Proc. of the 4rth International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET)
10-12 September 2018, Islamabad, Pakistan

Impact Analysis of PV Penetration on Radial Distribution Feeder of National University of Science and Technology (NUST)

Husnain Sadiq
Department of Electrical Power Engineering
USPCAS-E NUST
Islamabad, Pakistan
husnain_sadiq@ieee.org

Syed Ahmed Hassan Raza
Department of Electrical Power Engineering
USPCAS-E NUST
Islamabad, Pakistan
ahmed.hassan3@ptcl.net.pk

Usman Hameed
Department of Electrical Power Engineering
USPCAS-E NUST
Islamabad, Pakistan
uhameed1@asu.edu

Abdul Kashif Janjua
Department of Electrical Power Engineering
USPCAS-E NUST
Islamabad, Pakistan
kashif@uspcase.nust.edu.pk

Kashif Imran
Department of Electrical Power Engineering
USPCAS-E NUST
Islamabad, Pakistan
kashifimran@uspcase.nust.edu.pk

Abstract—**Distributed generation has potential to mitigate the problem of increasing energy demand with no extension of transmission and distribution system. Increased penetration of distributed generation on low voltage feeders has changed the distributed network from passive to active network. This penetration alsoaffectsthe power quality of the system and poses various problems too,such as the overall system voltage rises above the nominal value and current swings. This paper presents a case study of a 19 bus radial feeder network in NUST Islamabad to analyze the effects of varying distributed generation penetrationlevel on medium voltage feeder voltages using MATLAB Simulink. The maximum amount of distributed generation penetration that is feasible without violating feeder nominal voltage limits isalso suggested.**

Keywords—Distributed generation, photovoltaic system, voltage rise, MV distributed network, PV penetration, LV distributed network.

I. INTRODUCTION

Increasing world population and living standards has increased the energy demand. Our main energy sources are conventional which are unsustainable due to limited available resources which can be depleted, unfriendly to environment as they emit green house gases (GHGs) and their power generation capacities are sensitive to fuel prices. Renewable energy resources are best alternatives to meet the growing energy demand to address the challenges of sustainability and eliminations of harmful byproducts[1-3]. Distributed generation (DG) has transformed the distribution network from passive to active network that results in bidirectional power flow and reduction in line losses. However, distributed generation is still in the early stages of development due to several economic and technical barriers for the integration of DG into power grid. Various studies have been performed in the past for DG planning and modeling which consider various technical aspects like voltage rise, system fault level, power quality, power losses and protection [4].

Germany is leading the world in integrating the renewable energy into grid, mainly the integration of PV (photovoltaic) solar system. PV system already contributed approximately 40% of peak power during summer in Germany. By the end of 2015 it was planned to install 40 GW PV capacity plants. More than 50% of PV plants are installed in the Germany at low voltage(LV) distribution network i.e. residential and commercial side by installing roof top solar system. Globally USA is the 4th biggest market of the world in PV installation after Germany, Japan, and Spain[5].Grid connected PV system has been growing over the last decades. Grid connected PV distributed generation is the most promising renewable energy solution which could offer benefits to both the end users and as well as to the utility network [**6**].Small scaleDistributed generators were used for power backup to small customer in case of electricity outage from the grid, now in modern grid networks they are being integrated with LV distribution network at residential and commercial scale[7]. At large scale many universities have installed PV systems to fulfill the energy demand of the campus and integrated these PV systems with their medium voltage (MV) distribution networks e.g. University of Arizona (28MW), Arizona State University (23MW), Rutgers University (17.41MW), Colorado University (6.75MW), California State University Fullerton (6.5MW) and West Hill community college District (6MW)[8]. Output from PV system is intermittent as it depends on the irradiance and the temperature, higher irradiance varies short circuit current, which increases the output power of the PV system, higher temperature causes small increase in short circuit current and strong decrement in system voltage, which causes decrease in PV system overall output power[9,10].

One of the major hurdle in high PV penetration into MV and LV networks is that feeder voltage level rises due to reverse power flow in the distribution feeder[11].Optimal integration of PV system into MV network causes reduction in line losses

978-1-5386-7027-9/18/$31.00 ©2018 IEEE

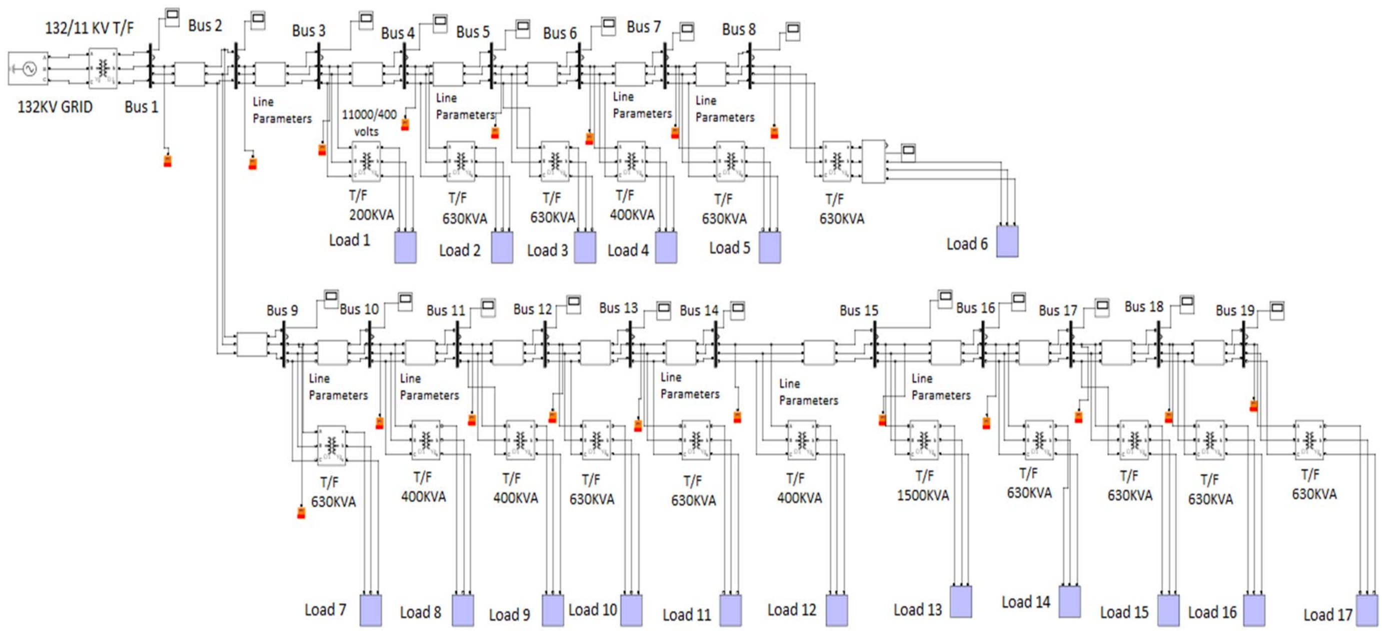

Fig. 1. 11kv radial feeder with power supply from 132kv main source.

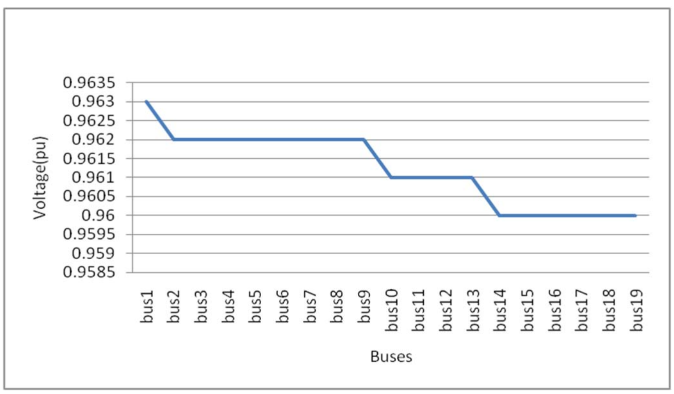

Fig. 2. Voltage profile of 11kv radial feeder with power supply from 132kv main source.

and grid stability. To obtain the optimal placement and size of distributed generation heuristic methodology based on genetic algorithm is used. Higher penetration of PV system into MV distribution network causes voltage rise and unstable grid operation[12, 13].Different level of PV penetration for MV network limited by voltage factor is proposed i.e. 110%, 40%, 33% and 18% of the feeder load. By regulation laws U.S. allows distributed PV generation with peak installation 15% of the peak load on the feeder [14, 18].A feeder can host additional40% to 90% PV distributed generation using reactive power control and on load tap changer with existing transformer[19].

In Pakistan, NUST is the first institution who is planning to integrate 4 MW PV into its distribution network. Before integration, impactful study is necessary to get fruitful outcome of the PV integration.

In this paper, a case study is presented on impact of increasing PV penetration on MV 19 bus radial distribution feeder of NUST Islamabad.

It consists of IV sections. Brief introduction of the importance of this study has been provided in Section I. Section II presents the methodology for this case study. Results with different scenarios have been discussed in Section III. At the end, this case study is summarized in section IV with concluding remarks.

II. Methodology

Real underground MV network of the university campus at sector H-12 Islamabad has been selected. The selected electric supply network is managed by IslamabadElectric Supply Company (IESCO). It represents the19 bus MV radial distribution feeder network with 17 buildings load block connected to the feeder through 11000/400 volts Delta-Wye transformer. The single line diagram of the network is shownbelow in Fig. 1.

The Fig. 1 shows the 11kv feeder that is connected to 132kv grid through 4MVA power transformer. Each building load is connected to the 11kv feeder through 11000/400 volts Delta-Wye transformer. 16mm^{2}conductor size is used with current carrying capacity of 81 amperes having feeder length of 5km. MATLAB Simulink is used to model the network. Required load data has been collected from the NUSTProject Management Office (PMO).The electrical network system under consideration is a conventional electric network having unidirectional power flow. Integration of PV distributed generation at various points of the network converts it into a non-conventional grid ultimately resulting in bidirectional power flow. This paper presents the effects on voltage profile as a result of PV distributed generation. Load flow analysis has been used in MATLB Simulink to analyze the voltage at each bus in the network. Grid tied solar PV inverters with reactive power control has been used to inject the generated power into the grid.

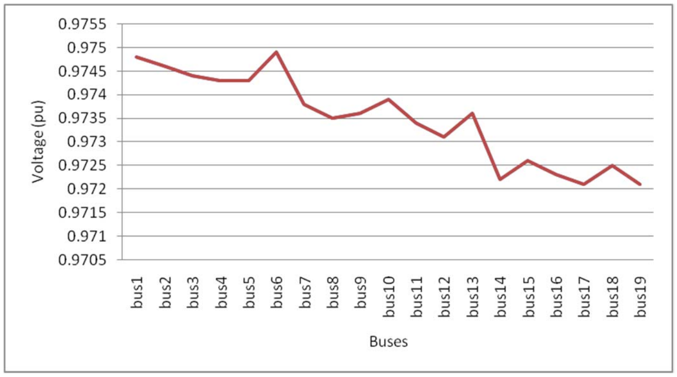

Fig. 3. Voltage profile of 11kv radial feeder with power supply from 132kv main source and singel PV DG.

TABLE I. PV INJECTION POINTS

Bus No.	PV Capacity (KW)	Bus No.	PV Capacity (KW)
Bus 6	70	Bus 15	60
Bus 8	180	Bus 17	220
Bus 12	200	Bus 19	380

The output power rating of the inverter matches the PV arrays STC (standard test condition) rating. Most of the grid tied PV inverters inject power at unity power factor, meaning that they only inject active power into the electric grid network. Hence power factor is decreased as grid is supplying same amount of reactive power but less active power. Inverter can address this poor power factor issue. Inverters with reactive power control are available in market which can be configured to have active power and reactive power.These inverters give output at non-unity power factor which resultsin decrease of active power and reactive power from the main source.Hence power factor of the system can be maintainedwithin the desired operating limits [20].

PV distributed generators with different generating capacities are integrated at different buses along the feeder is shown in TABLE I. The active and reactive load of the buildings that are connected to the feeder through 11000/400 volts transformer has been given in TABLE II and III. The load shown in TABLE II and III is the peak load taken at specific time interval. The highest building load is load 6 with 0.6 MW and lowest building load is load 1 with 0.045 MW and the range of the load is 0.56 MW. This paper represents four scenarios to study the impact of distributed PV generation on MV feeder.

III. RESULTS

To analyze the effect of PV integration, four scenarios havebeen discussed which shows the effect on feeder voltage in term of increasing PV distributed generation.

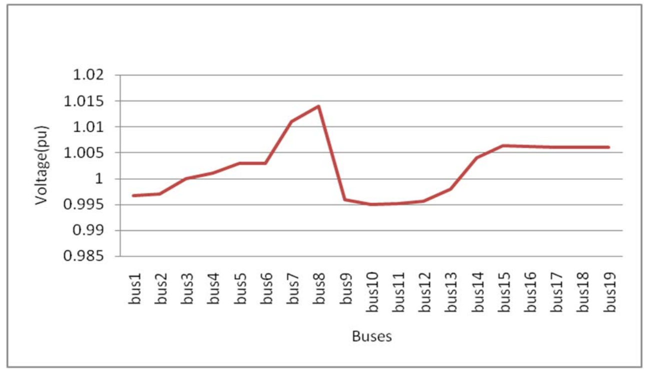

Fig. 4. Voltage profile of 11kv radial feeder with power supply from 132kv main source and 4 PV Distributed generators.

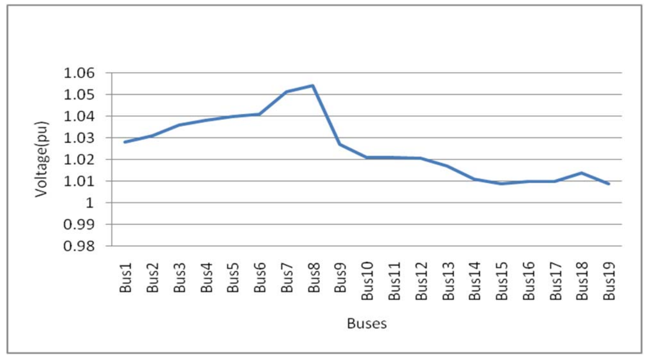

Fig. 5. Voltage profile of 11kv radial feeder with power supply from 132kv main source and 6 PV Distributed generators.

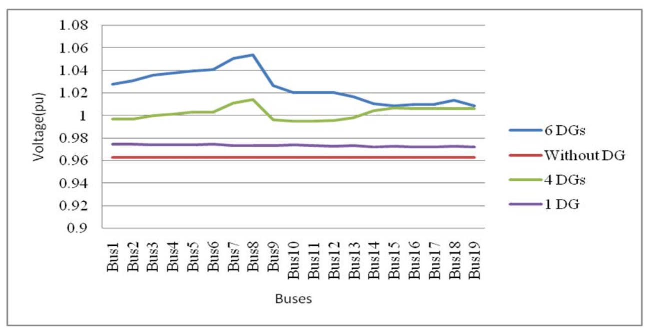

Fig. 6. Comparison of feeder voltages with multiple Distributed generators.

A. Voltage Profile of Feeder without PV Distributed Generation

The voltage profile of the MV feeder of NUST in per unit (p.u) without PV distributed generation is shown in Fig. 2.The 132kv grid is main source of power supply. The feeder voltage lies in the range of 0.96 - 0.963 p.u.

B. Voltage Profile of the Feeder with Single PV Distributed Generator

The voltage profile of the feeder with single PV distributed generator is shown in Fig. 3. PV system of 70kW is installed at bus 6. The system is operating at constant temperature and irradiance. Output of the PV system is constant as there is no change in temperature and irradiance.

TABLE II. CONNECTED BUILDINGS ACTIVE LOAD

Load No	**MW**	**Load No**	**MW**	**Load No**	**MW**
Load1	0.045	**Load 7**	0.16	**Load13**	0.32
Load2	0.176	**Load 8**	0.095	**Load14**	0.16
Load3	0.15	**Load 9**	0.03	**Load15**	0.16
Load4	0.25	**Load10**	0.1	**Load16**	0.16
Load5	0.305	**Load11**	0.43	**Load17**	0.176
Load6	0.6	**Load12**	0.45		

TABLE III. CONNECTED BUILDINGS REACTIVE LOAD

Load No	**MVAR**	**Load No**	**MVAR**	**Load No**	**MVAR**
Load1	0.0135	**Load 7**	0.048	**Load13**	0.096
Load2	0.0528	**Load 8**	0.0285	**Load14**	0.048
Load3	0.045	**Load9**	0.009	**Load15**	0.048
Load4	0.075	**Load10**	0.03	**Load16**	0.048
Load5	0.0915	**Load11**	0.129	**Load17**	0.0528
Load6	0.18	**Load12**	0.135		

Through inverter reactive power control inverter provides 13KVAR reactive powers to keep the system power factor at desired limit i.e. 0.95 lagging.With the integration of single PV DG voltage rises from 0.96-0.975 p.u, it lies within desired operating limits i.e. (0.95-1.05p.u). Voltage at bus 6 rises from 0.961-0.974p.u as shown in Fig. 3.

C. Voltage Profile of the Feeder with Four PV Distributed Generators

Voltage profile of the feeder with four PV Distributed generators is shown in Fig. 4. Four PV systems are installed at bus 6,8,12 and 15 with generating capacity of 70kW,180kW,200kW and 60kW respectively. Through inverter reactive power control system reactive power of overall 52KVAR is injected to the grid to keep the system power factor at desired operating limit. Due to multiple PV Distributed generators there is rise in voltage. Voltage rises from 0.96p.u with no DG to 1.006p.u with 4 Distributed generators, but it remains within the desired operating limits i.e. (0.95-1.05 p.u) as shown in Fig.4.

D. Voltage Profile of the Feeder with Six PV Distributed Generators

The feeder voltage profile with six PV Distributed generators is shown in Fig. 5. Now six PVDistributed generators are integrated with the feeder, PV systems are installed at bus 6,8,12,15,17 and 19 with generating capacity 70kW, 180kW, 200kW, 60kW, 220kW and 380kW respectively as shown in Fig.7. Through reactive power control of inverter, reactive power of 82KVAR is provided with solar active power. Voltage at bus 7 and 8 is 1.054pu that is slightly higher than the desired value of voltage i.e.1.05 p.u. Rise in voltage is from 0.96p.uwith no PV DG to 1.054p.u with 6 PV Distributed generators as shown in Fig. 2 and Fig. 5.

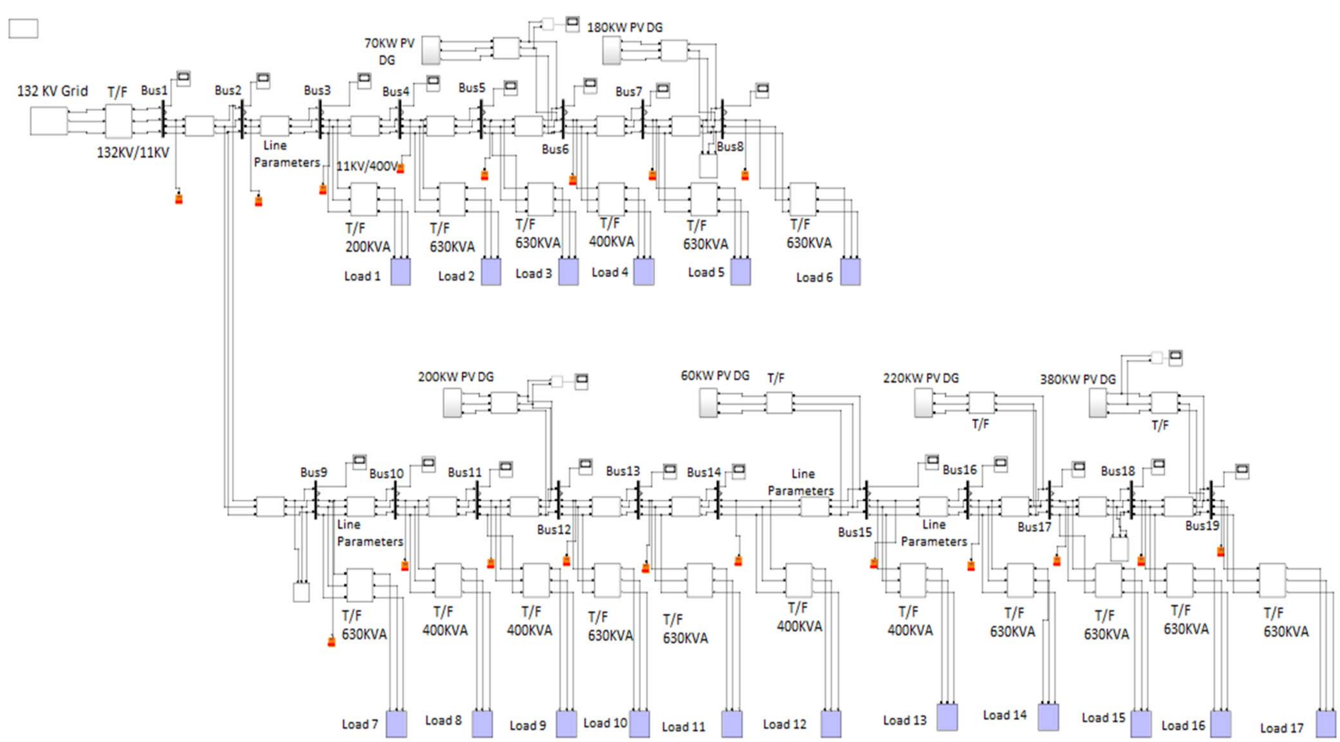

Fig. 7. 11kv radial feeder with power supply from 132kv main source and 6 PV Distributed generators integrated at bus 6, 8, 12, 15, 17 and 19.

IV. CONCLUSION

It can be observed in Fig.6 that the integration of PV on MV feeder of NUST does not affect the feeder voltageup to four Distributed generatorsand its voltage remains within the operating limits i.e. 0.95-1.05p.u. However, the integration of 6 PV Distributed generatorswith the grid network causes voltage at the bus 7 and 8 to increase slightly above the desired operating limit that is above 1.05 p.u due to which system becomes unstable. Further analysis and investigation reveals that when PV DGintegration on feeder is higher than 30% of the connected load to the feeder then voltage rises, causes the system to become unstable. To overcome these voltage variations, the rating of the installed PV Distributed generators at buses 6 and 8 should be lower than the installed value. So that voltage remains within desired operating limits and the system remains stable.

REFERENCE

[1] O. Green and G. Studies, “OECD Green Growth Studies,” *Director*, p. 104, 2012.

[2] N. Panwar, S. Kaushik, and S. Kothari, "Role of renewable energy sources in environmental protection: a review," *Renewable and Sustainable Energy Reviews,* vol. 15, pp. 1513-1524, 2011.

[3] B. Fais, M. Blesl, U. Fahl, and A. Voß, "Comparing different support schemes for renewable electricity in the scope of an energy systems analysis," *Applied energy,* vol. 131, pp. 479-489, 2014.

[4] M. A. Mahmud, M. Hossain, and H. R. Pota, "Analysis of voltage rise affect on distribution network with distributed generation," *IFAC Proceedings Volumes,* vol. 44, pp. 14796-14801, 2011.

[5] B. Bayer, P. Matschoss, H. Thomas, and A. Marian, "The German experience with integrating photovoltaic systems into the low-voltage grids," *Renewable Energy,* vol. 119, pp. 129-141, 2018.

[6] S. Ali, N. Pearsall, and G. Putrus, "Impact of high penetration level of grid-connected photovoltaic systems on the UK low voltage distribution network," in *International Conference on Renewable Energies and Power Quality*, 2012, pp. 1-4.

[7] M. Kashem, A. Le, G. Ledwich, and M. Negnevitsky, "Minimising Voltage Deviation in Distribution Feeders by Optimising Size and Location of Distributed Generation," 2005.

[8] F. Dincer, "The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy," *Renewable and Sustainable Energy Reviews,* vol. 15, pp. 713-720, 2011.

[9] H. Patel and V. Agarwal, "MATLAB-based modeling to study the affects of partial shading on PV array characteristics," *IEEE transactions on energy conversion,* vol. 23, pp. 302-310, 2008.

[10] H.-L. Tsai, C.-S. Tu, and Y.-J. Su, "Development of generalized photovoltaic model using MATLAB/SIMULINK," in *Proceedings of the world congress on Engineering and computer science*, 2008, pp. 1-6.

[11] R. Tonkoski, D. Turcotte, and T. H. El-Fouly, "Impact of high PV penetration on voltage profiles in residential neighborhoods," *IEEE Transactions on Sustainable Energy,* vol. 3, pp. 518-527, 2012.

[12] M. H. Bollen and F. Hassan, *Integration of distributed generation in the power system* vol. 80: John wiley & sons, 2011.

[13] C. Tautiva, A. Cadena, and F. Rodriguez, "Optimal placement of distributed generation on distribution networks," in *Universities Power Engineering Conference (UPEC), 2009 Proceedings of the 44th International*, 2009, pp. 1-5.

[14] T. Aziz and N. Ketjoy, "PV Penetration Limits in Low Voltage Networks and Voltage Variations," *IEEE Access,* vol. 5, pp. 16784-16792, 2017.

[15] S. Cobben, B. Gaiddon, and H. Laukamp, "Impact of photovoltaic generation on power quality in urban areas with high PV population," *PV Upscale,* 2008.

[16] B. Kroposki and A. Vaughn, "DG power quality, protection, and reliability case studies report," *National Renewable Energy Laboratory, Golden, CO, NREL/SR-560-34635,* 2003.

[17] W. Jewell, R. Ramakumar, and S. R. Hill, "A study of dispersed photovoltaic generation on the PSO system," *IEEE Transactions on Energy Conversion,* vol. 3, pp. 473-478, 1988.

[18] M. Thomson and D. Infield, "Impact of widespread photovoltaics generation on distribution systems," *IET Renewable Power Generation,* vol. 1, pp. 33-40, 2007.

[19] E. Demirok, P. C. Gonzalez, K. H. Frederiksen, D. Sera, P. Rodriguez, and R. Teodorescu, "Local reactive power control methods for overvoltage prevention of distributed solar inverters in low-voltage grids," *IEEE Journal of Photovoltaics,* vol. 1, pp. 174-182, 2011.

[20] W. Libo, Z. Zhengming, and L. Jianzheng, "A single-stage three-phase grid-connected photovoltaic system with modified MPPT method and reactive power compensation," *IEEE Transactions on Energy Conversion,* vol. 22, pp. 881-886, 2007.