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Performance of Grid Connected PV System with Variable Load System

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Abstract

The stability of grid is important to analyze due to integration of solar PV system. This paper deals with the investigation and analysis of performance parameters needed to be eliminated with the application of controlled devices irrespective of that penetration of solar PV on grid restrict up to a critical level. The stability of grid may be affected due to non-reliability of PV system. This study is performed for the actual site of PV system at Gaughat pumping station Ujjain (M.P.) with the total capacity of the PV system is 550 kW (300 kW+250 kW) for the variable load of 100 KW, 2 MW and 30 MW on the grid side. The reliability of the typical grid connected system is analyzed, investigated and validated through simulation work. The parameters evaluated are voltage and current injected to grid, frequency deviation; active and reactive power drawn and harmonic investigation. The simulation and experimental results are compared and presented. The results shows that the standard deviation in harmonic voltage, current and others parameters are nearly same for both simulation and experimental results.

Keywords: Grid stability; Harmonic distortion; PV system; Performance Ratio (PR)

Introduction

IIn orders to find out the instability of grid due to penetration integration of PV systemthe simulation model is developed in MATLAB for 550 kW Solar PV System of same capacity as (250kWP+300kWP) installed in Gaughat pumping station of municipal corporation Ujjain. The station is connectedto 2MVA Sub-station at 33kV Supply Voltage drawn from Jyoti Nagar 132 kv Grid (132/33 kV S/s JyotiNagar Ujjain). The single line diagram of the experimental setup of Gaughat station is presented in Figure 1. In this work the stability of the grid connected to PV is investigated and presented. The simulation and experimental setup investigate the harmonic profile of voltage, current and frequency deviation along with the Active and reactive power when the PV system power is injected to grid. The two PV system of 300 kW and 250 kW are used to inject power to the grid. The output of the PV system is fed to the VSI converter to convert DC power to the AC power through common mode operation. A simple inverter control is adopted to generate the pulse for the inverter. The output of the inverter is fed to the filter and then to the Step-up transformer 630kVA, 260V/25kVA. Three loads of 100 kW, 2 MW and 30 MW are connected to grid. The experimental results are drawn from the collection of data from the actual site with the help of metering unit. The data presented is observed and recorded on the daily basis for the analyzing the impact of grid connected PV system.

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Experiment and Methodology

Measurement of PV System Parameters

To analysis and evaluate the performance of PV system or impact of PV power injected to grid, parameters like voltage injected to grid, current to grid, Power factor, power drawn, frequency deviation, harmonics and all others parameters related to PV system (PV voltage, current, Power, Inverter Voltage, etc) must be properly monitored and recorded to check the feasibility of proposed system Dwivedi et al [1]. With the help of these recorded parameters a detailed analysis is performed that focuses on the impact of grid connected PV system. Thus with the help of proper measuring instruments the collected data are presented in this section.

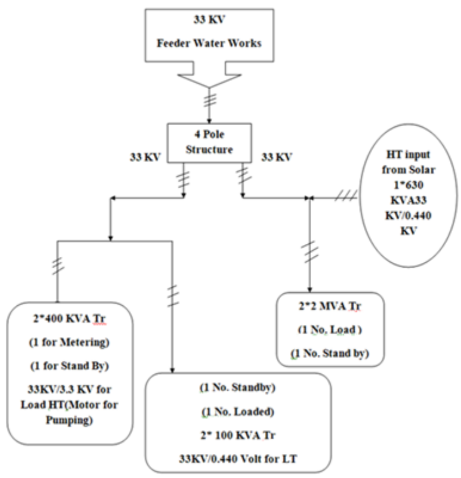

Figure 1: Single line diagram of PV system connected to grid..

Inverter Temperature

The efficiency of the inverter, needless to say, certainly influences the total performance of the PV systems Niitsoo et al [2]. The temperature effects on the inverter is thus a meaningful finding, and the quantitative analysis of this kind of loss is useful for forecasting energy yield of the PV systems especially in high temperature regions Agustín et al [3]. At present the temperature effects of unit-01 and unit-02 inverters are evaluated and analyzed. Table 1 shows the average temperature of the inverter unit. It is certain that high operating temperature has negative effects on all inverters. High temperature has negative impacts also on the performance of the inverter, not only on the PV modules Perera et al [4]. According to experimental results, the ambient temperature of higher than 37°C caused 2.5% drop in the inverter's maximum efficiency.

Table 1: IGBT temperature of inverter Unit.

S.No.	Inv-01 Unit-01 (°C)	Inv-01 Unit-02 (°C)	Inv-02 Unit-01 (°C)	Inv-02 Unit-02 (°C)	Inv-03 Unit-01 (°C)	Inv-03 Unit-02 (°C)	Inv-04 Unit-01 (°C)	Inv-04 Unit-02 (°C)
Average Temperature (°C)	30.9	34.4	33.2	36.5	36	34.1	37	34.1

Power Output from Inverter

The average output power generated from the inverters per day and monthly are presented in Table 2. The inverter total generation time is 4716.9 hours. The average input PV voltages for unit-01 and unit-02 with the phase voltages outputs from inverter are presented in Table 3.

Table 2: Average power generated by inverter.

S.No.	Measured Power	Values
1.	Inverter Per Day Gen(MWh)	11.2
2.	Inverter Total Gen Time (h)	4716.9
3.	Inverter Total Gen(MWh)	7638.3

From the observed reading of the metering unit it is clear that the average PV Voltage for the inverter input is 24 VDC for both the units and the average temperature is observed to be 27 °C. While the phase voltages from the inverter output is observed nearly as 625 VAC in all the three phases of both the units. This voltage is step up to 33KV through transformer unit.

Table 3: PV voltage, temperature and inverter output voltages of for unit-01 and 02

	Inverter's Unit -01	Inverter's Unit -02
Grid Voltage UV (V)	628.8	630.1
Grid Voltage VW (V)	625.4	623.5
Grid Voltage WU (V)	626	624.6
Inner Temperature (°C)	26.2	29.6
PV Voltage (V)	20.4	24.1

Analysis of Parameters of Grid Connected PV System (Gaughat Station)

This study aims to investigate the recent integration requirements including harmonics, voltage unbalance, and frequency variation Alexandru et al [5]. To analyze the impact of grid connected PV system the voltage injected to grid, current to grid, harmonic, power factor, frequency deviation and power generated of generating units (JBM solar power Limited) is presented in this section. All these parameters for evaluating the performance of PV system impact on grid are important constraints. The simulation model of the system is presented in Figure 2. The simulation results are compared with the experimental results to validate the performance of the grid stability.

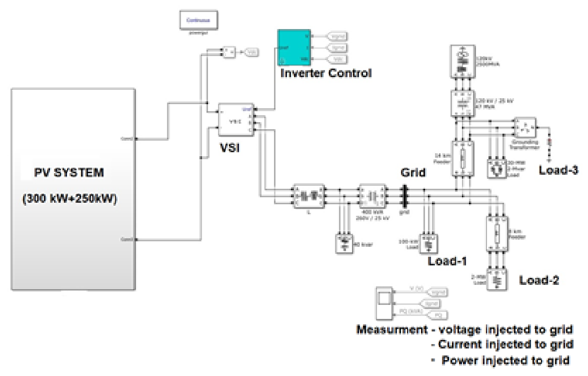

Figure 2: Simulation of 550 KW PV system injected to grid.

Voltage and Current Injected to Grid

The line and phase voltage injected to grid from the inverter output after stepping up are shown in Table 4. These values are measured and recorded on daily hourly basis and presented here as an average of the month for the analysis. It is being clearly observed that the average phase voltage is 19289.44 V while average line voltage is 33408.73 V.

Table 4: Monthly average voltage injected to grid.

S.No.	Phase and Line voltage of Grid	Values(V)
1.	VR_PH(V)	19367.38
2.	VY_PH(V)	19110.64
3.	VB_PH(V)	19385.54
4.	VPH_AVG(V)	19289.44
5.	VRY(V)	33276.89
6.	VYB(V)	33417.04
7.	VBR(V)	33536.75
8.	VLL_AVG(V)	33408.73

The current injected to grid are shown in Table 5. Here also these values are measured and recorded on daily hourly basis and presented here as an average of the month for the analysis. It is being clearly observed that the average current injected to grid is 88.54 A.

Table 5: Monthly average current injected to grid.

S.No.	Measured Current	Values (A)
1.	IR(Amps)	89.32
2.	IY(Amps)	88.17
3.	IB(Amps)	88.37
4.	IN(Amps)	0
5.	I_AVG(Amps)	88.54

Harmonics Analysis

These PV systems have both pros and cons associated with it. In terms of cons, it has power electronic devices which provides harmonics and thus affects the power quality of the grid by causing harmonic distortion Rai et al [6]. The aim of this study is the harmonic analysis of PV systems (experimental) on grid. The PV systems provide harmonic distortion in the grid which affects the power quality of the grid as it is large in number and with the no. of PV systems increasing rapidly it may become a bigger problem Jarkovoi et al [7]. The experimental values recorded for voltage injected to grid and current injected to grid are presented in Table 6 and Table 7 respectively.

Table 6: Voltage harmonics.

Harmonics order	Frequency (HZ)	% of Magnitude with fundamental	Magnitude of Voltages (Volts)
h1(fundamental)	50	100	33022.19
h2	100	1.07	360.21
h3	150	0.92	300.34
h4	200	0.94	312.76
h5	250	1.09	368.54
h6	300	0.93	298.23
h7	350	0.94	300.31
h8	400	1.10	370.87
h9	450	0.96	333.32
h10	500	0.97	342.76
h11	550	1.06	351.33

The percentage magnitude of THD for voltage injected to grid and current injected to grid are analyzed with by analytical method for the calculation of THD Dwivedi et al [8]. Equation 1 and equation 2 shows the standard relation for finding the THD. The THD is calculated as (percentage of magnitude of fundamental frequency) as 2.73% and 0.85% for Voltage and current injected to grid respectively.

Table 7: Current harmonics.

Harmonics order	Frequency (HZ)	% of Magnitude with fundamental	Magnitude of currents (Amperes)
h1(Fundamental)	50	100	88.5
h2	100	1.49	1.28
h3	150	1.72	1.41
h4	200	1.99	1.77
h5	250	2.55	1.96
h6	300	1.42	1.30
h7	350	1.33	1.29
h8	400	1.53	1.50
h9	450	1.61	1.60
h10	500	1.02	0.92
h11	550	1.55	1.52

% THD Grid Voltage(Experimental Setup)

$$= \frac{\left(\sqrt{V1^2 + V2^2 + \ldots\ldots Vn^2}\right)}{n}$$

$$= \frac{\left(\sqrt{33022.19^2 + 360.21^2 + \ldots\ldots 351.33^2}\right)}{11} = 2.73\%$$

% THD Grid Current(Experimantal Setup)

$$= \frac{\left(\sqrt{11^2 + 12^2 + \ldots\ldots \mathrm{In}^2}\right)}{n} = 0.85\%$$

Variation in power factor, frequency and Power with Load

As the level of grid-connected PV penetration continues to rise, the importance of power factor and power factor correction is going to become increasingly relevant both from the perspective of the grid and the customer Tobnaghi et al [9]. Most grid connected PV inverters are only set up to inject power at unity power factor, meaning they only produce active power. In effect this reduces the power factor, as the grid is then supplying less active power, but the same amount of reactive power Du et al [10]. Thus it is important to record and evaluate the power, power factor and frequency deviation of the experimental setup also. Table 8 presents the average monthly power drawn and variation in frequency range and power factor.

Table 8: Variations in power, power factor and frequency.

Power factor variation	Active power(Kw)	Reactive power(Kvar)	Apparent power(Kva)	Frequency range
1-0.95	4977.21	-41.54	4977.68	50-50.7

Form the Table 8 it is observed that the actual site with the inverter set to a power factor of 0.95 - leading. The PV system is now producing 4977.21 kW of active power and 41.54 kVAR of reactive power, reducing the amount of both active and reactive power from the grid. The resultant power factor is therefore maintained 1 to 0.95 and the variation in frequency is of 50 Hz- 50.7 Hz.

Average Power Import and Export

In grid-tied solar PV system if generated power by solar PV system is higher than the load requirement then the extra power will be exported to grid or if generated power lower than the load requirement then required power will be imported from the grid Ibrik et al [11]. The actual site import and export power is presented on Table 9.

Table 9: Average power import and export.

S.No.	Energy import and export	Values
1.	Av. Daily Export(MWh	46.91
2.	Total Export(MWh)	63053.44
3.	Av. Daily Import(kWh)	89.56
4.	Total Import(kWh)	274142.18

Results & Discussion

The simulation results and actual site (experimental) results are presented; both the results are compared to analysis the impact of PV system on grid stability.

Simulation results

The three phase voltage injected to grid waveform is presented in Figure 3. The current injected to grid is shown in Figure 4 at time t=0 sec to t=0.05 sec some transient is observed while after t=0.05 sec the constant current for load-1 is injected to grid. With the change in load from load-2 and load-3 the magnitude of current varies [12].

The harmonic profile of Voltage & current injected to grid is also investigated and presented in Figure 5 and Figure 6 respectively. It is observed that the voltage THD is 1.13% of fundamental frequency and current THD is 0.49 % of fundamental frequency [13].

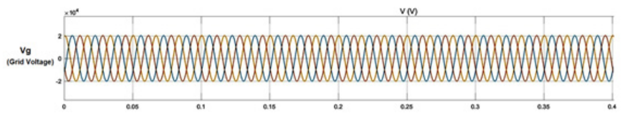

Figure 3: Three phase voltage injected to grid.

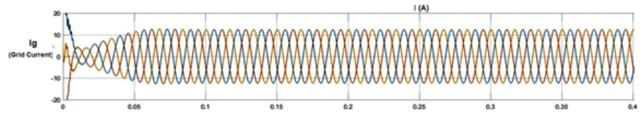

Figure 4: Three phase current injected to grid.

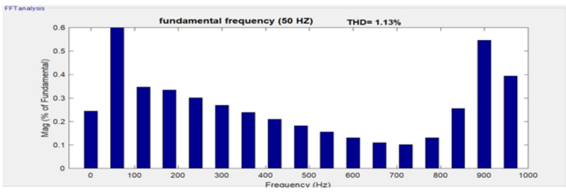

Figure 5: % THD of Voltage injected to grid.

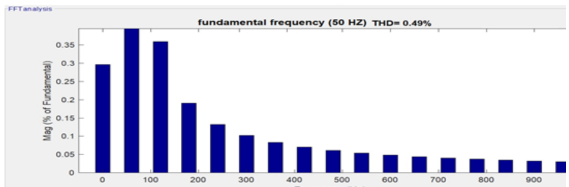

Figure 6: %THD of current injected to grid (load-1).

Validation of Results

The comparison of average Phase voltage injected to grid form the simulation and experimental setup is presented in Figure 7 and it is clearly observed that the average magnitude of voltage is 19500V in the simulation and 19300 V in the experimental setup up which is nearly same and validating the magnitude of voltage injected to grid.

The comparison of average current injected to grid form the simulation and experimental setup is presented in Figure 8 and it is clearly observed that the average magnitude of current is 89.2A in the simulation and 88.5A in the experimental setup up which is nearly same and validating the magnitude of current injected to grid.

The active and reactive power drawn is presented in Figure 9 and Figure 10 respectively. The PV system is now producing 5040 kW of active power and 41.54 kVAR of reactive power, reducing the amount of both active and reactive power from the grid while in case of simulation the active power is 5100 kW and the reactive power is nearly approaching to zero.

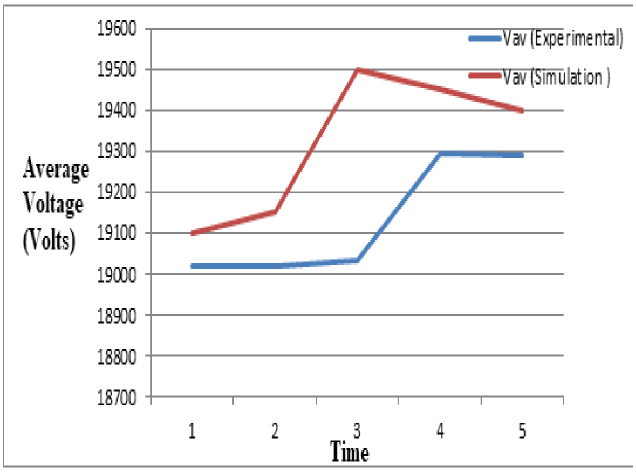

Figure 7: Average phase voltage injected to grid.

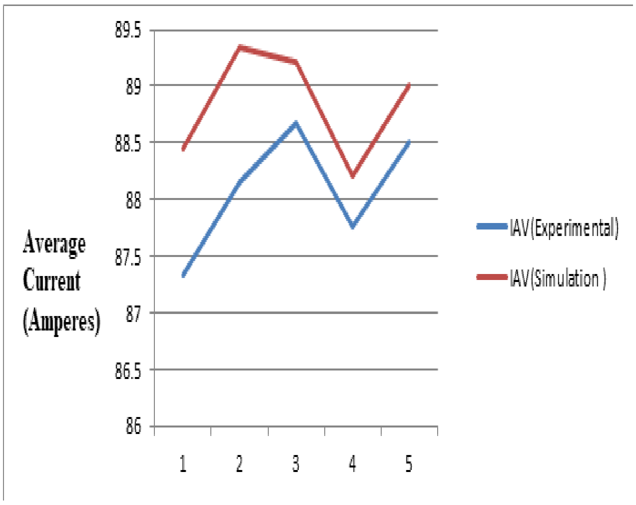

Figure 8: verage phase current injected to grid.

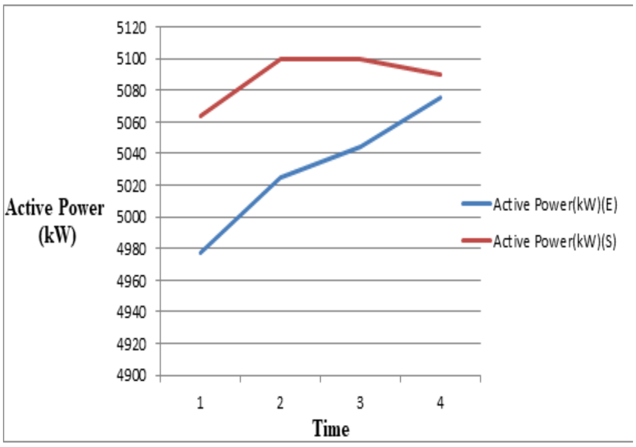

Figure 9: Active power drawn.

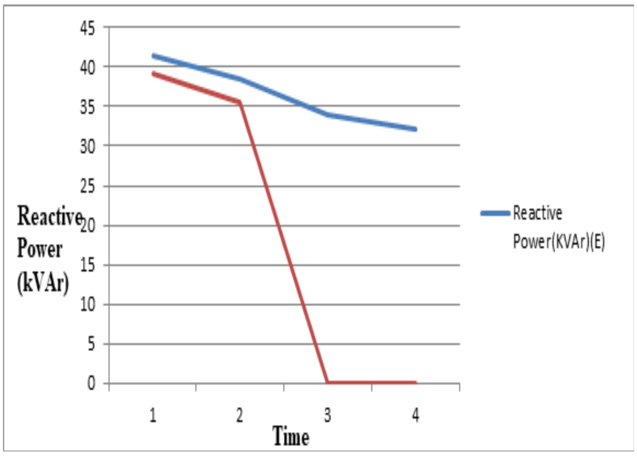

Figure 10: Reactive power drawn.

The harmonic investigation is performed from the simulation of proposed system and the actual deviation in magnitude recorded at the selected site is calculated and both are compared. Figure 11 shows

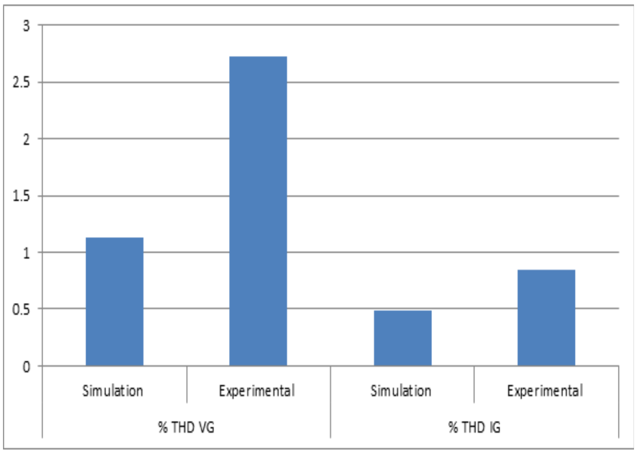

Figure 11: % Magnitude of THD (voltage &current).

the percentage variation magnitude of voltage and current injected to grid. It is clearly observed that the THD of voltage is 2.7% in experimental and 0.8 % in simulation while the current THD is observed as 1.8% in experimental and 0.5 % in simulation.

Thus from the validation of it is observed that the stability of grid is affected by two parameters, one is mechanical and another is electrical, under the mechanical parameter devices, instruments and equipment installed already lost their lives up to a certain level on the grid and can't perform up to ideal condition of full rated range due to depreciation of its life. The electrical parameter analyzed and it is observed as one of the most important part which decides the quality of the power causes voltage rise, recur, frequency and power factor reduction etc. may respond to sever problem on the grid component although many devices are available to compensate reactive power harmonic current, neutral current, unbalances current and harmonic.

Conclusion

This study focuses, on one side particular level of penetration shall be defined are maximum efficiency of the existing grid and another is direct to define their independent separate grid a solar power distribution without interconnecting the existing grid, so that it could not affect the quality of power, this quality of power under which variation in current, voltage, frequency, harmonic distortion affect the ageing of electrical equipment in long term outcomes observed like:

- Overloading of electrical equipment.
- Increased heating of neutral conductor, it can cause serious damage.
- Transformer heating due to higher order of harmonics
- Higher order of harmonics can cause telecommunication interference.
- Over stress due to switching frequency can cause damage to the components.

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