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Mitigation of Voltage Sag and Swell in a PV Integrated Live 11kV 7-Bus System using Dynamic Voltage Restorer

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Abstract:

In the present scenario,the demand for supplying the good quality of power to the load centers is very much necessary. Abrupt increased load, short circuits, faults in the distribution line, starting of motors and increased source impedance causes voltage sag and swell in non-linear or critical load, domestic and industrial applications. In order to mitigate these voltage issues, the concept of application of Dynamic Voltage Restorer system has emerged.The Dynamic Voltage Restorer (DVR) is a power electronic device which is used to inject and compensate the 3-phase voltage in series and in synchronism with the primary distribution feeder in order to mitigateoccurred voltage sagcondition.In this paper, a Simulink model of 66kV grid integrated with a 2MW PV array with the application of DVR is developed. The performance of the DVR with an effective adaptive controller in mitigating the voltage sag and swell at the point of common coupling is evaluated over the PV integrated distribution system.Modeling and simulation of the proposed system is carried out by usingMATLAB electrical simulation software.Results shows that the proposed controller for DVR works effectively in mitigating the voltage sag and swell issues at point of common coupling(PCC). Modeling and simulation of the proposed system is carried out by using MATLAB electrical simulation software
text.

Keywords — Low **voltage, Dynamic voltage restorer, Voltage sag, Voltage swell, Photovoltaic cell.**

I. INTRODUCTION

The electrical power system consists ofpower generation, transmission and its distribution to the load centers in an efficient, economical and reliable manner. Due to the expansion of existing electrical networks and increasing demand of power supply to load centers, faces several technical power quality issues in both the power transmission and distribution levels [1]. The prime importance has to be given to quality of power supply in an efficient utilizable form to consumers.

In the present context of power systems engineering, power quality (PQ) and online PQ monitoring systems are experience the challenging issues. PQ can be referred as a quality of voltage and current supplied or occasionally only the qualityof voltage. Hence,significant researches are aimed to improve the power qualityissues in electrical power systems and also to mitigate the power stability issues. Power quality (PQ) can be defined as, the ability of the power system to supply the power generated constantly to the load centers in a clean, stable and utilizable form where the power flow should have pure sinusoidal wave form with specifies voltage and frequency tolerances (50-60Hz) [2].

The PQ issues that may occur in electrical power systems are, voltage sag & swell, harmonic distortion, voltage unbalance, very short interruptions, long interruptions, voltage spike, voltage fluctuation etc. Presently, the most frequently occurred power quality issue in the power distribution network is the unbalanced supplyvoltage which is the ratio of maximum deviation of phase voltage to the average phase voltage magnitude leading to voltage sag and voltage swell [3]. These cases are muchpredominant in interconnection of PV array to grid which requires more scrutiny with the synchronization to power grid [4][14].

Voltage sag occurs when there is a decrement in RMS value of supply voltage in between 10 to 90% of the nominal value at power frequency for duration of half cycle to one minute [4] which willdistort the amplitude of the sinusoidal wave of supply voltage. This condition will be observed in the case ofoccurrence of single line to ground faults, where the amplitude of voltage sag depends on location of fault occurred, fault type and line impedance. And voltage swell is said to be occurred when the increment in the RMS value of voltage in between 110% to 180% of the nominal value at power frequency for duration of half cycle to one minute, which is not frequentlyobserved in the power distribution side.

Therefore, the above mentioned traits can be solvedby compensating the voltage in the supply line with the use of power electronic devices to improve the quality of power supply. Various kinds of power electronics devices are being used to compensate the distorted supply voltage and to mitigate power quality issues. Power electronic devices such as static var compensator (svc), static synchronous compensator (STATCOM), unified power quality conditioner (UPQC) [1][3], thyristor controlled series compensator (TCSC), interline power quality conditioner or improved power quality conditioner (IPQC), thyristor protected series compensation (TPSC), unified power flow controller (UPFC) and dynamic voltage restorer (DVR) are used [1]. In this paper, the application of dynamic voltage restorer (DVR) to enhance the quality of power supply to the consumers in case of voltage sag and swell with PV-grid connected system is propounded.

II. DYNAMIC VOLTAGE RESTORER (DVR)

An Dynamic voltage restorer (DVR) are the custom poweredelectric devices which provides theproductive solution to compensatethe supply voltage from the source to load centers in case of occurrence of voltage sag and swell conditionswith the injection of required voltage atappropriate magnitude withsynchronized phase in order to consume the power in utilizable formby the load centers. These are referred as the series voltage boosterand the static series compensator, including solid state power electronic components connected in series with the primary distribution network. DVR’s are having the potential toinject three phase controlledvoltage to the supply voltage to restore the primary distribution voltage level to pre-sag conditions with rated voltage and phase angle so that it boost up the primary distribution voltage level whichwould be free from impact of occurrence of voltage sag conditions. In turn these DVR could also be useful in the mitigation of line voltage harmonics, reducing the transient voltage and fault current that may occur for distribution line faults. The electric circuitryof DVR comprised of several components such as, voltage source inverter, voltage injection transformer, dc energy storage device, low pass filter and a control method which is as shown in fig.1. The operation of DVR to inject voltage to the voltage sag line to the supply voltage represented by waveform is as shown in fig.2.

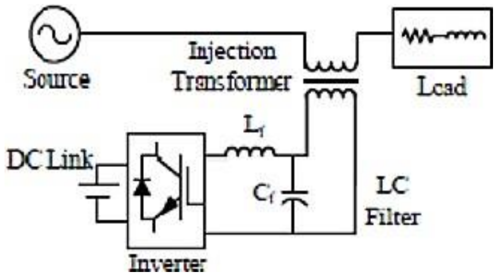

Fig-1: Basic components of a dynamic voltage restorer.

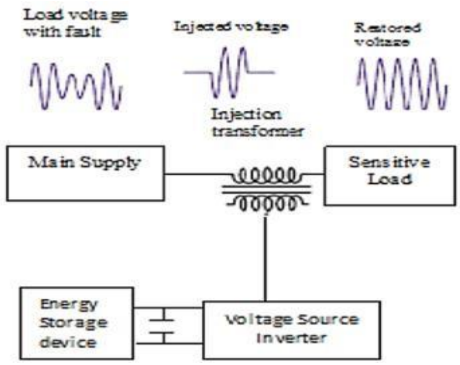

Fig-2: Principle of operation of dynamic voltage restorer

III. Simulation of PV Grid Connected System with Dynamic Voltage Restorer

A Simulink model has been developed to evaluate the performance of 66kV grid connected system with 2MW PV array connected to grid with the application of DVR to substantiate voltage sag and swell which is as shown in the fig.3. This model comprises of Simulink blocks such as, three phase source, three phase series RLC branch, three phase transformer, PV array with universal bridge, VSC main controller, grid block and three phase load with voltage and current measurement system connected to scope.

The three-phase programmable voltage source block has been implemented. The common node (neutral) of the three sources is accessible through input 1 (N) of the block. The variation oftime for the amplitude, phase and frequency of the fundamental signal is able to pre-program. Voltage sag and swell operation has been introduced to the system from a simulation time of 0.03s to 0.05s. The time variation in amplitude, phase and frequency could also be incorporated to substantiate voltage sag and swell. In this case, time variation in amplitude is chosen with a variation from [1pu 0.1pu 1pu] for voltage sag and [1pu 1.5pu 1pu] for voltage swell condition.

This source is connected with three phase series RL branch with a resistance of 2.9987 ohms and inductance of 0.019H. Further it is connected to three phase transformer by using three single-phase transformers and set the winding connection to Delta to Star by 66/11kV, 12.5MVA, 50Hz with a magnetization resistance Rm of 500pu and magnetization inductance Lm of 500pu followed by grid block system of VI measurements.

The set of 10 PV array implemented a strings of PV modules connected in parallel by 64 strings. Each string consists of 5 modules connected in series with MPPT control. These PV array has been fed with irradiance of 1000 W/Sq.m and temperature of 25 Degree Celsius. These were connected to universal bridge which implements a bridge of selected power electronics devices. Then, these blocks were connected to three phase transformer 380V/11kV, 2 MVA which connects to a grid system of VI measurements.

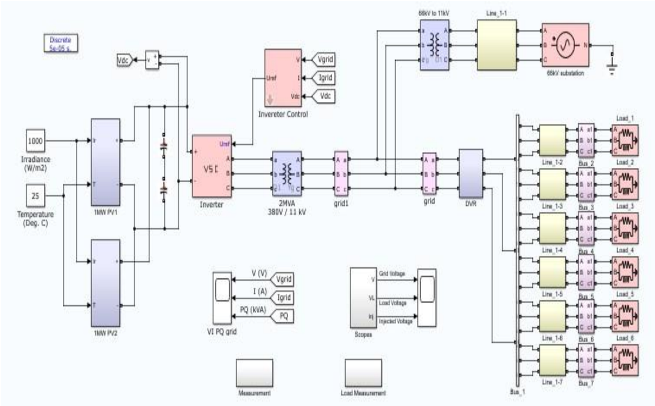

Fig-3: Simulink model of 2MW PV Array Grid Connected System with DVR to Substantiate Voltage Sag and Swell

In this paper, the real time data of active and reactive power has been gathered from66/11kV Santhebachalli Sub-Station KPTCL, Mandya, Karnataka,which is having 2 MW Solar Power Generation integrated to the Sub-Station at 11kV feeder. The connected load and line details of 11kV feeders from Santhebachalli substation has been tabulated in the Table.1 and Table.2.

The connected load is by passed through grid system with DVR subsystem which is as shown in Figure.3consisting of three saturable transformers 2MVA, 50Hz to each phase of power line in a grid system of VI measurement. These are connected with series filter circuit as shown in theFigure.5 with logical expressions to compensate the voltage sag and swell wit hexternal circuitry with a stored energy of DC 25kV. The external voltage source inverter circuit is as shown in Figure.6. Required VI measurement blocks were incorporated to required location as shown in the Simulink model. And then the entire system is built and run for evaluation of the 66kV grid connected system with 2MW PV array connected to grid with DVR to substantiate voltage sag and swell.

TABLE-1: LOAD DETAILS OF 11KV FEEDERSOF 66/11KV SANTHEBACHALLI SUB-STATION KPTCL, MANDYA.

Sl No	Feeder Name	Type	Load	Active Power in kW	Reactive Power in kVAR
1	ChottanaHalli	NJY (Domestic)	1	496	280
2	GRS	Rural (IP)	2	663	430
3	Adihalli	Rural (IP)	3	575	365
4	C S Halli	Rural (IP)	4	417	284
5	S B Halli (Town)	NJY (Domestic)	5	245	169
6	Sarangi	NJY (Domestic)	6	372	210

TABLE-2: LINE DETAILS OF 11KV FEEDERSOF 66/11KV SANTHEBACHALLI SUB-STATION KPTCL, MANDYA.

Sl No	Feeder No.	Feeder Name	Type	Length of Line in km	Sending End Bus	Receiving End Bus	R in Ohms	X in Ohms	To be Calculated L=X/(2*3.142*50)
1	F1	Chottana Halli	NJY (Domestic)	46	1	1	31.004	22.402	0.071
2	F2	GRS	Rural (IP)	36	1	2	24.264	17.532	0.056
3	F3	Adihalli	Rural (IP)	28	1	3	18.872	13.636	0.043
4	F4	C S Halli	Rural (IP)	28	1	4	18.872	13.636	0.043
5	F9	S B Halli (Town)	NJY (Domestic)	5	1	5	3.37	2.435	0.008
6	F10	Sarangi	NJY (Domestic)	22	1	6	14.828	10.714	0.034

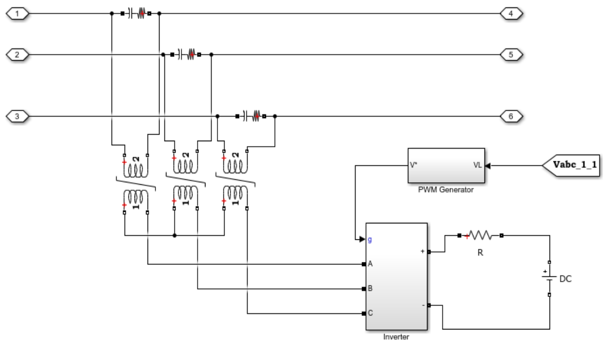

Fig-4: Simulink model of DVR Sub-System

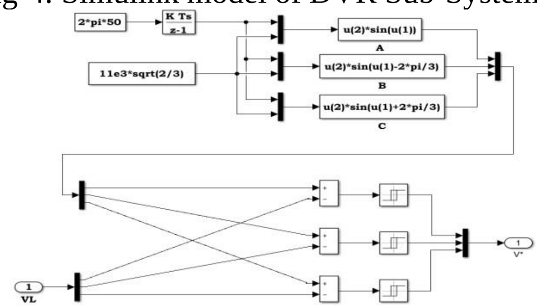

Fig-5: Subsystem model of Series Filter circuit in DVR Sub-System

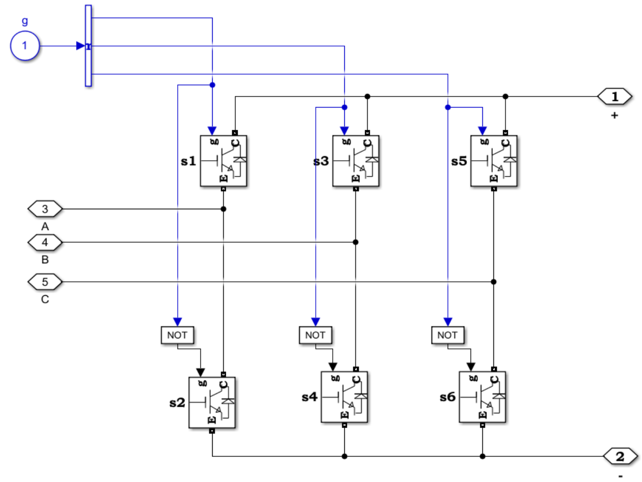

Fig-6: Subsystem model of Voltage Source Inverter in DVR Sub-System

From this Simulink model of 2MW PV Array Grid Connected System with DVR to Substantiate Voltage Sag and Swell, the normal operation of system, with voltage sag and voltage swell can be examined with required settings in the three-phase programmable voltage source.

TABLE-3: THREE PHASE PROGRAMMABLE VOLTAGE SOURCE SETTINGS

Operation	Amplitude value (pu)	Time value (s)
Normal operation	[1 1 1]	[0.03 0.05]
Voltage sag	[1 0.1 1]	[0.03 0.05]
Voltage swell	[1 1.5 1]	[0.03 0.05]

IV. RESULTS AND DISCUSSION

The Figure.7 shows the voltage profile of the grid voltage, load side voltage and injected voltage from DVR for simulation duration of 0.5s. The voltage profile of grid, load and injected voltage from DVR is found in healthy state as observed from the simulation results.

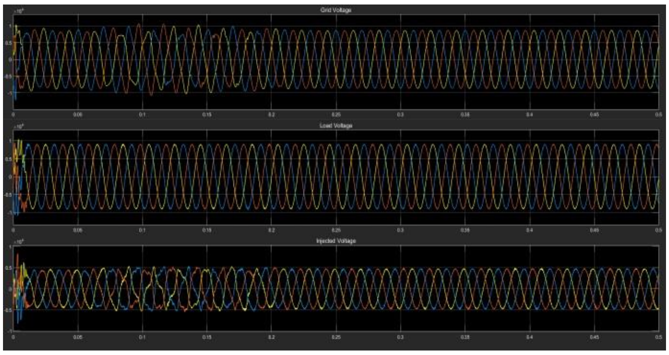

Fig-7: Voltage profile of the grid voltage, load side voltage and injected voltage from DVR

A. *Results of Simulink Model of 2MW PV Array Grid Connected System with DVR to Substantiate Voltage Sag*

The Figure.8 shows the VI measurement with irradiance of 1000 W\Sq.m at a temperature of 25C and duty cycle of the generation of power from 2MW PV array in presence of DVR connected to grid. Figure.9 shows the PV grid voltage and current profile with generated reactive power with the generation of power from PV array and its connection to grid, which is evident that voltage sag is observed and dipped to 0.1pu from nominal voltage of 1pu in the PV grid from an instance of 0.03s to 0.05s and hence the system is unstable.

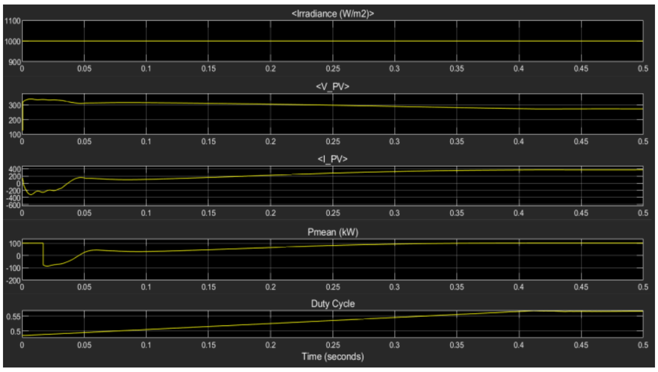

Fig-8: VI measurement with irradiance and duty cycle of the PV array under normal operation of the system with DVR

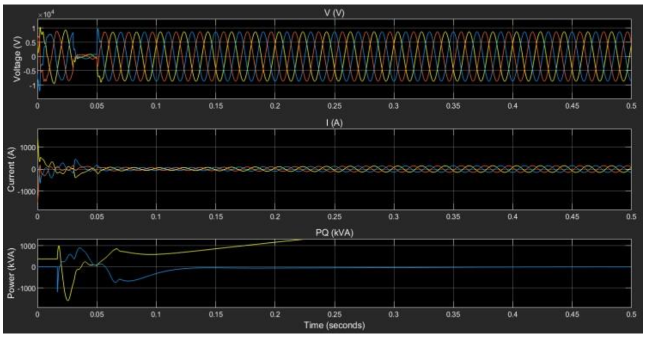

Fig-9: PV grid voltage and current profile with generated reactive power when Voltage Sags

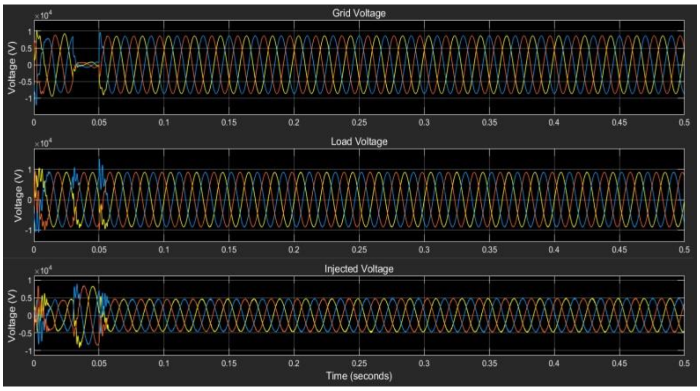

Fig-10: Voltage profile of the grid voltage, load side voltage and injected voltage from DVR in case of Voltage Sag

The Figure.10 shows the voltage profile of the grid voltage, load side voltage and injected voltage from DVR for a case of voltage sag in the system from a simulation time of 0.03s to 0.05s which is introduced to the system by three phase programmable voltage source. It is evident from the figure that the load voltage is compensated to its normal acceptable voltage with the injected voltage from the DVR which is observed by the injected voltage plot. And hence the grid voltage and load voltage were maintained at its normal acceptable profile. Therefore, the DVR is capable of handling the voltage sag issues in the system, and thereby mitigated the voltage sag by the injection of power from the stored energy to normalize the load voltage and maintained desired supply voltage to consumer load centres.

B. Results of Simulink Model of 2MW PV Array Grid Connected System with DVR to Substantiate Voltage Swell

The Figure.11 shows the VI measurement with irradiance of 1000 W\Sq.m at a temperature of 25C and duty cycle of the generation of power from 2MW PV array in presence of DVR connected to grid. Figure.12 shows the PV grid voltage and current profile with generated reactive power with the generation of power from PV array and its connection to grid, which is evident that voltage swell is observed by increment in the voltage to 1.5pu from a nominal voltage of 1pu in the PV grid at an instance of 0.03s and hence the system is unstable. The Figure.13shows the voltage profile of the grid voltage, load side voltage and injected voltage from DVR to the system by three phase programmable voltage sourc for a case of voltage swell in the system for a simulation time ranging from 0.03s to 0.05s .It is evident from the figure that the load voltage is compensated to its normal acceptable voltage with the injected voltage from the DVR by reducing the voltage sag which is observed by injected voltage plot. And hence the grid voltage and load voltage is maintained at its normal acceptable profile.

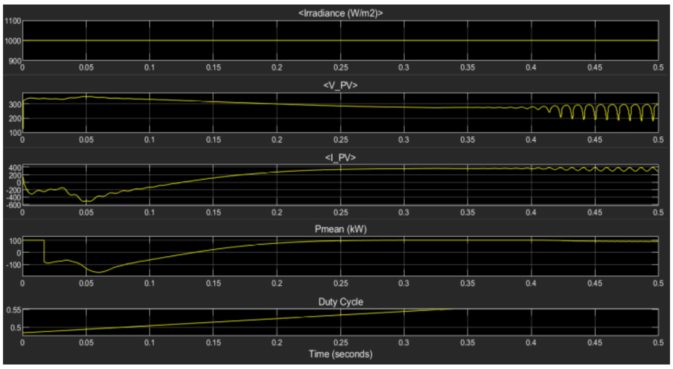

Fig-11: VI measurement with irradiance and duty cycle of the PV array under normal operation of the system with DVR

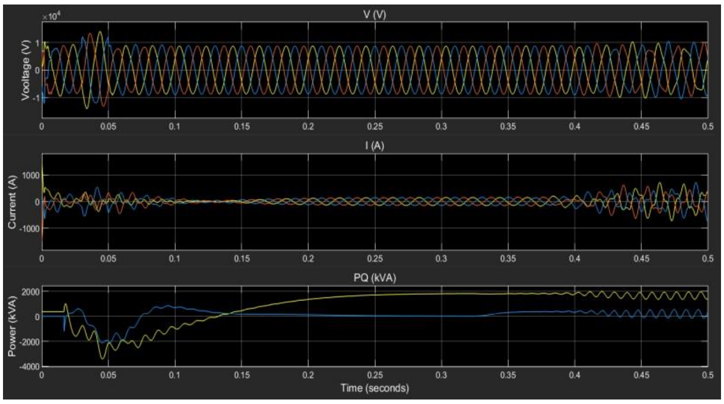

Fig-12: PV grid voltage and current profile with generated reactive power when Voltage Swells.

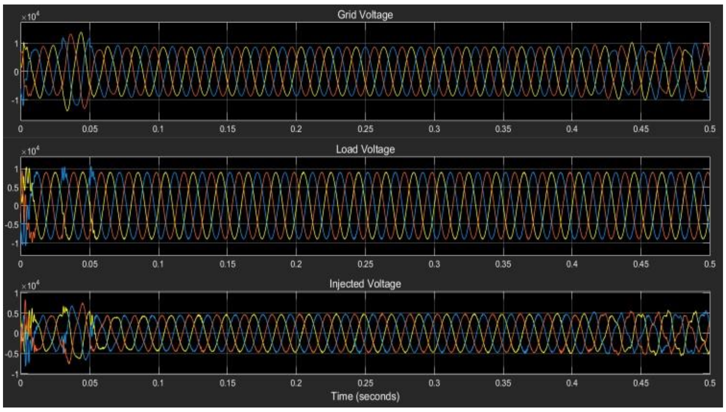

Fig-13: Voltage profile of the grid voltage, load side voltage and injected voltage from DVR in case of Voltage Swell

V. CONCLUSIONS

This paper is focused on the evaluation of power quality issues, particularly the voltage sag and voltage swell issues in the grid integrated with a 2MW PV generation systems to meet the increased demand for electricity . Simulink model is developed to evaluate the performance of DVR to mitigate the voltage sag and swell issues . The effectiveness of the DVR in rectifying these voltage sag and swell issues is evaluated.DVR injects and compensates the required voltage to the primary distribution line during voltage sag and swell condition by the backup DC sourceto bring the supply voltage back to the nominal level. From the results it is evident that incorporation of DVR with an adaptive controller to the grid integrated with PV helps to keep the system under normal operating condition by compensating the voltage across the load and thereby providing quality power to the connected load without any interruption.

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