International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-9 Issue-4 November 2020

Power Quality Analysis of Distribution System Integrated with Multiple PVs

Sathish K R, T Ananthapadmanabha

Abstract: ***In this work, the Impact of integration of multiple Photo Voltaic distributed generators (PV-DGs) on power quality of the distribution system is analyzed under static and dynamic loads. Major power quality parameters considered for the analysis are voltage deviation (V_D), Total Real power and reactive power line losses ($P_{T\ L}$ & $Q_{T\ L}$) and Total Harmonic Distortion of Voltage at Buses (THD_v). Test system considered for the study is the IEEE-9 bus test system and types of loads considered are Static RL and Induction motors. Modeling and simulation of test system, PVs and Induction motor loads are carried out in MATLAB/SIMULINK software package.***

Keywords: Power Quality; loss measurement; Power system Harmonics; PV-Photovoltaic system.

I. INTRODUCTION

Presently, the solar photovoltaic electric power generator becomes a significant renewable distributed generation. The integration of photovoltaic distributed generators (PV-DG) leads to precariousness in distribution system planning and operation. The integration of PV-DGs can increase the performance of the Distribution system like an increase in voltage profile, reduction of line losses and reduction of burden over the grid and tap changers of the transformers [1].When PV-DGs is integrated into the distribution systems, the impact of Integration should be analyzed by considering performance indicators like Quality of voltage, line losses, feeder loading, harmonic distortion, and frequency fluctuations. Hence, some researchers observed the assessment of the impact of PV- DGs on voltage unbalance and harmonics [2, 3]. M. Farhoodnea et.al observed the effects of installing grid-connected PV systems on the dynamic behavior of the distribution network under different weather conditions by using MATLAB /SIMULINK [4]. However, the simulations are performed based on the small-scale test system in short-time periods with average load data profiles. In this paper, the Open Distribution System Simulator (Open DSS) [5] developed by Electric Power Research Institute (EPRI) is applied to perform the simulations for analyzing PVDG impacts on power quality problems of distribution networks.

Revised Manuscript Received on October 25, 2020.
Manuscript Received On October 06, 2020

* Correspondence Author
Sathish K R, Department of EEE, ATMECE, Mysuru, India. Email: sathish.kr@atme.in
Dr. T Ananthapadmanabha, Former Principal of NIEIT, Mysuru, India. Email:.drapn@gmail.com

Several studies have been carried out to ccess the impacts of DG in the power distribution system using Open DSS [6, 7]. The main objective of this research paper is to accurately analyze the effects of integrating multiple PV-DGs on the power quality of the distribution system under static and dynamic loading conditions.

Power quality analysis includes percentage voltage deviation, line loss reduction and total harmonic distortion of Voltage (THD) caused by the integration of PV-DGs. The rest of the paper is organized as follows. Section 2 Explains about the Modeling of PV-DG in MATLAB/ SIMULINK software package. Test system used in this paper and its parameters are presented in section 3. Power flow results of test system when PV-DGs. are integrated are discussed in section 4. Section 5 concludes the summary of the work carried out

II. MATHEMATICLA MODELING OF PV-DG

The equivalent circuit of a PV cell is shown in Fig. 1. The current source Iph represents the cell photocurrent. Rsh and Rs are the intrinsic shunt and series resistances of the cell, respectively. Usually, the value of Rsh is very large and that of Rs is very small, hence they may be neglected to simplify the analysis. Practically, PV cells are grouped in larger units called PV modules and these modules are connected in series or parallel to create PV arrays which are used to generate electricity in PV generation systems. The equivalent circuit for the PV array is shown in Fig. 2

$$I_{ph} = \left[\frac{I_{sc} + K_i(T - 298) * I_r}{1000}\right] - - - - - (1)$$

Where, I_{ph}: photo-current (A); I_{sc}: short circuit current (A); K_i: short-circuit current of cell at 25 ◦C and 1000 W/m2; T: operating temperature (K); I_r :solar irradiation (W/m2).Module reverse saturation current I_{rs}:

$$I_{rs} = \frac{I_{sc}}{\left[e^{\frac{q*V_{oc}}{N_s K n T}} - 1 \right]} - - - - - (2)$$

analysis includes Here, q: electron charge, = 1.6 × 10−19C; Voc: open-circuit voltage (V); Ns: number of cells connected in series; n: the ideality factor of the diode; k: Boltzmann's constant, = 1.3805 × 10−23 J/K. The voltage-current characteristic equation of a solar cell is provided as Module photo-current I_{ph}:

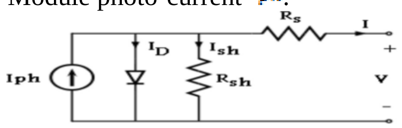

Figure 1 PV-Cell Equivalent Circuit

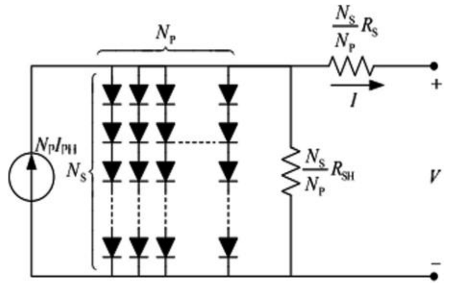

Figure 2 Equivalent Circuit of solar array

The module saturation current I_0 varies with the cell Temperature, which is given by:

$$I_0 = I_{rs}\left[\frac{T}{T_r}\right]^3 * \exp\left[\frac{q * E_{go}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] - - - (3)$$

Here, Tr: Nominal temperature = 298.15 K; E_{g0}: bandgap energy of the semiconductor, = 1.1 eV; The current output of PV module is:

$$I = N_p * I_{ph} - N_p * I_0 * \left[\exp\left(\frac{\frac{V}{N_s} + I * \frac{R_s}{N_p}}{n * V_t}\right) - 1\right] - I_{sh} \quad - - - - - - - - -(4)$$

With $V_t = K * T)/q — (5)$ and $I_{sh} = \frac{V * \frac{N_P}{N_S} + I * R_S}{R_{sh}} - -(6)$

Here: Np: number of PV modules connected in parallel; Rs: series resistance (Ω); Rsh: shunt resistance (Ω);Vt: diode thermal voltage (V).The complete model of PV-DG in SIMULINK is as shown in figure 3:

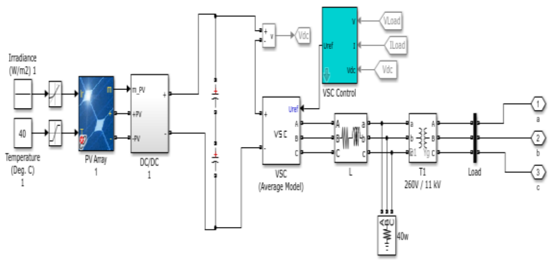

Figure 3 PV-DG SIMULINK MODEL

PV array is a DC electrical source which cannot be interfaced with the AC Distribution system directly. Hence Voltage Source Converter (VSC) is used to convert DC to 3-phase AC of 260V @ 50 Hz. VSC controller regulates the output of VSC such that output of PV-DG is synchronized with the Distribution system Load

III. TEST SYSTEM DESCRIPTION AND BASE-CASE RESULTS

Test system considered for the study is a modified IEEE 9 bus radial distribution system [9] as shown in fig. Operating voltage and frequency of the considered system is 11KV & 50HZ with 100MVA base. Modeling and Simulation of test systems are carried out in MATLAB/SIMULINK software package.

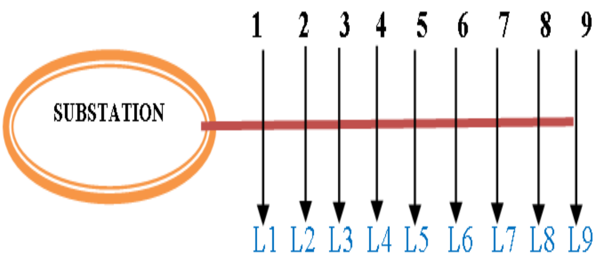

Figure 4: IEEE 9-Bus System

Two scenarios are considered for the study i.e.: 1. Scenario 1- Loads are modeled as Static RL & 2. Scenario 2- Loads are modeled as Induction motor. Power/Load flow Simulation results of test system in scenario 1(S1) without the integration of PV-DGs (Base case) are mentioned in Table1.0 & 1.1. Where Vb, Pb & Qb are Bus Voltage in per unit, Bus real power flow and reactive power flow respectively.

Table 1: Power flow results of Test system- Base case (S_1)

Bus No.	*V_b in PU*	*P_b in KW*	*Q_b in KVAR*	*% V_D*	*%THD(V_b)*
1	0.9971	1190.24	478.24	0.2867	0
2	0.9949	1007.15	426.46	0.5158	0
3	0.9853	904.03	382.92	1.4902	0
4	0.9793	726.39	336.84	2.1133	0
5	0.9674	567.84	155.09	3.3722	0
6	0.9635	415.70	97.66	3.7897	0
7	0.9566	340.99	86.15	4.5408	0
8	0.9461	233.32	29.86	5.7002	0
9	0.9388	144.54	17.63	6.5191	0

Where Percentage voltage deviation (% V_D) is calculated using the following equation:

$$\%V_D = \frac{[1 - V_b]}{V_b} * 100 - - - -(7)$$

Table 2: Total line losses- Base case (S1)

Total Real power line losses (P_{TL}) in KW	25.1544
Total Real power line losses (Q_{TL}) in KVAR	34.7921

In Table 1.0 it can be observed that voltage deviation is more than 5% at Bus 9 & 8.and % Total harmonic distortion of voltage at all buses is Zero.

Similarly, Power/Load flow Simulation results of the test system in scenario 2 (S2) without the integration of PV-DGs (Base case) are mentioned in Table 3 & 4.

Table 3: Power flow results of a Test system- Base case (S2)

Bus No.	V_b in PU	P_b in KW	Q_b in KVAR	% V_D	%THD(V_b)
1	0.9884	2041.64	2757.998	1.1768	0.22
2	0.9750	1839.99	2563.908	2.5684	0.48
3	0.9386	1673.47	2393.572	6.5459	1.03
4	0.9174	1430.17	2224.196	9.0092	1.30
5	0.8622	1138.68	2011.820	15.9840	1.94
6	0.8395	916.29	1869.269	19.1247	2.14
7	0.8022	734.13	1766.468	24.6504	2.39
8	0.7278	407.14	1585.337	37.4043	2.67
9	0.6799	191.44	913.137	47.0865	2.90

Table 4: Total line losses- Base case (S2)

P_{TL} in KW	665.19882
Q_{TL} in KVAR	589.76037

In Table 3 it can be observed that the voltage deviation is more than 5% at Bus 3 to Bus 9 and % Total harmonic distortion of voltage at all buses is more than 2% at Bus 6 to Bus 9. From Table 3 & 4 it can be observed that both line losses are more when loads are loads are induction motors than static RL load.

IV. INTEGRATION OF PV-DG'S

In each Scenario many cases are worked out depends on the number of PV-DGs to be integrated to maintain all bus voltages within the acceptable limits i.e. %VD<5%

Scenario 1(S1): In this Scenario, four 100KW PV-DGs are integrated into the test system at Bus 9 and Bus 8 to maintain all bus voltages within permissible limits. When each PV-DG is integrated into the test system, afterload flow simulation total Line losses, %VD and %THD of Vb at all buses are recorded and Consolidated Results are tabulated as follows.

Table 5: % Voltage Deviation after integration of PV-DGs– S1

Bus No.	% VD			
	1-PV	2-PVs	3-PVs	4-PVs
1	0.275457	0.26517	0.255316	0.245649
2	0.501405	0.48894	0.477431	0.466508
3	1.413103	1.34134	1.271894	1.203124
4	1.977646	1.849904	1.725437	1.601475
5	3.066232	2.776062	2.492339	2.209009
6	3.404544	3.039112	2.681791	2.325003
7	3.974095	3.435947	2.91015	2.385726
8	4.701139	3.755693	2.836155	2.323836
9	5.030527	3.630189	2.728038	2.224903

Table 6 : % THD of Vb after integration of PV-DGs– S1

Bus No.	%THD of Vb			
	1-PV	2-PVs	3-PVs	4-PVs
1	0.01	0.01	0.02	0.02
2	0.02	0.03	0.05	0.06
3	0.04	0.07	0.10	0.13
4	0.05	0.08	0.12	0.16
5	0.07	0.13	0.18	0.24
6	0.08	0.15	0.21	0.27
7	0.10	0.17	0.24	0.32
8	0.13	0.23	0.33	0.40
9	0.17	0.30	0.39	0.46

Table 7 :Total line losses after integration of PV-DGs– S1

No. of PV-DGs	1-PV	2-PVs	3-PVs	4-PVs
P_{TL} in KW	17.47215	12.459586	9.1614862	6.8287948
Q_{TL} in KVAR	26.93	21.090358	16.640969	13.108894

Table 5 summarizes the results of Voltage Deviation at all buses after the integration of PV-DGs in scenario 1 and it can be observed that after the integration of PV-DGs to the considered test system, Voltage deviation at all buses decreases compared to the base case.

Table 6 summarizes the results of Total Harmonic distortion of Voltage at all buses after integration of PV-DGs in scenario 1 and it can be observed that after integration of PV-DGs to the considered test system, %THD of voltage at all buses increases compared to the base case. Table 7 indicates the results of Total line losses after integration of PV-DGs in scenario 1 and it can be observed that after the integration of PV-DGs to the considered test system line losses decreased compared to the base case. Since the number of PV-DGs is placed at Bus 9, Power Quality indicators at this bus will indicate whether the Power Quality enhanced or decreased after the integration of PV-DGs. In Fig.2 it can be observed that after integration of PV-DGs to the test system under scenario-1 Real and reactive power line losses reduced by 72.843% and 62.31% respectively, Voltage deviation at Bus 9 reduced by 65.95% and THD of Voltage at Bus 9 increased by 0.46%.

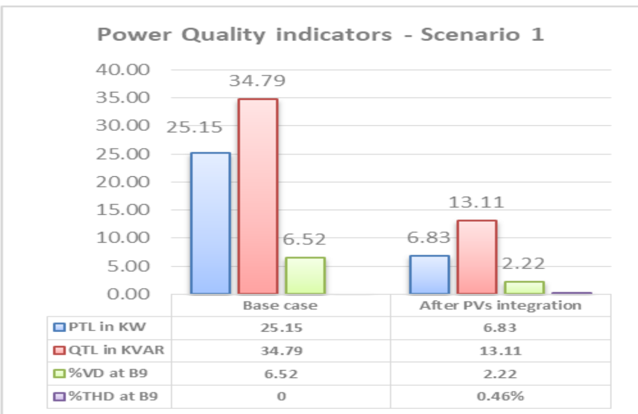

Figure 5: Power Quality indicators- Scenario 1

Scenario 2(S2): four 100KW and one 200KW PV-DGs are integrated into the test system at Bus 9 to maintain voltages at all buses within permissible limits. When each PV-DG is integrated into the test system, afterload flow simulation total Line losses, %VD and %THD of Vb at all buses are recorded and Consolidated Results are tabulated as follows.

Table 8: % Voltage Deviation after integration of PV-DGs – S2

Bus No.	$\%V_D$				
	1-PV	*2-PVs*	*3-PVs*	*4-PVs*	*5-PVs*
1	1.1833	0.9449	0.9485	0.9528	0.4177
2	2.5978	2.0451	2.0668	2.0896	0.8461
3	6.5699	5.0967	5.1021	5.1125	1.9384
4	9.0017	6.9022	6.8714	6.8492	2.4455
5	15.8618	11.7642	11.6119	11.4793	3.4085
6	18.9364	13.8279	13.6107	13.4187	3.6191
7	24.2433	17.2469	16.8391	16.4703	3.6668
8	36.2490	24.5003	23.5293	22.6392	2.9960
9	44.7140	31.5739	29.7725	28.1217	1.5296

Table 9: % THD of Vb after integration of PV-DGs – S2

Bus No.	% THD of Vb				
	1-PV	*2-PVs*	*3-PVs*	*4-PVs*	*5-PVs*
1	0.22%	0.24%	0.24%	0.24%	0.30%
2	0.47%	0.53%	0.53%	0.54%	0.69%
3	1.02%	1.16%	1.16%	1.17%	1.52%
4	1.29%	1.48%	1.48%	1.48%	1.96%
5	1.93%	2.28%	2.27%	2.27%	3.12%
6	2.12%	2.56%	2.54%	2.54%	3.56%
7	2.38%	2.96%	2.92%	2.93%	4.27%
8	2.67%	3.56%	3.47%	3.46%	5.61%
9	2.89%	3.66%	3.59%	3.60%	6.61%

Table 10 :Total line losses after integration of PV-DGs – S2

No. of PV-DGs	*1-PV*	*2-PVs*	*3-PVs*	*4-PVs*	*5-PVs*
P_{TL} in KW	666.205	423.64	414.46	363.106	29.138
Q_{TL} in KVAR	588.92	423.64	417.39	365.80	33.951

Table 8 summarizes the results of Voltage Deviation at all buses after the integration of PV-DGs in scenario 2 and it can be observed that after the integration of PV-DGs to the considered test system, Voltage deviation at all buses decreases compared to the base case.

Table 9 summarizes the results of Total Harmonic distortion of Voltage at all buses after integration of PV-DGs in scenario 2 and it can be observed that after integration of PV-DGs to the considered test system, %THD of voltage at all buses increases compared to the base case.

Table 10 indicates the results of Total line losses after integration of PV-DGs in scenario 2 and it can be observed that after the integration of PV-DGs to the test system line losses decreased compared to the base case.

In Fig.6 it can be observed that after integration of PV-DGs to the test system under scenario-2 Real and reactive power line losses reduced by 95.62% and 94.2% respectively, Voltage deviation at Bus 9 reduced by 95.11% and THD of Voltage at Bus 9 increased to 6.61%.

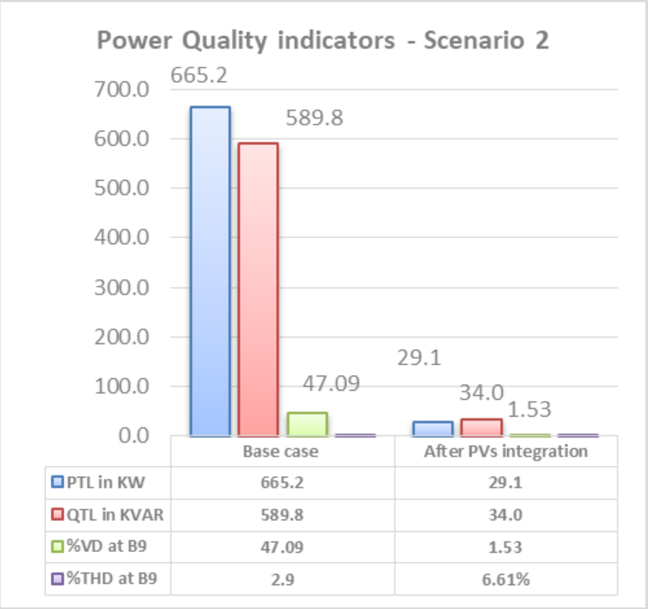

Figure 6:Power Quality indicators- Scenario 2

V. CONCLUSION

Effect of integration of PV-DGs on power quality of distribution system under two different loading conditions i.e.: Static RL & Induction motors is presented. Under static RL loading condition integration of PV-DGs will not alter the power quality of the distribution system much since voltage harmonic distortion and voltage magnitude at PV-DG connected buses are within the limits. Under Induction motor loading condition integration of PV-DGs leads to voltage harmonic distortion of more than 5% at DG connected bus. The major scope of this work is significant input for the design of the Power quality controller to be placed in the distribution system connected with PV-DGs. In future work other power quality indicators like THDi, Voltage rise and drops, frequency deviations, etc will be considered for the study.

ACKNOWLEDGMENT

This research was supported by Visvesvaraya Techno-logical University, Jnana Sangama, Belagavi -590018

REFERENCES

1. Omarn, M.A. et.al: *A study of the impacts of power fluctuations generated from large PV systems*, IEEE PES/IAS Conference on Sustainable Alternative Energy, 2009.
2. Ruiz-Rodriguez, F. J., Hernandez, J. C., Jurado, F.: *Voltage unbalance assessment in secondary radial distribution networks with single-phase photovoltaic systems*, International Journal of Power and Energy System, 2015, Vol. 64, pp. 646-654.
3. Hernandez, J. C., Ortega, M. J., Medina, A.: *Statistical characterization of harmonic current emission for large photovoltaic plants*, International Transactions on Electrical Energy System, 2014, Vol.24, No.8, pp. 1134-1150.
4. Farhoodnea, M. et.al: *Power quality analysis of gird connected photovoltaic systems in distribution networks*," Przeglad Elektrotechniczny, 2013, Vol. 89 (2A), pp. 208-213
5. EPRI: *Distribution system Simulator, OpenDSS*, 2016. Available: http://sourcefore.net/projects/electridsss/

6. Paulo Radatz et.al: *Assessing maximum DG penetration levels in a real distribution feeder by using OpenDSS*, IEEE 17th International Conference on Harmonics and Quality of Power (ICHQP), Belo Horizonte, Brazil, 16~19 October, 2016.
7. Smith, J. W.: *Distribution modeling and analysis of high penetration PV*, IEEE Energy Society General Meeting, Detroit, MI, USA, 2011.
8. Xuan Hieu Nguyen[1] and Minh Phuong Nguyen[2]: Mathematical modeling of photovoltaic cell/module/arrays with tags in Matlab/Simulink Environmental System Research (2015) ,DOI 10.1186/s40068-015-0047-9
9. Om Prakash Mahela, Sheesh Ram Ola, Lalit Goyal "Optimal Capacitor Placement for Loss Reduction in Radial Distribution Feeder" *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN:2278-1676 Volume 4, Issue 6 (Mar - Apr. 2013), PP 43-48*

AUTHORS PROFILE

Sathish K R M.Tech in Power Electronics from UVCE, Bengaluru, India. Currently pursuing Ph.D. in Visvesvaraya Technological University, Belgaum and his research area are Electrical Power System. Presently working as an Assistant Professor in the Department of Electrical and Electronics Engineering, ATME College of Engineering, Mysuru -28.

Dr. T. Ananthapadmanabha received a B.E. degree in Electrical Engineering in 1980, an M.Tech degree in Power Systems (1st Rank) in 1984, and a Ph.D. degree (Gold Medal) in 1997 from University of Mysore, Mysuru. He has served the Engineering Educational stakeholders for over three decades. He is the **former Principal of NIEIT, Mysuru,** Karnataka, India. His research Interest includes Reactive Power Optimization, Voltage Stability, Distribution Automation, and AI applications to Power Systems.

.