes a leakage reactor, coupling transformer, voltage source inverter (VSI), and a DC capacitor.

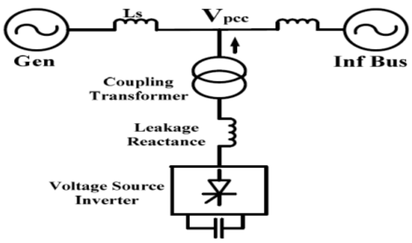

Fig.12: Schematic Diagram of D-STATCOM.

Working Principle:

The charged capacitor serves as the input for the VSI in D-STATCOM, which then generates voltage. For this, it makes use of the PWM switching technology. The coupling inductor coupled to the D-STATCOM transfers the reactive power to the Gird at the Point of Common Coupling (PCC) voltage difference across the reactor. The performance of the system is improved by managing D-STATCOM so that it only exchanges reactive power with the grid. To do this, current is injected in quadrature with the gird voltage.

b) Operating Modes of D-STATCOM

To control the bus voltage by generating or absorbing reactive power is the fundamental working concept of a D-STATCOM in voltage sag mitigation. As a result, depending on the magnitude of the bus voltage, the DSTATCOM works as an inductor or a capacitor (Supply Voltage).

i) Inductive Mode of Operation: When the bus voltage magnitude (VB) exceeds the rated voltage, the D-STATCOM functions as an inductor, absorbing reactive power from the system. The circuit and phasor diagram are shown in Fig.13(a).

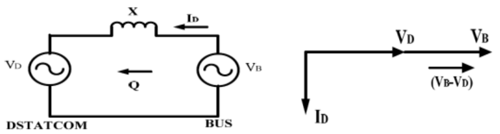

Fig.13 :(a) Inductive Mode of Operation.

ii) *Capacitive Mode of Operation*: The D-STATCOM functions as a capacitor, generating the reactive power for the system if the bus voltage magnitude (VB) is less than the rated value of voltage. Fig.13 (b). Shows the circuit and phasor diagram for this mode of operation.

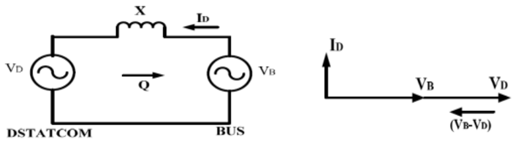

Fig.13: (b) Capacitive Mode of Operation.

iii) *Floating Mode of Operation*: As illustrated in Fig.13(c), there is no exchange of reactive power between the grid and the D-STATCOM when their voltages are equal in magnitude. Then the D-STATCOM is in the floating mode of operation.

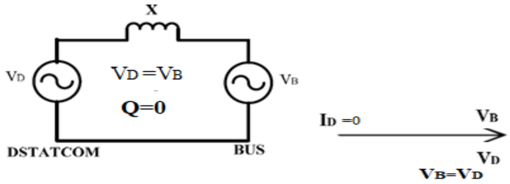

Fig.13 :(c) Floating Mode of Operation.

c) Mathematical Modeling of D-STATCOM

- The Three Phase instantaneous Voltages at PCC is,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \sqrt{\frac{2}{3}}\, V_s \begin{bmatrix} \sin \mathrm{wt} \\ \sin\left(\mathrm{wt} - \frac{2\pi}{3}\right) \\ \sin\left(\mathrm{wt} + \frac{2\pi}{3}\right) \end{bmatrix} \quad (1)$$

- The relationship between the PCC voltages, the inverter output voltages and currents are obtained by writing the KVL equation for the single line diagram of DSTATCOM.

$$\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} {-R_f}/{L_f} & 0 & 0 \\ 0 & {-R_f}/{L_f} & 0 \\ 0 & 0 & {-R_f}/{L_f} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{1}{L_f}\begin{bmatrix} V_a - V_{ca} \\ V_b - V_{cb} \\ V_c - V_{cc} \end{bmatrix} \quad (2)$$

The system differential equations in the abc reference frame are described by the aforementioned equations. These equations must be transformed to the synchronous reference frame in order to manage the current that the VSC injects. The Park's transformation is applied to convert the synchronous dq0 reference frame from the abc reference frame.

- As the system is assumed a balanced, only d and q components exist. The transformed results in the d-q frame are given by,

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} {-R_f}/{L_f} & \omega \\ -\omega & {-R_f}/{L_f} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L_f}\begin{bmatrix} V_{sd} - V_{cd} \\ V_{sq} + V_{cq} \end{bmatrix} \quad (3)$$

- Neglecting the voltage harmonics produced by the direct and the quadrature axes voltages, we get,

$$V_{cd} = m\, V_{dc} \cos\alpha$$
$$V_{cq} = m\, V_{dc} \sin\alpha \quad (4)$$

- The power balance equation is,

$$V_{dc}\, i_{dc} = \frac{3}{2}\left(V_{cd}\, i_d + V_{cq}\, i_q\right) \quad (5)$$

- The DC side of the DSTATCOM's current is,

$$i_{dc} = \frac{3}{2} m\left(i_d \cos\alpha + i_q \sin\alpha\right) = C\,\frac{dV_{dc}}{dt} \quad (6)$$

- The mathematical representation of the DSTATCOM's state space is,

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \\ V_{dc} \end{bmatrix} = A\begin{bmatrix} i_d \\ i_q \\ V_{dc} \end{bmatrix} - \frac{1}{L_f}\begin{bmatrix} V_{sd} \\ 0 \\ 0 \end{bmatrix} \quad (7)$$

Where, A is,

$$A=\begin{bmatrix} -R_f/L_f & \omega & \frac{-m}{L_f}\cos\alpha \\ -\omega & -R_f/L_f & \frac{m}{L_f}\sin\alpha \\ \left(\frac{3}{2}\frac{m}{C}\right)\cos\alpha & \left(\frac{3}{2}\frac{m}{C}\right)\sin\alpha & 0 \end{bmatrix}$$

- The instantaneous active and reactive powers is,

$$p=\frac{3}{2}\left(V_{sd}i_d+V_{sq}i_q\right)=\frac{3}{2}V_{sd}i_d=\frac{3}{2}V_s i_d$$

$$q=\frac{3}{2}\left(V_{sq}i_d-V_{sd}i_q\right)=-\frac{3}{2}V_{sd}i_d=-\frac{3}{2}V_s i_q \quad (8)$$

By control the active and reactive components of currents in order to change how well the DSTATCOM performs. To achieve the control objectives, the control algorithm developed in the synchronous reference frame should control either the d or q component of the current.

d) D-STATCOM Controller Principle

The D-STATCOM is performed in the control using a two-level VSC. By absorbing or providing reactive power to the bus, the bus voltage is controlled. The voltage regulation application's cascade controller is depicted in Fig.14.

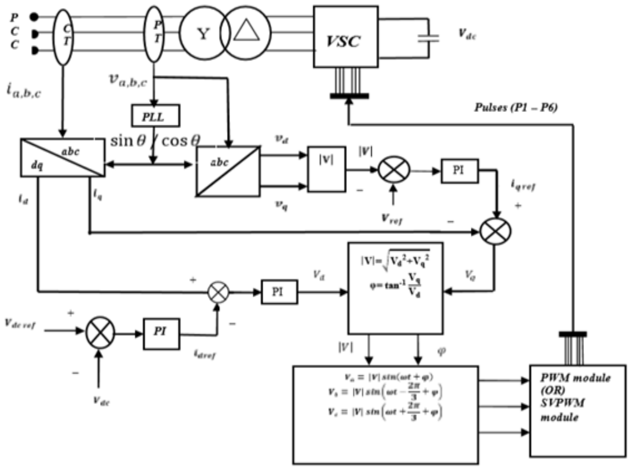

Fig.14: Control Principle of D-STATCOM

Two voltages are managed in the DSTATCOM for voltage regulation. The AC power system voltage at the bus, where the DSTATCOM is linked, is one, and the DC link voltage across the capacitor is the other. They are both proportional integral (PI) regulators. Using Park's transformation technique, the output current from the VSC is transformed into the d- and q-axis components. To obtain the ref Id, the error is controlled by a PI controller. A different PI controller controls the ref Vrms and Vrms signals to produce the ref Iq. Then, in a different set of PI regulators, these reference currents are controlled by comparing the d and q components of the currents with the corresponding components of the reference current, whose outputs are the d-axis and q-axis control voltages for the D-STATCOM.

Instead of using the inverse Park's transformation to speed up computation, the three phase sinusoidal reference signals are generated using magnitude and phase angle, as shown in Equations.

$$|V|=\sqrt{V_d^2+V_q^2} \quad (1)$$

$$\phi=\tan^{-1}\left(\frac{V_q}{V_d}\right) \quad (2)$$

$$\begin{aligned} V_a&=|V|\sin(wt+\phi)\\ V_b&=|V|\sin(wt-\frac{2\Pi}{3}+\Phi)\\ V_c&=|V|\sin(wt+\frac{2\Pi}{3}+\Phi)\end{aligned} \quad (3)$$

VI. SIMULATION RESULTS AND DISCUSSION

MATLAB Simulink will be used to perform the simulation, here, the modeling of 250KW GCPV System, Modeling of Utility Grid and Modeling of D-STATCOM are discussed.

A. Modeling of Grid Connected PV(GCPV) System

The PV system has 88 parallel strings, each with 7 series-connected modules. The PV system's maximum voltage and current are 72.9 V and 5.69 Amp, respectively. PV panels generate variable power using variable solar irradiance at variable temperatures between 25 and 45 degrees Celsius. A voltage source inverter with a 50 KW rated capacity is connected to the PV system. The PV system's inverter transforms the DC voltage into AC voltage. Sampling duration is 2.02* 10^{-6} sec, and the switching frequency is 4950 Hz (5 KHz). With an inductor value of 0.0016 H, the VSI is linked to an LC filter to lower the harmonics. The Simulink model of 250KW PV integrated to the grid is depicted in Fig.15.

B. Modeling of Utility Grid

The Proposed grid consist of a Three Phase Source of 120 kV, 2500 MVA which is stepped down to 11 kV (47 MVA) using Step down Transformer. The Simulink Model of Utility Grid is depicted in fig.15. The simulation of a GCPV with the existing grid under a linear and Non-Linear load scenario is shown below.

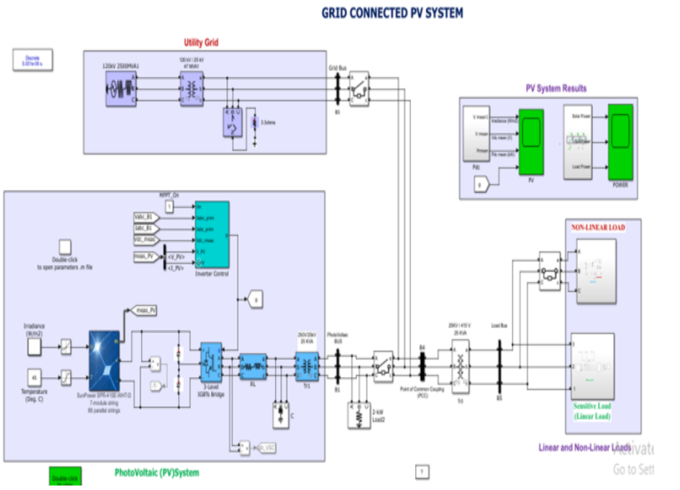

Fig.15: Simulation Model of 250KW GCPV System with utility grid.

- *Irradiance variation in the PV System.*

Sun Irradiance has an Impact on the Power generation of PV System. For low value of Irradiance, The Power Output of PV lowers than its maximum Power output capacity. The simulation results of PV Outputs (such has Solar Irradiance, DC voltage V_{DC}, DC Power P_{DC} & Duty Cycle of inverter) at Inverter input terminals as shown in fig.16.

Initially Solar irradiance is 1000 W/m^2 the system has approximately DC Voltage of 480Volts at input terminal of Inverter and produces the DC Power of 250 KW. Due to

Intermittent nature of Source, solar irradiance reduces gradually to 200 W/m^2 it impacts on Power produced by the PV system i.e., Power decreases to 50 KW. The DC Voltage of 480 volts at input terminal of Inverter maintains remains constant even there is a variation in solar irradiance.

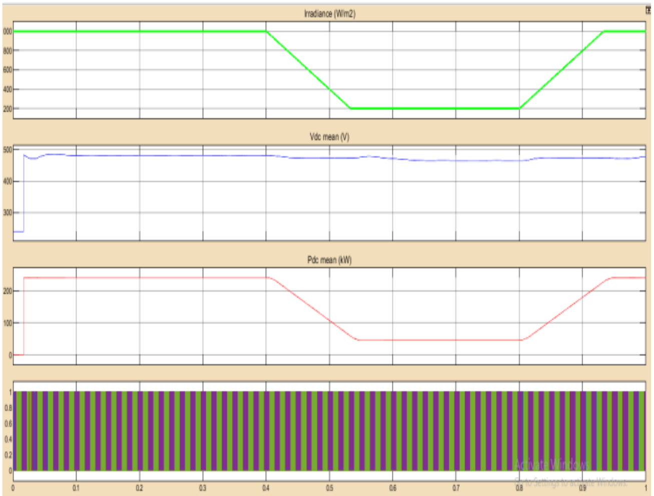

Fig.16: Solar Irradiance, Vdc, Pdc and Duty Cycle of Inverter.

- *Load sharing by PV and existing utility grid.*

The Linear Load connected to the system and kept constant to 515 KW. The Power produces from the solar shown in fig.17(a) It generates 250 KW power under standard Temperature and Irradiance test conditions. However, PV Output Power varies with the variations in the value of Irradiance, the power curve of the grid system increases in the same proportion as solar Power decreases. Thus, the remaining load taken care by utility grid power as depicted in fig.17 (b) and Load demand curve as shown in fig.17 (c).

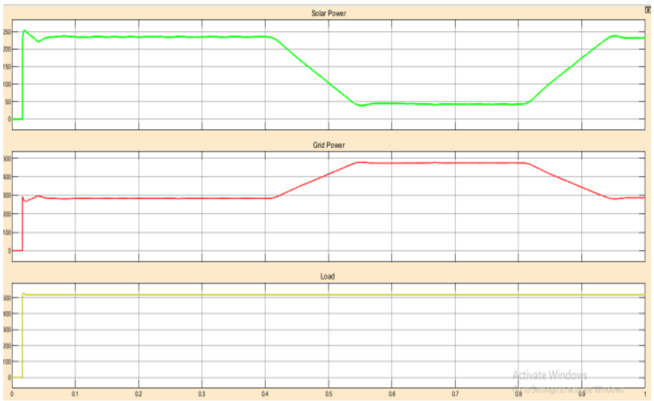

Fig.17: Solar power, Grid Power and Load Demand Curve under Linear Load.

C. Modeling of D-STATCOM

There are several ways to reduce PQ problems, such as voltage sag, swell, and harmonics. The D-STATCOM is the one of them that is used to manage the load voltage by being connected shunt to sensitive loads. MATLAB SIMULINK simulates the D-STATCOM control strategy and discusses the D-STATCOM performances in Mitigate Power Quality issues in proposed System.Table.5.1. Lists the System Parameters utilized for Simulation with D-STATCOM.

Main Supply Voltage at PCC	11 KV
Coupling Transformer Voltage	11KV
Coupling Transformer Turns Ratio	1:1
DC link voltage	2400 volts
Capacitance	10000 μF
Filter Parameter:	
i. Inductance	800 μH
ii. Capacitor	100 μF
Load Active Power	4 MW
Reactive Power	±3 Mvar
Frequency	50 Hz

Table.5: D-STATCOM Parameter Specification.

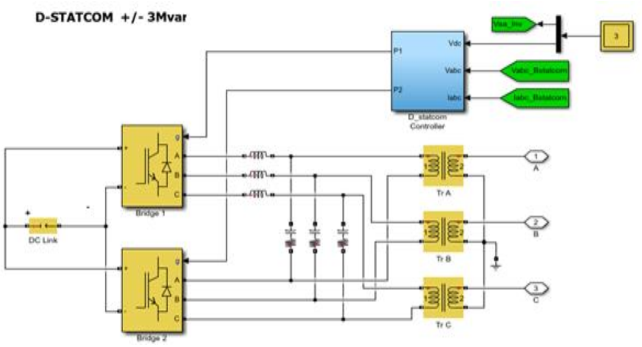

Fig.18: Simulation model of Two-Level VSC for D-STATCOM for improving power quality at PCC of distribution system.

D. Proposed System wth D-STATCOM

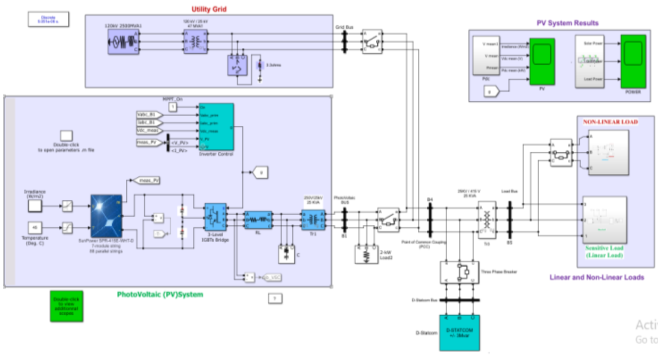

Fig.19: 250KW Grid Connected PV System with D-STATCOM.

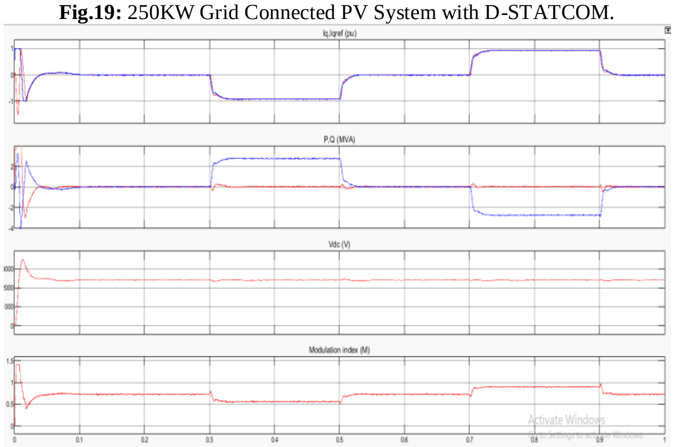

Fig.20: (a) Quadrature axis current I_q & reference quadrature axis current I_{qref}. (b) Active & reactive power generated from D-STATCOM (C) The DC connection voltage remains constant at 2.4 kV, which is its nominal value. (d) Modulation index less than 1.

Voltage Magnitude V from Supply voltage compare with reference voltage (Vref) to generate reference quadrature axis current Iqref from PI Controller and quadrature axis current Iq from source current as shown in fig.20 (a). The active & reactive power generated / absorbed based on voltage magnitude is greater or lesser than rated voltage observed n fig.20 (b).DC Voltage magnitude is constant to 2400V as shown in fig(c) and fig (d) is a modulation index curve it shows value less than 1 indicates that the obtained Voltage waveforms had less distortion.

Case.1: Voltage Swell

Voltage swell s started in the system for between 0.3 to 0.5 sec by switching capacitors or reducing the load and consequently, the voltage at PCC is increased (say by 50%) from its rated Value of 1 Pu voltage depicted in fig.21 (a). throughout this time, the control circuit of the D-STATCOM gets stimulated. It generates compensating current which is injected into the system. Based on the magnitude of compensation current (during voltage swell, it will inject negative magnitude) which is injected into the system. Based on the magnitude of this compensation current reactive power exchange (absorbs reactive power +2.7 MVA shown in fig.20 (b)) takes place between the D-STATCOM and the Supply Bus to maintain a 1 Pu voltage at PCC. Based on this the load voltage is regulated. The waveform of the compensation current of D-STATCOM is shown in Fig.21 (b) and regulated Load Voltage is shown in Fig.21 (c).during Voltage Swell the D-STATCOM acts as inductive mode of operation & absorbs reactive power and injects negative magnitude of compensation current to remove voltage swell.

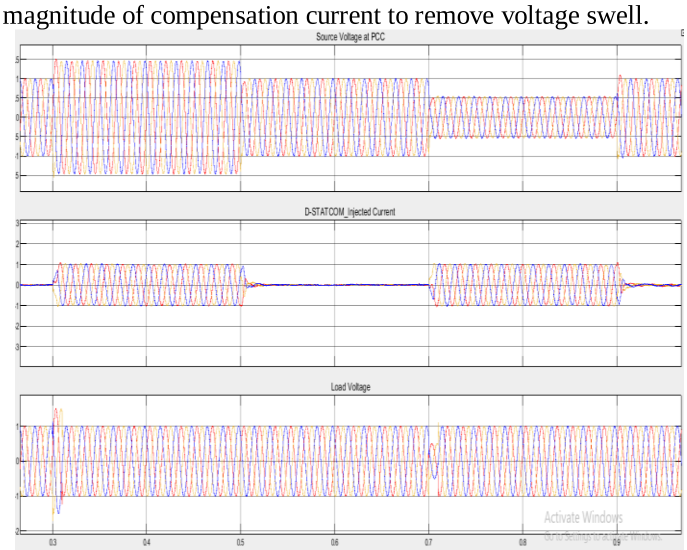

Fig.21: (a) Supply Voltage (b) D-STATCOM_Injected Current (c) voltage at load.

Case.1: Voltage Swell

Voltage swell s started in the system for between 0.3 to 0.5 sec by switching capacitors or reducing the load and consequently, the voltage at PCC is increased (say by 50%) from its rated Value of 1 Pu voltage depicted in fig.21 (a). throughout this time, the control circuit of the D-STATCOM gets stimulated. It generates compensating current which is injected into the system. Based on the magnitude of compensation current (during voltage swell, it will inject negative magnitude) which is injected into the system. Based on the magnitude of this compensation current reactive power exchange (absorbs reactive power +2.7 MVA shown in fig.20 (b)) takes place between the D-STATCOM and the Supply Bus to maintain a 1 Pu voltage at PCC. Based on this the load voltage is regulated. The waveform of the compensation current of D-STATCOM is shown in Fig.21 (b) and regulated Load Voltage is shown in Fig.21 (c).during Voltage Swell the D-STATCOM acts as inductive mode of operation & absorbs reactive power and injects negative magnitude of compensation current to remove voltage swell.

Case.2: Voltage Sag

Voltage Sag is started in the system for between 0.7 to 0.9 sec by connecting an extra load (say for ex: Starting of induction Motor) in the circuit. Thus, throughout this time the resultant dip in the voltage at the PCC in per unit is depicted in fig.21 (a). At t=0.7 to 0.9 sec , the voltage at PCC is decreased (say by 50%) from its rated Value of 1 Pu voltage. throughout this time, the control circuit of the D-STATCOM gets stimulated. As it is a shunt connected device, it generates compensating current which is injected into the system. Based on the magnitude of this compensation current reactive power exchange (generates reactive power -2.7 MVA shown in fig.20 (b)) takes place between the D-STATCOM and the Supply Bus to maintain a 1 Pu voltage at PCC. Based on this the load voltage is regulated. The waveform of the compensation current of D-STATCOM is shown in Fig.21 (b) and regulated Load voltage is shown in Fig.21 (c). During Voltage Sag the D-STATCOM acts as a capacitive mode of operation & generates reactive power and injects magnitude (i.e., Positive Magnitude) of compensation current to compensate Voltage sag.

ACKNOWLEDGMENT

I convey my gratitude to Dr. S. G Ankaliki (Professor& HOD), Department of Electrical & Electronics Engineering, for their sincere support & suggestions in successful completion of this work.

CONCLUSION

A PV system was integrated into the existing grid using PLL technique to overcome synchronization issue and the output was simulated & results are presented. Voltage fluctuations like Sag & Swell were observed in the Grid integrated grid PV System at PCC in distribution network because of Non-Linear Loads connected. Voltage fluctuations in the Proposed System is Mitigating using D-STATCOM (Shunt Connected D-Fact device) to limit Power Quality Issues in distribution network within IEEE Standard is evident from the results.

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