International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Email:editorijoer@gmail.com http://www.ijoer.in

Vol.4., Issue.3., 2016 (May-June)

RESEARCH ARTICLE

ISSN: 2321-7758

DESIGN OF DYNAMIC VOLTAGE RESTORER WITH INTEGRATED PV SYSTEM FOR POWER QUALITY IMPROVEMENT OF A DISTRIBUTION SYSTEM

BALAJI.P[1], Dr. B.BASKARAN[2], Dr.GHADIR RADMAN[3]

[1]PG Visiting Scholar at TTU, USA from M.E Power Systems , Annamalai University,India.
[2]Professor,Dept of Electrical Engg., Annamalai University,India
[3]Professor, Dept of Electrical & Computer Engg,TTU, USA.

ABSTRACT

This Paper focuses on the major power quality issues and its mitigation using suitable custom power devices. Power quality has become serious issue as the development of sophisticated electrical and electronic equipment which are very sensitive to disturbances. Design of Dynamic voltage restorer is demonstrated using matlab simulink platform for the traditional secondary distribution system. Performance Evaluation of Dynamic Voltage Restorer (DVR) along with status of uncompensated Distribution system are highlighted.

Energy Storage Device in DVR was integrated with a PV system to charge the Batteries. The Integrated PV system was designed as per the DVR requirements and its performance characteristic was analyzed appropriately with respect to charging the batteries of DVR.

Key Words-- FACTS, DVR, Voltage Sag / Swell, Transients, PV system, battery Charge control, Distribution Network (DN).

I. INTRODUCTION

The factors that contribute to the occurrence of power quality problems in developing countries are listed as follows.

A) When the Power Demand exceeds that of Generation.

B) Due to Power theft.

C) When Natural causes like Lightning, disasters, etc occurs.

D) Poor Maintenance of Grid / Distribution Network..

E) Poor Workmanship.

In order to mitigate this power quality problem and to safeguard the sensitive electronic Equipment which prone to early failure of its guaranteed Life period, this Dynamic Voltage Restorer integrated with Solar power system was chosen. The primary motivation is to create a new innovative methodology to utilize the available renewable energy as power source and meanwhile counter the power quality problems using DVR as a solution. Like this technology shall be considered as equal with the Solar Calculator, Solar Mobile charging Points, Solar utilized buildings,etc...

II. Power quality Problems

The occurrence of Voltage sag, Under voltage, Interruption, Voltage Swell, Transient, Harmonics & Inter-harmonics, Voltage Flicker, Notching, Noises, Dc Offset, any distortion in Sinusoidal Waveform will contribute to power quality issues.

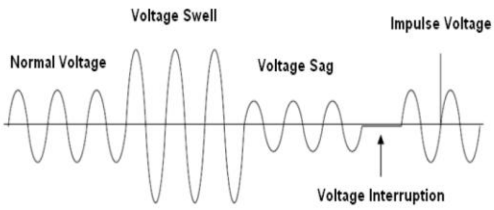


Fig.1.Power quality problems

Voltage sag: Voltage sags can be defined as the occurrence of change in the amplitude of voltage at any instant of time, ranging from 10 – 90% and its duration would be around 1/2 cycle to 1 minute.

Voltage swell: Voltage swell can defined as the rise in root mean square value of voltage / current at the nominal power frequency. It also has duration between 0.5 to 1 minute.

Voltage transients: It can be defined as the short time undesirable voltage fluctuation that occurs in the power system. Transients are high over-voltage disturbances.

Causes: The causes were due to faults that occur in the power system, starting of electric motors, consumer load exceeding than scheduled loads.

Other than this, there may be some vast load fluctuations (Increase / Decrease) and switching surges in the power system.

Standards for Power Quality:

I. IEEE(Institute of Electrical & Electronics Engineers): 446-1995,493-1990,1100-1999, 1250-1995.
II. SEMI (Semiconductor Equipment and Materials International): F47-0200
III. CBEMA (Computer & Business Equipment manufacturer's Association)
IV. IEC (International Electrotechnical Commission).

III. Dynamic Voltage Restorer (DVR):

It is a custom power device which is connected in series with the line through an injecting transformer. The general configuration of the DVR is portrayed in Fig.2.

1. **Injection/ Booster transformer:** This Injection transformer connects the Dynamic Voltage restorer through its HV side by which it transforms and couples in series for compensating voltage from the voltage source inverter to supply side . Additionally, it acts as an isolating medium of the load from the maim supply side system.

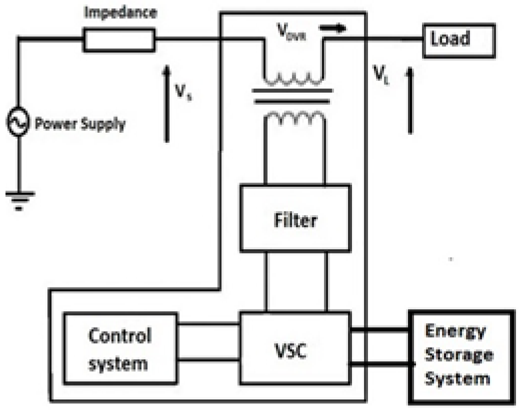


Fig.2.DVR Configuration

2.Passive filters: The nonlinear characteristics of semiconductor devices cause distorted waveforms associated with high frequency harmonics at the inverter output. To overcome this problems and to provide high quality energy supply, a harmonic filtering unit is used. This can cause voltage drop and phase shift in the fundamental component of the inverter output and has to be accounted for, in the compensation voltage.

3.Voltage Source Converter (VSC): A VSC is a power electronic system that consists of a switching converter arrangements, capable of producing sinusoidal voltage of required frequency, magnitude & phase angle. In this system, the Voltage source converter supports for dynamic injection of voltage from the energy storage device to the main system for its missing constant voltage envelope.

In DVR, Voltage source Inverter operation is based on sinusoidal pulse width modulation (SPWM). Sinusoidal pulse width modulation involves the comparison of a reference waveform (modulating signal) to a triangular wave of a much higher frequency (carrier wave) in order to produce a desired output voltage, so as to obtain required modulation index given by the expression.

$$m_a = \frac{A_m}{A_c} = \frac{A_{sin}}{A_{tri}} \quad (1)$$

4.Storage Devices: Batteries, flywheels or SMES can be used to provide real power during compensation. Compensation using real power is essential when large voltage sag occurs.

5.**Control System of DVR:** It consists of the Control algorithm of Power quality Issue detection and Mitigation in the subsystem.

Methodologies :

A) abc to dqo Algorithm using Parks Transformation.
B) PWM Scheme for Voltage Source Inverter using PI controller.

The modulating angle δ or delta is applied to the PWM generators in phase A, whereas the angles for phase B and C are shifted by 240° or -120° and 120° respectively to generate firing sequence for inverter.

$$V_a = \sin(wt+\delta) \quad (2)$$

$$V_b = \sin(wt+\delta - 2\pi/3) \quad (3)$$

$$V_c = \sin(wt+\delta + 2\pi/3) \quad (4)$$

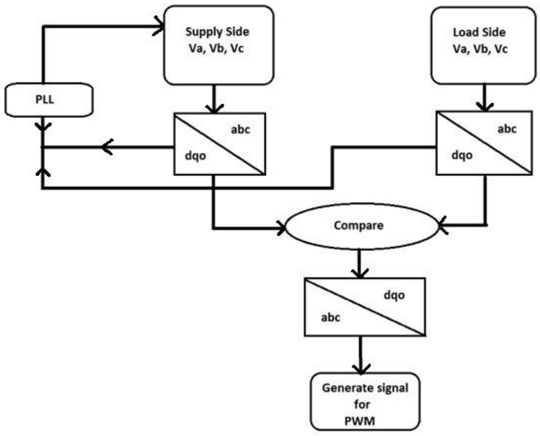


Fig.3.abc to dqo Algorithm Flowchart

Equation related to DVR: The mathematical expression governing the injected voltage, power injection, etc can be obtained from the equivalent circuit of DVR as portrayed in fig.4.

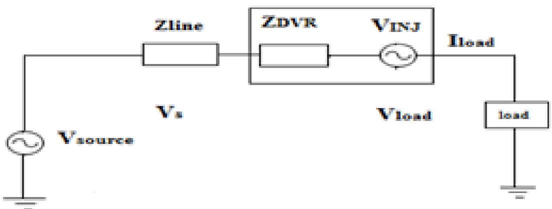


Fig.4.Equivalent circuit diagram of DVR

The system impedance (Z_{th}) depends upon the magnitude of fault occurrence at load side. If the Voltage of the system (V_{th}) drops, then Dynamic voltage restorer injects a series voltage (V_{DVR}) in order to restore the system voltage to nominal value through the coupled transformer. The equation governing the series voltage injection can be as follows

$$V_{DVR}=V_L+Z_{th}I_L-V_{th} \quad (4)$$

V_L: Voltage magnitude of Load
Z_{th}: Load impedance
I_L: Load Current
V_{th}: Voltage of system during fault occurrence.

The equation for load current I_L can be written as

$$I_L = (P_L+jQ_L) / V_L \quad (5)$$

Where V_L is reference taken for consideration.

$$\theta = \tan^{-1}(\theta_1 / P_1) \quad (6)$$

The complex power injection of the DVR can be written as,

$$S_{dvr} = V_{dvr} I_L^{*} \quad (7)$$

The phase injected voltage by DVR with reference to system voltage during sag & swell conditions are represented in fig.5.

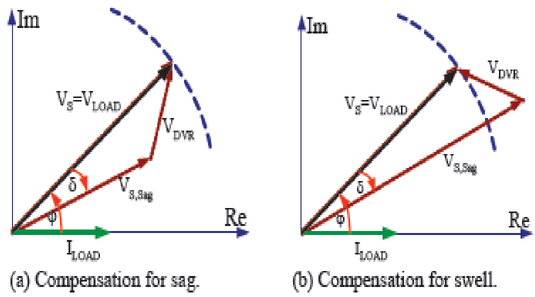


Fig.5.Phasor Diagram for DVR Compensation

IV.PV System: The PV system has many components such as solar panels which converts the sun light energy into electrical energy by the process called photoelectric effect. It has solar charge controller which takes care of charging mechanism with respect to maximum power drawn from PV system. Then Inverter which converts DC to AC power. Other than this DC cables, accessories,etc forms the whole PV system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution.The circuit schematic regarding the working of PV cell,its equivalent circuit along with its characteristics are shown in fig.6,fig.7 & fig.8. respectively.

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Email:editorijoer@gmail.com http://www.ijoer.in
Vol.4., Issue.3., 2016
(May-June)

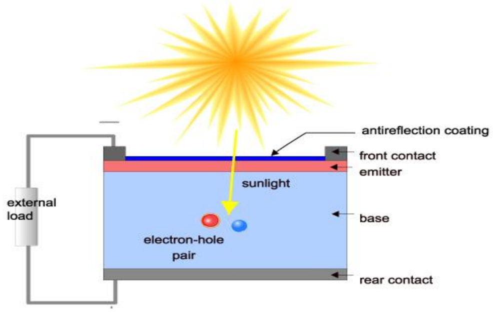


Fig.6. Simple PV Cell working

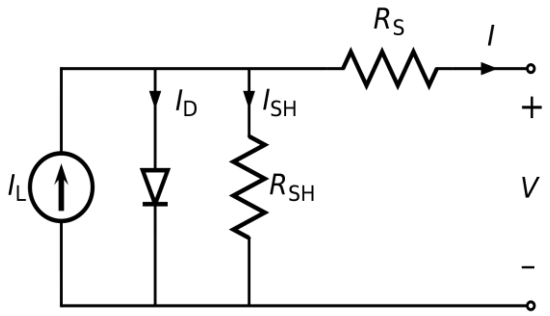


Fig.7.PV Cell circuit diagram

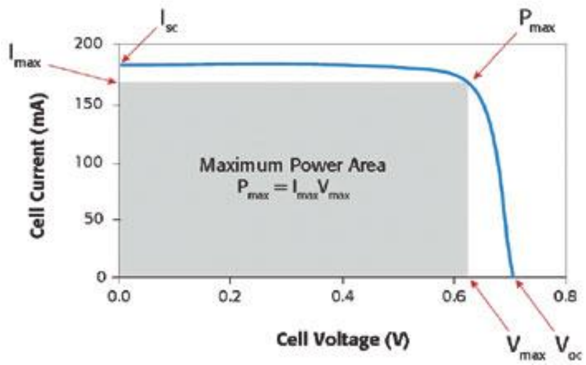


Fig.8. PV cell Characteristics

Solar Charge Controller : The function of a charge controller is to limit the rate at which a charge is added or current is drawn from batteries. It also prevents batteries from overcharging and over voltage, which can reduce battery performance and lifespan.

The Algorithm for MPPT controller used was " PERTURB & OBSERVE" Technique. P & O Algorithm is very simple and it works as the principle of hill climbing in which it tracks for Maximum power output for the maximum voltage.

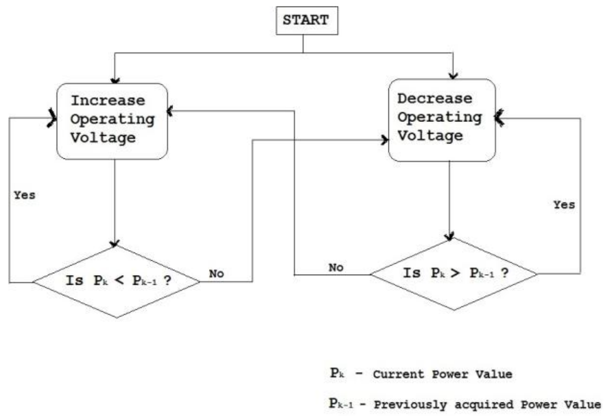


Fig.9.P & O Algorithm flowchart

DVR Integrated Solar System Design:

Step:1- Calculation of DVR Voltage compensation required

Voltage Level for Compensation :

Required Voltage = 300 Volt approx.

Step:2 - Sizing of the PV Module

As the Battery Storage of DVR is about 2KW based on the battery voltage and current rating.

Energy Required from PV = Total Energy required per day / $\eta_B \eta_I \eta_O$

Where,

η_B- Battery Efficiency (Assume 85%)

η_I - Inverter Efficiency (Assume 93%)

η_o - Other BOS System Efficiency(Assume 90%).

Step3: Solar Charge Controller Sizing

Voc and Isc of the PV module are obtained from the manufactured data sheet.

For Parallel Charge Controller = (No. of Modules x I_{sc}) x 1.3

Where,

V_{oc} - Open circuit voltage of PV module.

I_{sc} - Short circuit current of PV module.

Step:6 - Inverter Sizing:

Using total Power Required / day with Inverter efficiency and assuming a overload factor capacity of Inverter can be obtained.

Inverter Power = Total Power required /day x Inverter Efficiency x 1.25

After the practical consideration of PV system Design, Concentration is mainly on the DVR Energy Storage system . So the Power rating is not given much significance in this system design configuration. Other than the above mentioned parts, the suitable DC Cables are used to connect the whole system.

V. Overall Single Line Diagram:

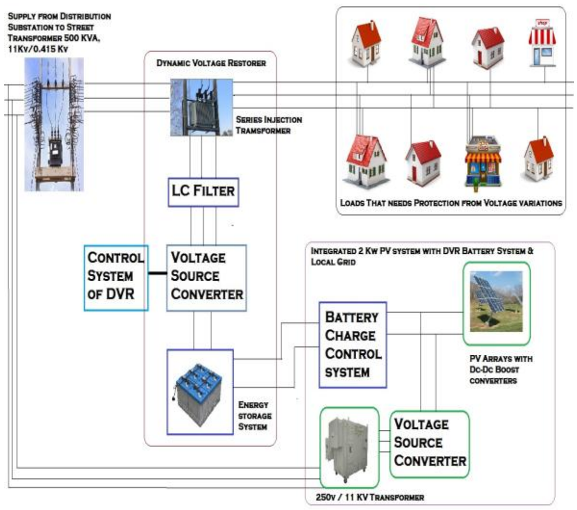


Fig.10.DVR with PV Integrated system

Simulation Method: Integrated PV system will be charging the Battery of DVR when its State of Charge (SOC) falls below 40%.

Remaining Time or when battery of DVR reaches 99% & above of its SOC, the power from PV system will be pumped into the grid. Suitable battery charge control system logic is used in the simulation.

This DVR integrated with PV system shall be considered as hybrid version of DVR for taking care of both power quality and satisfying the demand to some extent which is purely clean and green energy.

VI. Simulation & Results: Simulations were carried out in the Matlab simulink platform. Since DVR , PV System & Charge control of Batteries are done in different time we consider 3 cases for simulation in which the battery utilized for DVR, PV system & charge control are one and the same rating &configuration.

Technical System parameters of each system considered for simulation is listed in table 1.

System Parameters :

A) DVR:

Sno	System quantities	Standards
1.	Three phase source	11Kv, 50Hz.
2.	Step-down transformer (Street Level)	Δ-Y , 11Kv / 415 v
3.	Load (8 Houses)	40Kw & 10 Kvar
4.	Series Injection Transformer	1:2 Turns Ratio
5.	Filter Inductance	20mH
6.	Filter Capacitance	$1500\mu F$
7.	Inverter	IGBT based,3 arms , 6 Pulse, Carrier Frequency =1080 Hz, Sample Time= $5\mu s$
8.	DC battery	300 V , Li-Ion ,6.5Ah rating

B) PV System:

Table.1. System parameters for simulation

Sno	System quantities	Standards
1	PV Module	Sun power SPR 305 E WHT D
2	Connected Grid	11 Kv / 110 Kv
3	PV power output	Upto 2 Kw
4	Solar Charge Controller	MPPT Controller
5	Inverter	2.5 Kva rating
8	DC battery	300 V , Li-Ion ,6.5Ah rating

Case:1- DVR:

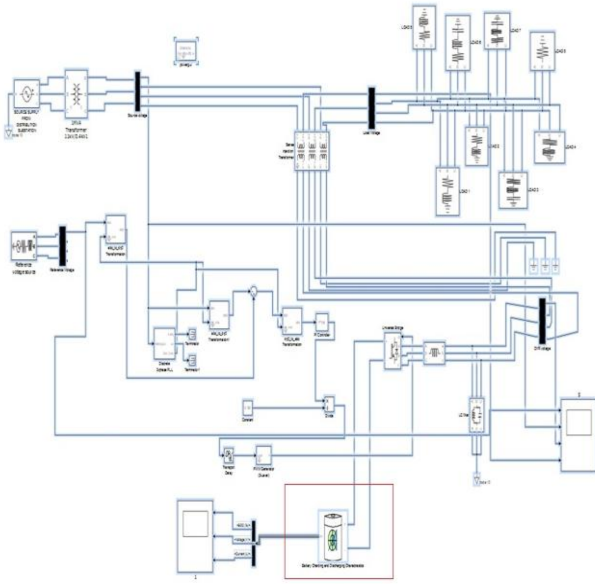


Fig.11.Dynamic Voltage Restorer Matlab Model

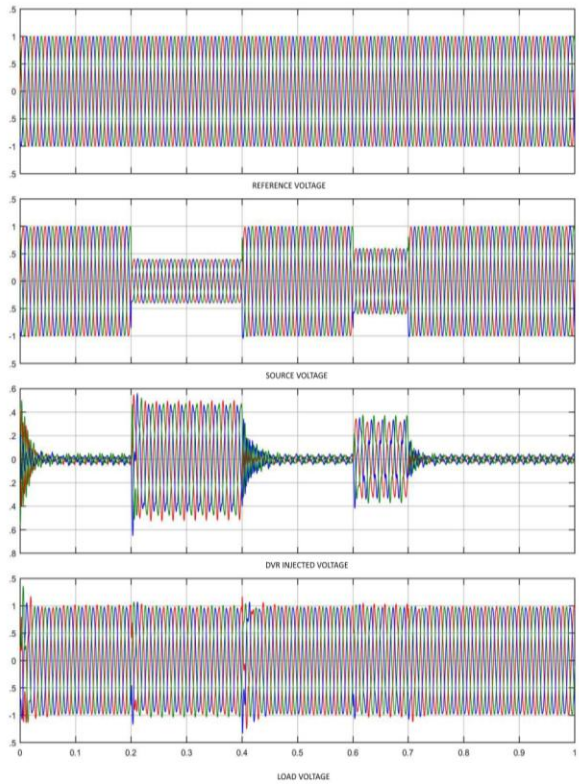


Fig.12.Simulated response of reference voltage, source voltage, DVR injected voltage & Load voltage during the occurrence of Sag at t= 0.2 to 0.4 and t= 0.6 to 0.7 secs

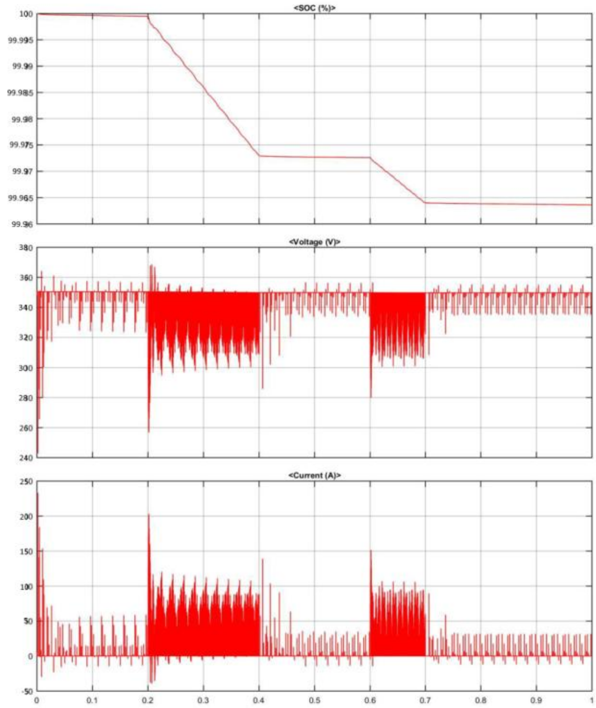


Fig.13.Simulated SOC Characteristics of battery during voltage sag at t= 0.2 to 0.4 secs and t=0.6 to 0.7 secs.

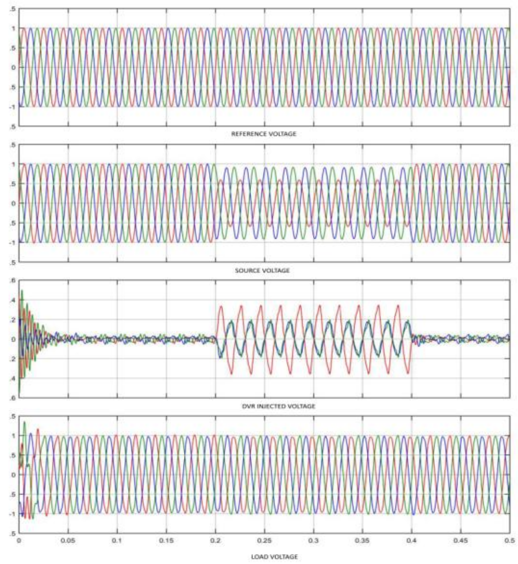


Fig.14..Simulated response of reference voltage,source voltage, DVR injected voltage & Load voltage during the occurrence of sag at one phase of 3 phase system at t= 0.2 to 0.4 sec

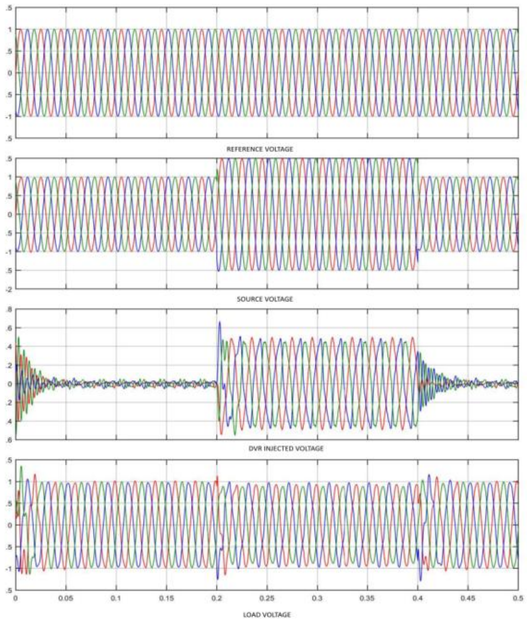


Fig.15.Simulated response of reference voltage,source voltage, DVR injected voltage & Load voltage during the occurrence of Swell at t=0.2 to 0.4 sec.

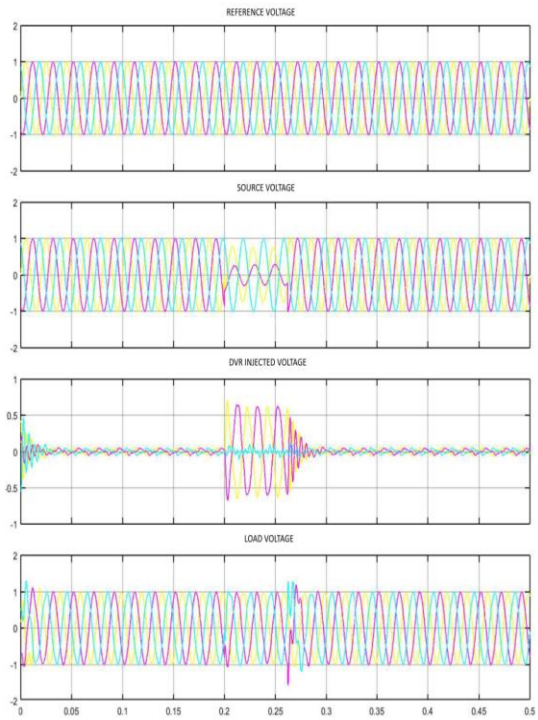


Fig.16.Simulated response of reference voltage,source voltage, DVR injected voltage & Load voltage during the occurrence of Transients:L-L fault at t=0.2 to 0.25 secs.

Case-2:PV System:

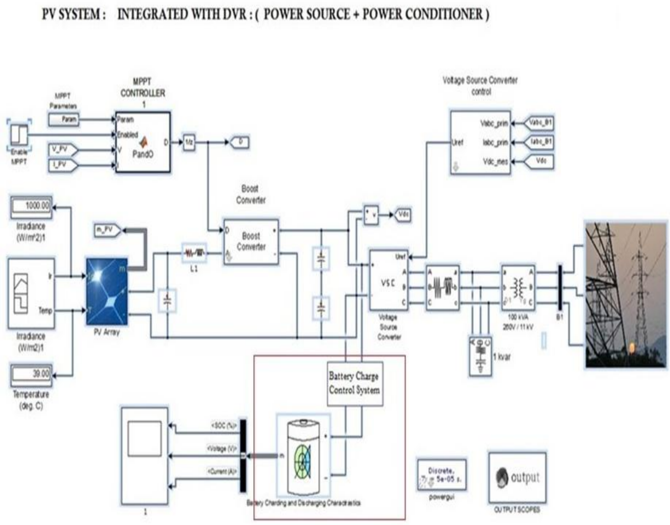


Fig.17.PV system Matlab Model

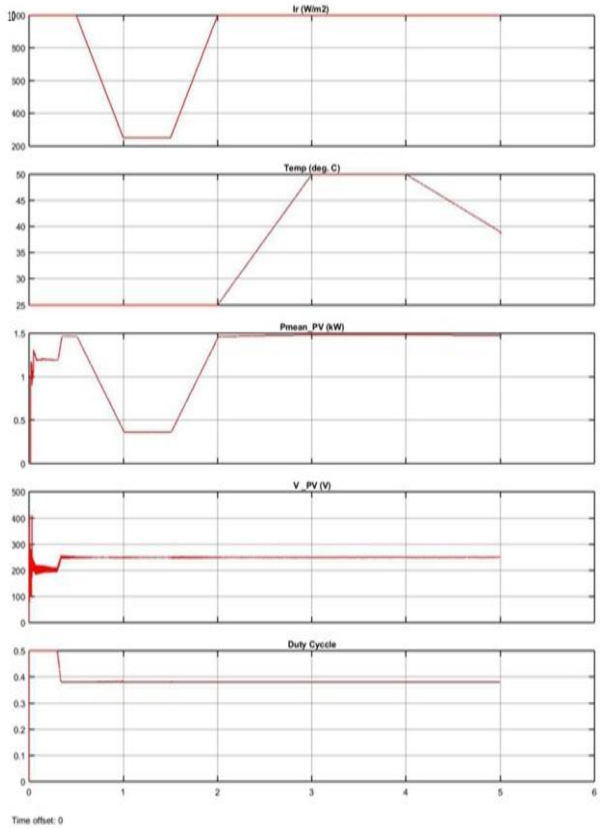


Fig.18.PV System - On grid Simulation X- axis: Irradiance, Temperature, Power output, Voltage & Duty cycle of PVsystem Y- axis : Time

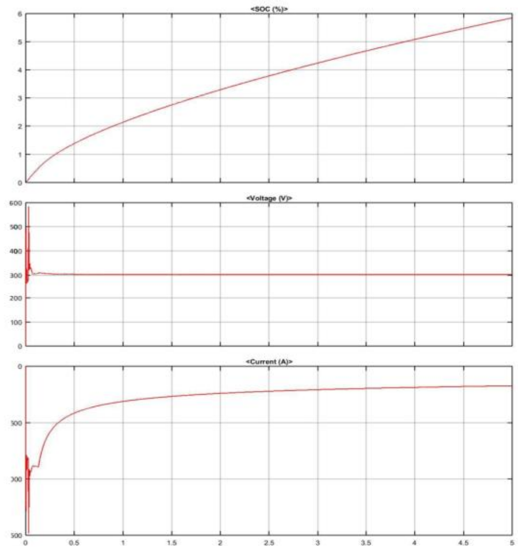


Fig.19. PV System : Battery Charging Characteristics
X-axis: SOC %, Voltage & Current of Battery
Y-Axis : Time

Case-3:Battery Charge control System:

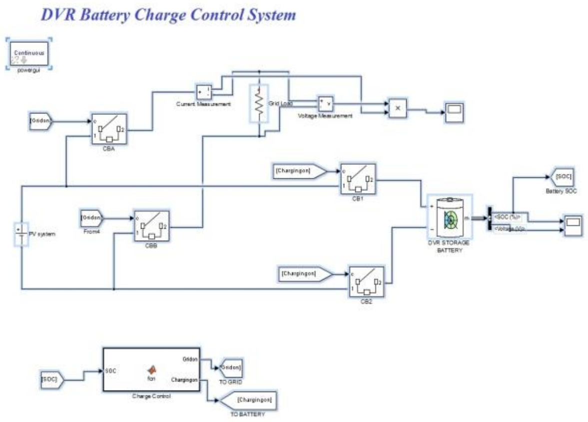
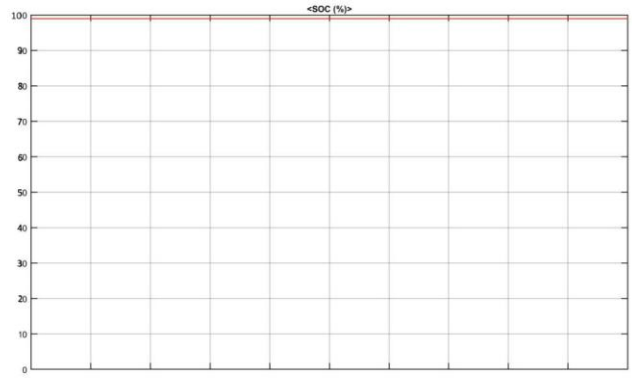


Fig.20.Battery Charge Control System Matlab Model

Battery Charge control Algorithm:

```
function [ Gridon, Chargingon ]= fcn(SOC)
%%codegen
Gridon =0;
Chargingon =1;
 if (SOC >= 99)
   Gridon =1;
   Chargingon =0;
end
if (SOC <= 40)
    Gridon =0;
    Chargingon =1;
End
```



Grid Power Flow

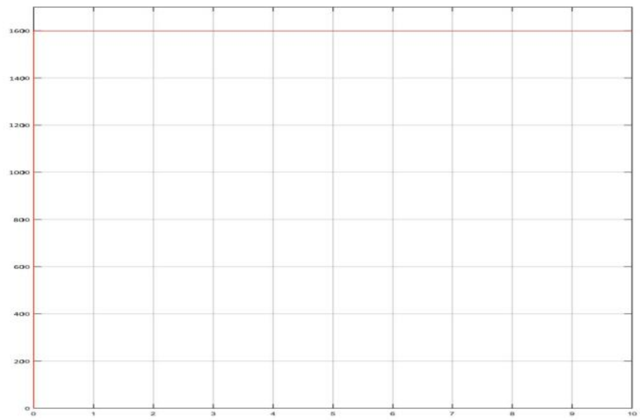
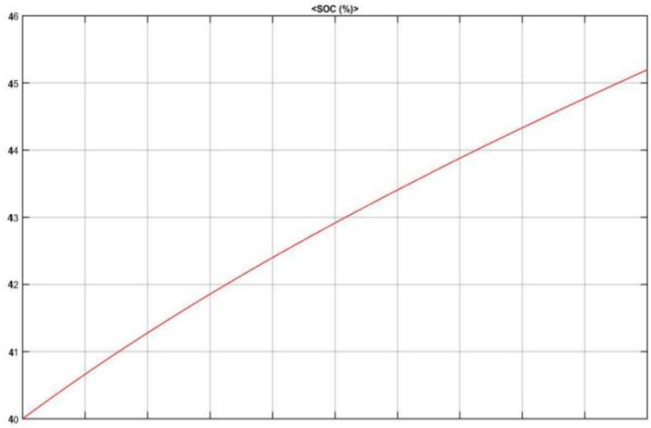


Fig.21.Battery Charge Control When SOC =99% & Grid Power Flow is 1.6 KW



Grid Power Flow

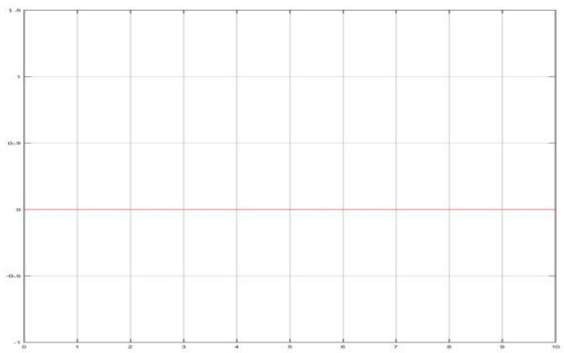


Fig.22..Battery Charge Control When SOC >99% & Grid Power Flow is 0.

VII. Performance Of DVR:

Event	System Voltage	System Voltage %	DVR compensated Voltage	DVR Compensation %	System voltage after compensation
Sag	249	60%	166	40%	415
Normal	415	100%	0	0%	415
Swell	581	140%	-166	40% (out of phase)	415
Transient	124.5	30%	290.5	70%	415

IX. Future Scopes:

- The DVR Inverter and PV system Inverter shall be integrated into single system for future research.
- Also Power quality issue needs to be analyzed in the existing Traditional Grid.
- Due to growing Power Demand, Renewable energy like Wind , Fuel cells,etc can be integrated along with this Power Quality Controllers in future to open a new innovative approach of handling the Power System problems.

X. Conclusion:

- Using the proposed Simulation of DVR, both balanced and unbalanced situations can be handled without any difficulties and appropriate voltage component gets injected to maintain the nominal value of Voltage at the load side by rapidly compensating for the Voltage sag/swells occurring at supply side.
- The main advantages of the proposed DVR are simple control, fast response and low cost.
- Integrating the solar Power with the DVR satisfies both the Power quality mitigation and meeting out Power demand in the existing Grid.
- Also the Power produced is clean and green by Solar system.
- DVR can also be used to enhance the resiliency of the Power System
- Also It adds smartness to the existing traditional grid.

Acknowledgement:

The Authors thank the authorities of Annamalai University, UGC ,India and Center for Energy System Research, Tennessee Technological university, USA for their help and support.

References

[1]. Narain G. Hingorani, Laszlo Gyugyi,"Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems",452 pages,December 1999, Wiley-IEEE Press

[2]. H. Hingorani "Introducing custom power" IEEE spectrum, vol.32 no.6 June 1995 p 41-48.

[3]. O. Anaya-Lara, E. Acha, "Modeling and Analysis of Custom Power Systems by PSCAD/EMTDC," IEEE Trans., Power Delivery, PWDR vol-17 (1), pp. 266-272, 2002.

[4]. MAS Solars system for Practical System Design and cost Evaluation of PV system integrated with the DVR simulation.

[5]. A Case Study of 100kW solar installation at Marbaselios College of Engineering and Technology, Kerala journal obtained from internet.

[6]. H.P. Tiwari, Sunil Kumar Gupta, "Dynamic Voltage Restorer Based on Load Condition", International Journal of Innovation,

Management and Technology, Vol. 1, No. 1, April 2010.

[7]. Mohan,T.M.Undeland,W.P. Robbins, Power Electronics: Converters,Applications and Design . New York: Wiley, 1995.

[8]. Paisan Boonchiam and Nadarajah Mithulananthan, "Understandingo f Dynamic Voltage Restorers Through MATLAB Simulation", ThammasatI nt. J. Sc.Tech.,Vol. 11,N o. 3, July-September 2006.

[9]. H. Ezoji, A. Sheikholeslami, M. Tabasi and M.M. Saeednia," Simulation of Dynamic Voltage Restorer Using Hysteresis Voltage Control", European Journal of Scientific ResearchISSN 1450-216X Vol.27 No.1 (2009), pp.152-166

[10]. Changjian Zhan,V.K. Ramachandrara murthy, A. Arulampalam,M.Barnes and G.Strbac N.Jekin, "Dynamic Voltage Restorer Based on Voltage Space Vector PWM Control", Applied Power Electronics Conference and Exposition, 2001. APEC 2001. Sixteenth Annual IEEE Volume 2, 4-8 March 2001Vol.2, Page(s):1301 - 1307.

[11]. Ray Arnold "Solutions to Power Quality Problems" power engineering journal 2001 pages: 65-73.

[12]. John Stones and Alan Collinsion "Introduction to Power Quality" power engineering journal 2001 pages: 58 -64.

[13]. C.Zhan,M. Barnes,V.K. Ramachandara murthy, and N. Jenkis, "Dynamic Voltage Restorer with Battery Energy Storage for Voltage Dip Mitigation" Power Electronics and Variable Speed Drives, 18-19, Conference Publication No. 475, IEE September 2000.

[14]. Mehmet Tumay, Ahmet Teke, K. Cağatay Bayındır, M. Uğras Cuma, "Simulation and modeling of a dynamic voltage restorer" .

[15]. John Stones and Alan Collinsion "Introduction to Power Quality" power engineering journal 2001 pages: 58 -64.

[16]. **Websites referred :** Wiki Pedia.com, Google search.com,Electric4U.com,mathwork.com, IEEE xplore.com,Sciencedirect.com.

About Authors:

Mr. BALAJI.P , B.E (Electrical & Electronics Engineering), MBA (International Business).Currently pursuing final year M.E degree in Power Systems at Annamalai University, India. He has work experience in electrical installations & commissioning as a Project Engineer.His current research interests are FACTS, Smart Grid,Transmission loss reduction, Renewable Energy systems,Power system Resiliency. Email: balajicode88@gmail.com

Dr.B.Baskaran received the Ph.D. Degree in power electronics from Annamalai University,India. He is currently a professor in the department of Electrical engineering, Annamalai university and his specialization is Matrix converter. His research interests include Power electronics applications to power systems,Improved Power quality converters, FACTS devices,power quality and power Transmission issues

Dr.Ghadir Radman received the Ph.D. degree in electrical engineering from Tennessee Technological University, Cookeville, TN, USA. He is currently a Professor of electrical engineering at Tennessee Technological University. His research interests include power system dynamics, power flow control, FACTS, distributed generations, smart grid, and large-scale Systems. Prof. Radman is a senior member of the IEEE Power & Energy Society.