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LOADING BEHAVIOURAL ASPECTS ON DISTRIBUTION TRANSFORMER DUE TO PENETRATION OF ROOF-TOP SOLAR INTO DISTRIBUTION GRID

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ABSTRACT:

The efficiency of these systems relies upon determining the intensity of solar irradiation considering solar energy serves as both the foundation for the system and the main power source for numerous varieties of renewable energy systems. In the prior ten years, research has been concentrating on finding electric energy sources whose services can meet society's expanding demands while having little environmental effect and high effectiveness [1]. The existence of clouds in the sky, however, is the most unpredictable aspect that interferes with catching solar irradiation and prevents a good conversion of sunlight into power [1]. Numerous approaches to tracking and forecasting irradiation have been put forth for enhancing the effectiveness of photovoltaic cells ability to produce energy. The penetration level of solar photo voltaic generation (SPVG) must be boosted in order to satisfy the growing need for electricity [3]. It might compromise the system's stability and security, leading to problems with power quality, inadequate protection coordination, and reverse power flow, to name a few [3]. The study investigates how the PV model responds to various levels of solar irradiation as a result of environmental factors. Processing the measurements with a mathematical model of a photovoltaic cell in conjunction with a PI controller yields an estimate of the solar irradiation.

Key phrases- Solar PV, Solar irradiations, Voltage profile, Current profile, Boost converter, Environmental effects on Solar panel.

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1. INTRODUCTION

Research towards green energy sources can assist in sustaining the world's electricity supply as a way to overcome the difficulty of relying on fossil fuels [4]. Photovoltaic (PV) technology, which also provides an appealing method of power generation, serves the goals of green and sustainable energy [6]. For the purpose of to boost system efficiency, stability, and cost reduction, photovoltaic (PV) generators are connected to the power grid using an effective power electronic converter [4]. When contrasted to other techniques for electricity generation, solar PV delivers a variety of advantages; 1. Renewable power: Photovoltaic solar power (PV) systems generate electricity from the sun, a renewable energy source that does not consume natural resources in the same manner that fossil fuels do. 2. Clean power: Solar photovoltaic energy generation does not release dangerous contaminants or greenhouse emissions into the environment, reducing air pollution and enhancing public health. This is in contradiction to fossil fuel-based power generation. 3. Low running Cost: Compared to conventional power generation, solar PV offers a relatively low running cost since it does not need fuel or routine upkeep. 4. Scalable: From tiny residential systems to huge commercial and utility-scale projects, solar PV systems can be created to fulfil the unique energy needs of a variety of consumers. 5. Modular capacity: Solar PV is a versatile option for power generation due to the fact it is simple to set up and can be gradually increased. 6. Distributed generation is made accessible by the fact that solar PV may be mounted in small-scale systems. This enables power to be generated where it is required, eliminating the need for expensive transmission and distribution infrastructure. Numerous studies are still being done to maximise energy output and increase PV cell efficiency by reducing power losses and better utilising incident solar irradiation. The atmospheric conditions are one of the most crucial factors in the operation of PV systems since they have a significant impact on the efficiency and response of the entire system in terms of power quality.

2. TYPES OF PV SYSTEMS

The availability of storage systems serves in this chapter to distinguish between the PV systems. They can be broadly divided into three types [9]:

- **Grid Tied or Grid Direct PV system:**

There is no storage battery bank in the grid-tied solar PV system. Only during the daytime can power be generated and employed from a grid-tied system. This system is extremely cost effective, easy to construct, manage, and requires minimal maintenance [9]. Fig. 1 displays an architectural representation of the system. A significant portion instances, the solar panels convey more electricity than the loads realistically desire. Consequently, in lieu of storing the excess power in batteries, it can be reverted to the grid. Furthermore, selling the excess power the fact that the rooftop solar panels produce may rake in some additional revenue and diminished the system's levelized cost of energy. An inverter is essential for converting DC power concerning the PV panels into AC owing to the power they yield is in DC [9].

The grid-direct system's a downside is that it is accessible only during the day. Power cannot be stored for use at a subsequent date and time, specifically amid electricity outages. Despite the fact that this consolation can be overcome by using a battery bank to store the power emitted during the day, the system's cost will inevitably go up as a consequence of this new configuration [9].

- **Off Grid PV System :**

The standalone system is a further prevalent designation for the off-Grid PV system. For recipients who seek it challenging to connect their load to the grid, this system is advantageous. Batteries serve a purpose in independent photovoltaic (PV) installations to preserve the electricity generated during the day whose services can be used subsequently, at night, or for other purposes [9].

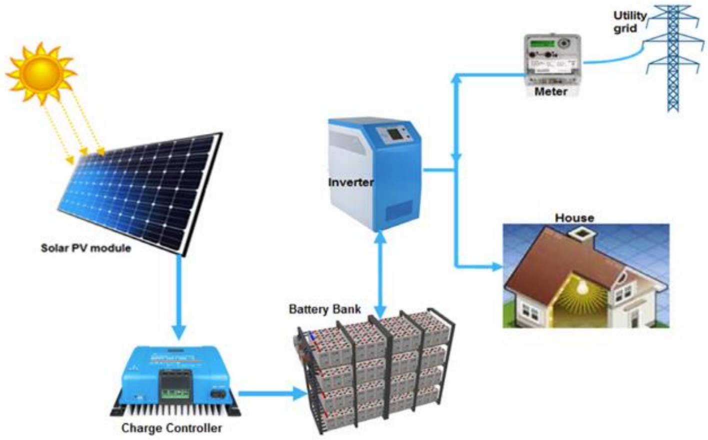

Figure 1. Standalone / Off-grid Solar PV system [9].

Weather fluctuations and year-round conditions must be considered notice of whilst expanding this system. Backup generators are vital if the sun isn't visible for numerous days in a row or if snow accumulates up on the PV panels. The generator can be driven throughout gasoline, diesel, petroleum, or propane. Backup generators' AC output can either be employed directly or converted to D.C. for retention in batteries. Fig. 4 illustrates an overview of the system [9]. The perceived advantage of this system is that it can power inaccessible areas while maintaining a household plenty ample electricity to run on. Off-grid systems are more complicated as well as expensive than grid-direct systems owing to the other aspects typically entail [9].

- **Grid / Hybrid – Interaction system with Energy Storage :**

Customers whose services want a battery backup and are already connected to the grid ought to pick this system. This system offers the perks of both an off-grid and a grid-direct manoeuvring [9]. via the implementation a variety of incentives, that strategy may aid with mitigating energy expenses. However, this grid system is not only used for certain massive operations incentive campaigns; during the possibility of a power outage, energy from the battery bank can be used. The batteries' stored energy can be executed at instances of peak demand [9].

3. IMPACT OF ROOF-TOP PV PREVALENCE ON DISTRIBUTION SYSTEM

A. Impact on voltage quality:

I. Power losses :

The parts that integrate the PV panel into the system, the usage of panels with various I&V characteristics in the same system, shadowing and pollution of the panel surfaces, and increased PV penetration level are all causes of power losses. Among the techniques used to reduce power losses in renewable energy systems, one option is to incorporate Distributed generation to the system, generation (DG). When DG is included in the system for renewable energy, it must be properly dimensioned and positioned. If not, it can cause the feeder to overload, which can cause power outages [10].

When DG is added to the renewable energy system, it must be correctly positioned and dimensioned. Otherwise, it may cause feeder to overload, which could result in power losses. Feeder current varies if the energy produced by the PV panels is returned to the network because it is greater than the net demand of the user. With high-level PV penetration, the network's feeder current can shift even more, which will increase power losses [10].

II.Reverse Power Flow :

Normally, high voltage power travels toward low voltage as it enters the electrical grid. Energy that is not used by the customer affects the direction of power flow by reversing the flow of electricity. Rooftop PV systems typically have direct connections to distribution networks. However, the storage devices help to lessen voltage rise and problems with reverse power flow. While the size of the storage devices places a limit on this reduction, it can still be greatly lowered with enough storage space [10].

III.Voltage Rise :

The biggest issue RPF creates is voltage rise. The voltage at the Point of Common Coupling (PCC) of the inverter and the grid rises when the amount of power produced by PV exceeds the consumer load. The best method to lessen the drawbacks of high PV level is to reduce the higher voltage in the network [10].

IV.Voltage Unbalance :

Rooftop PV system installation rates that are significantly higher than average might lead to grid difficulties like voltage imbalance. Voltage unbalance develops over time as a result of irregular PV panel layout, unknown current, and impedance brought on by an imbalance between net demand and net generation. Due to the consumer side's single phase, current imbalances are another reason generating voltage unbalance. To reduce this detrimental effect that leads to voltage unbalance in the network after the system has been implemented, power must be restricted [10].

V.Voltage Fluctuations :

Voltage fluctuation is the difference in voltage along the distribution line between the generation and consumption points. Voltage variations must fall within the permitted ranges because they only happen when the voltage at the PCC exceeds a specific threshold. The severity indices for both long- and short-period flicker set these boundaries. Indicators for this should not exceed 1 for the shortest time and 0.65 for the longest. Voltage fluctuations in renewable DG systems are often caused by bad weather or connection problems, which can lead to power quality problems [10].

4. DISTRIBUTION NETWORKS

A network of electrical components and devices termed an electrical distribution system conveys electrical energy via an energy source, such as a generator or utility company, to end user. System is made to furnish vitality to homes, buildings, manufactures, and other utilizes in an effective and secure manner. Transformers, controls, safety devices and meters often appear as part of an electrical distribution system. Together, these constituents manage and regulate how electrical power travels all over the system. First segment here depicts the side of generator where 33 KV is generated before being delivered forward to a step-down transformer. Following this, 33KV is stepped down to the 11KV stage, and the high-voltage (HV) consumers are connected across the 11KV feeder.

FIGURE 2. Flow Diagram of Distribution Network

Electrical secondary distribution is region of power distribution system that delivers electricity from primary distribution system to end-users, such as residences, buildings, and industries. Transformers, switchgear, and distribution lines tend to form part of secondary distribution system, which runs at lower voltages than primary system. To guarantee that end customers receive dependable and secure electrical power, secondary distribution system must be regulated and serviced. To find and fix possible challenges which may influence end users, equipment and components must undergo frequent checks, testing, and repairs. Distribution system's flow diagram demonstrates how it operates. It states that the substation's 33KV generation is stepped down to 11KV for primary distribution, and then 11KV is stepped down once more to 415V for secondary distribution.

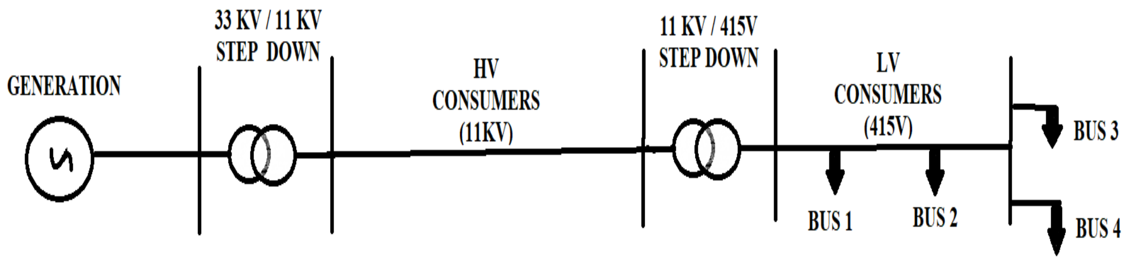

FIGURE 3. Electrical Distribution System

5. SIMULATION & RESULTS

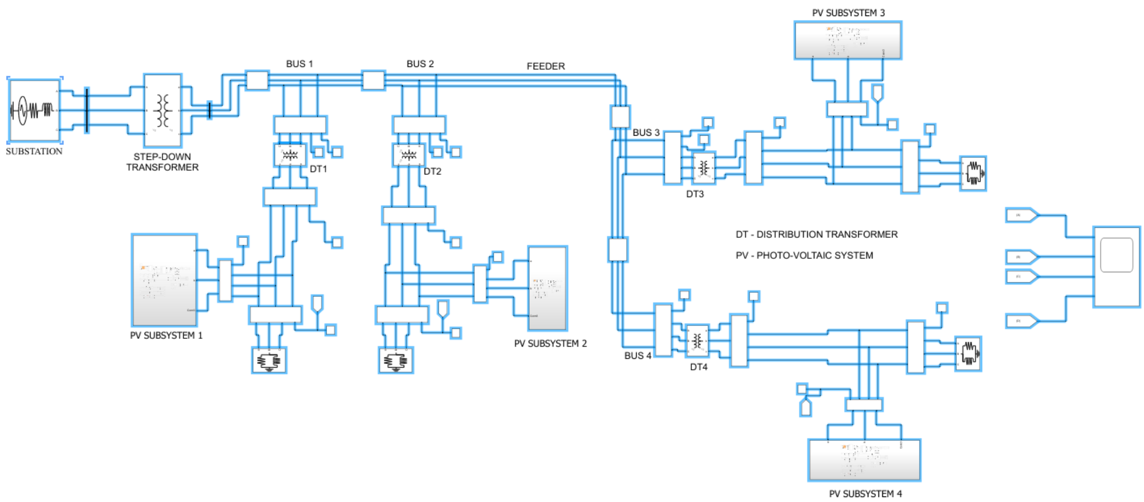

Figure 4. The Main Grid System

According to the Simulink model, the feeder receives power from a 33KV supply which is gradually stepped down to 11KV by a step-down transformer. Each of the four distribution transformers is independently linked to a separate feeder. Transformers provide the load to consumers linked to them via a secondary distribution network. The operating voltages will be 415V at the secondary distribution level, accordingly. The electricity generated by the rooftop solar PV will be sent back to the transformer since a number of secondary side clients have solar rooftop panels installed on their properties. The solar radiation received by the PV panels and the quantity of that energy delivered into the system between the transformer and the load determine how much power is pulled from the rooftop.

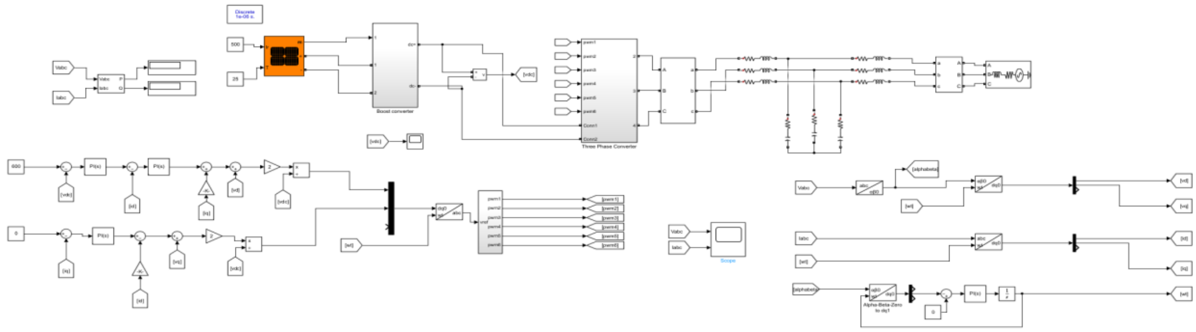

Figure 5. The PV Array Subsystem

One part of the total energy produced in the system comes from the rooftop solar PV system, shown above as a solar sub-system. The output of the PV system is highly influenced by irradiance level and the current temperature. The output of the PV subsystem increases with increasing irradiance, and decreases with decreasing irradiance levels. A boost converter is added in the system to increase the PV array's output voltages. A boost converter was added to the system to meet grid voltages because PV array generation is still below average. Utilizing a three-phase converter to convert the DC voltages from the boost converter into AC voltages, the renewable energy is then introduced into the grid.

In order to efficiently smooth the inverter current output and provide harmonic free current into the grid, an LCL filter is installed between the three-phase converter and the grid. The V_{abc} and I_{abc} blocks are used to monitor the PV sub-system's output, and the system-related scope may be used to view any future changes in output power.

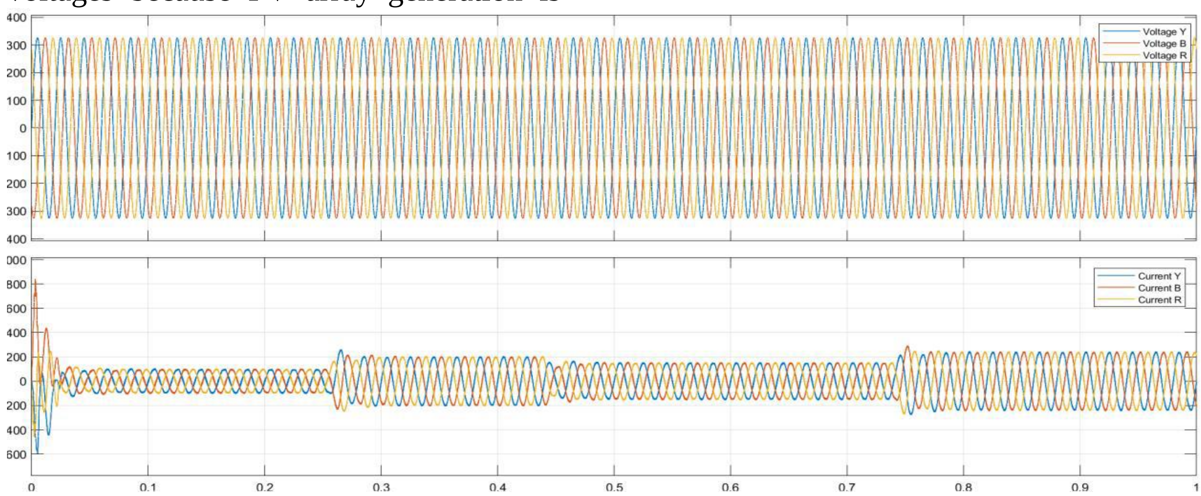

Figure 6. Variation in Solar PV Output current w.r.t. variation in Irradiance Level

The behaviour of solar PV in relation to changes in irradiance level is seen in the above image. Therefore, it can be said that it greatly depends on both the temperature and the amount of solar irradiance. When the solar irradiance changes from 500 to 1000, 1000 to 750, 750 to 250, etc., the output waveform's variance is seen to change accordingly.

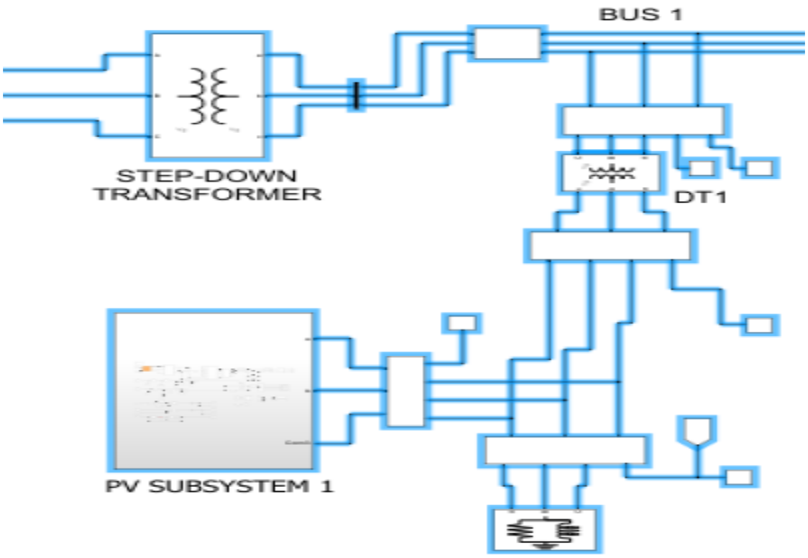

Figure 7. Penetration of Solar PV and Distribution Transformer

The distribution transformer that is connected to the grid and the penetration of solar PV are depicted in the above diagram. The amount of penetration as visible on the Distribution Transformer is observed to alter as the Solar Irradiance varies with the time of day, which might potentially cause some imbalance in the total grid voltage and current. The waveforms of the scopes linked across the Distribution Transformer show the variances as well.

When different PV subsystems integrated with different transformers have different outsources, distribution transformer output waveforms may change. Different environmental factors may have an impact on a solar PV array's capacity to penetrate a distribution transformer, which is referred to as "different penetration levels". This also sheds light on how transformers behave during monsoons due to the variations in PV penetration on the distribution transformers.

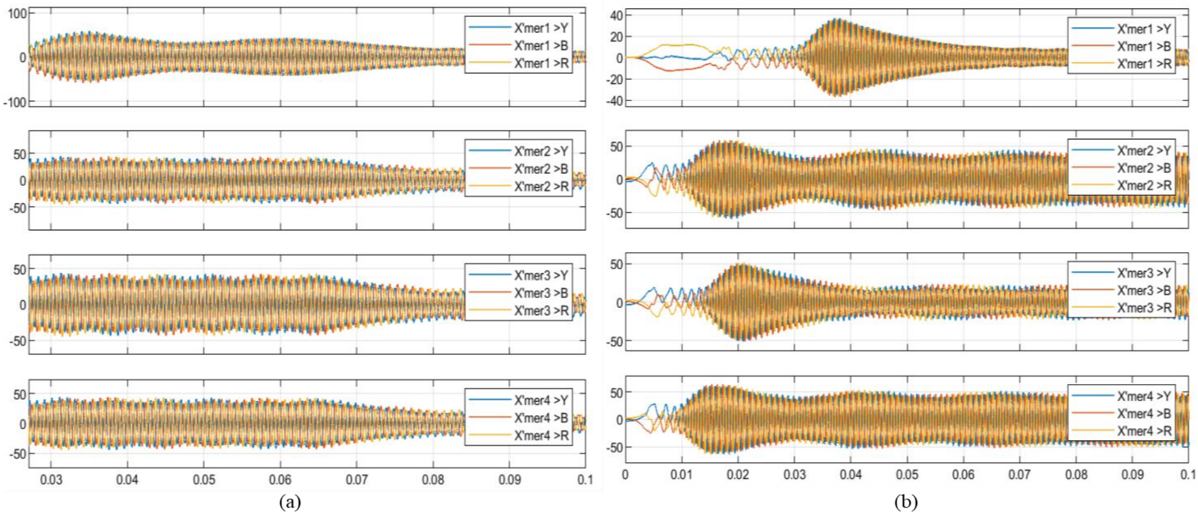

Figure 8. Variation in output of Distribution Transformer w.r.t. change in Penetration

The aforementioned waveforms show the changes that take place in the distribution transformer's waveform as a result of adjustments made to the PV subsystem's penetration levels. Figure (a) depicts how changing penetration levels affect all Grid DTs, whereas Figure (b) depicts how changing penetration levels affect specific Distribution Transformers.

6. CONCLUSION AND FUTURE SCOPE :

It can be concluded from the research that different levels of PV penetration on Distribution Transformer causes current and voltage of the transformer to change according to irradiance level of the solar rooftop. Rooftop power from the consumer side changes the voltage level on the transformer side with different penetration levels.

In future, this simulation can be carried out by MATLAB coding and in case of high penetrations of solar rooftop a battery bank system can be installed which charges during high penetration periods and behaves as a voltage source during the low penetration periods such as monsoons etc.

7. REFERENCES

1) Hermes José Loschi, Yuzo Iano, Julio León, Angelo Moretti, Fabrizzio Daibert Conte, Horácio Braga, "*A Review on Photovoltaic Systems: Mechanisms and Methods for Irradiation Tracking and Prediction*.," Smart Grid and Renewable Energy Vol.06 No.07(2015), Article ID:57965, 21 pages.

2) H. H. H. De Silva, D. K. J. S. Jayamaha, N. W. A. Lidula, "*Power Quality Issues Due to High Penetration of Rooftop Solar PV in Low Voltage Distribution Networks: A Case Study*," 2019 IEEE 14th International Conference on Industrial and Information Systems (ICIIS), 18-20 Dec., Peradeniya, Sri Lanka.

3) Sreena Sreekumar, Savier J. S, "*Estimation of maximum penetration level of Solar PV and its enhancement by STATCOM,"*2019 International Conference on Computing, Power and Communication Technologies (GUCON) Galgotias University, Greater Noida, UP, India. Sep 27-28, 2019.

4) Mohamed Abuagreb, Mohammed, Allehyani Brian K, "*Design and Test of a Combined PV and Battery System Under Multiple Load and Irradiation Conditions*.," 978-1-5386-8232-6/19/$31.00 ©2019. IEEE.

5) Lhoussain EI Bahir, Touria Hassboun, Youness Aite Driss, Mustapha EI Adnani, "*Estimator of local solar irradiation based on a PV model* ",1st International Conference on Electrical and Information Technologies ICEIT'2015.

6) Abayomi A. Adebiyi Innocent E. Davidson, "*Analysis of Solar Irradiation Impact on Grid-tied Photovoltaic Systems' Power Quality Characteristics*," 2023 SAUPEC Conference, Johannesburg, South Africa, January 24-26, 2023.

7) Vanika Sharma a, Syed Mahfuzul Aziz a , Mohammed H. Haque a , Travis Kauschke b, "*Effects of high solar photovoltaic penetration on distribution feeders and the economic impact* ", Renewable and Sustainable Energy Reviews 131 (2020) 110021.

8) Houman Pezeshki, Peter J. Wolfs, and Gerard Ledwich, "*Impact of High PV Penetration on Distribution Transformer Insulation Life*," IEEE TRANSACTIONS ON POWER

DELIVERY, VOL. 29, NO. 3, JUNE 2014.

9) Anshul Awasthi, Akash Kumar Shukla, Murali Manohar S.R., Chandrakant Dondariya, K.N. Shukla, Deepak Porwal, Geetam Richhariya, "*Review on sun tracking technology in solar PV system*", Energy Reports 6 (2020), pp. 392–405.

10) Busra Uzum, Ahmet Onen, Hany M. Hasanien and S. M. Muyeen*," Rooftop Solar PV Penetration Impacts on Distribution Network and Further Growth Factors—A Comprehensive Review*", Electronics 2021, 10, 55.

11) K.N. Nwaigwe, P. Mutabilwa, E. Dintwa, "*An overview of solar power (PV systems) integration into electricity grids*", Materials Science for Energy Technologies 2 (2019), pp. 629–633.

12) Mohit Bajaj, Amit Kumar Singh, "*Grid integrated renewable DG systems: A review of power quality challenges and state-of-the-art mitigation techniques*", Int J Energy Res., pp.1–44, 2019.'

13) G. Murali, Dr. A. Manivannan "*Analysis of Power Quality Problems in Solar Power Distribution System*," International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622, Vol. 3, Issue 2, March -April 2013, pp.799-805.

14) Om Prakash Mahela, Abdul Gafoor Shaik, Neeraj Gupta, Mahdi Khosravy, Baseem Khan, "*Recognition of Power Quality Issues Associated With Grid Integrated Solar Photovoltaic Plant in Experimental Framework*", IEEE SYSTEMS JOURNAL, VOL. 15, NO. 3, SEPTEMBER 2021.

15) Abhiram S, Ilango K, A. M. Narayanan, " *The Impacts of Rooftop Solar PV Systems on Secondary Distribution System and Advanced Net Metering*", 3rd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT-2018), MAY 18th & 19th 2018.

16) Eklas Hossain, Ron Perez, Adel Nasiri, Sanjeevikumar Padmanaban," *A Comprehensive Review on Constant Power Loads Compensation Techniques*;" Preparation of Papers for IEEE Access (February 2017).

17) Bazilah Ismail, Noor Izzri Abdul Wahab, Mohammad Lutfi Othman, Mohd Amran Mohd Radzi, Kanendra Naidu Vijaykumar, Muhammad Najwan Mat Naain," *A Comprehensive Review on Optimal Location and Sizing of Reactive Power Compensation Using Hybrid-Based Approaches for Power Loss Reduction, Voltage Stability Improvement, Voltage Profile Enhancement and Loadability Enhancement*," VOLUME 8, 2020.

18) K.N. Nwaigwe, P. Mutabilwa, E. Dintwa, "*An overview of solar power (PV systems) integration into electricity grids*," Materials Science for Energy Technologies 2 (2019), pp. 629–633.

19) A. Kharrazi a, V. Sreeram, Y. Mishra, "*Assessment techniques of the impact of grid-tied rooftop photovoltaic generation on the power quality of low voltage distribution network - A review*", Renewable and Sustainable Energy Reviews 120 (2020) 109643.

20) Patrick Taiwo Ogunboyo, , Remy Tiako, Innocent E. Davidson," *Effectiveness of Dynamic Voltage Restorer for Unbalance Voltage Mitigation and Voltage Profile*

Improvement in Secondary Distribution System," CANADIAN JOURNAL OF ELECTRICAL AND COMPUTER ENGINEERING, VOL. 41, NO. 2, SPRING 2018.

21) Vanika Sharma, Syed Mahfuzul Aziz, Mohammed H. Haque, Travis Kauschke, *"Effects of high solar photovoltaic penetration on distribution feeders and the economic impact"*, Renewable and Sustainable Energy Reviews 131 (2020) 110021.

22) Houman Pezeshki, Peter J. Wolfs, Gerard Ledwich, *" Impact of High PV Penetration on Distribution Transformer Insulation Life"*, IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 29, NO. 3, JUNE 2014.

23) Kamel A. Alboaouh and Salman Mohagheghi, "*Impact of Rooftop Photovoltaics on the Distribution System*", Journal of Renewable Energy Volume 2020.

24) Wilson Sánchez, Nelson Granda, Franklin Quilumba, "*Methodology for Assessment and Improvement of Long-Term Voltage Stability of Electric Power Systems*", IEEE Fourth Ecuador Technical Chapters Meeting (ETCM), 2019.

25) Fahad Iqbal, Mohd Tauseef Khan, Anwar Shahzad Siddiqui, "*Optimal placement of DG and DSTATCOM for loss reduction and voltage profile improvement"*, Alexandria Engineering Journal (2018) 57, 755–765.

26) D. Chathurangi, U. Jayatunga, M. Rathnayake, A. Wickramasinghe, A. Agalgaonkar, S. Perera,*"Potential Power Quality Impacts on LV Distribution Networks With High Penetration Levels of Solar PV"*.

27) Ali Kharrazi, Victor Sreeram, Yateendra Mishra," *Assessment of Voltage Unbalance Due to single phase Rooftop Photovoltaic Panels in Residential Low Voltage Distribution Network"*, A Study on a Real LV Network in Western Australia.

28) Hermes José Loschi, Yuzo Iano, Julio León, Angelo Moretti, Fabrizzio Daibert Conte, Horácio Braga, '*A Review on Photovoltaic Systems: Mechanisms and Methods for Irradiation Tracking and Prediction'*, Smart Grid and Renewable EnergyVol.06 No.07(2015), Article ID:57965,21 pages.

29) A. Jäger-Waldau, "*Research, solar cell production and market implementation of photovoltaics*," European Commission Joint Research Centre Institute for Energy, July 2011.

30) T. Degner, G. Arnold, T. Reimann, B. Engel, M. Breede, and P. Strauss, *"Increasing the photovoltaic system hosting capacity of low voltage distribution networks* " 21st International Conference on Electricity Distribution. Frankfurt, 6-9 June 2011, paper 1243.

31) T. Degner, G. Arnold, T. Reimann, B. Engel, M. Breede, and P. Strauss, *"Increasing the photovoltaic system hosting capacity of low voltage distribution networks* " 21st International Conference on Electricity Distribution. Frankfurt, 6-9 June 2011, paper 1243

32) F. Almonacid, C. Rus, P. Perez, and L. Hontoria, *"Estimation of the energy of a PV generator using artificial neural network,"* Renewable Energy 2009, vol. 34, pp. 2743-2750

33) G. Makrides, B. Zinsser, M. Norton, G. Georghiou, M. Schubert, and J. Werner, *"Potential of photovoltaic systems in countries with high solar irradiation,"* Renewable and Sustainable Energy Reviews 2010, vol. 14, pp. 754-762.

34) Y. Feng, P. J. Tavner, H. Long, and J. W. Bialek, *"Review of early operation of UK Round 1 offshore wind farms,"* in Power and Energy Society General Meeting, 2010 IEEE, pp. 1-8

35) J. Hernandez, A. Medina, and F. Jurado, *"Impact comparison of PV system integration into rural and urban feeders,"* Energy Conversion and Management. 2008, Vol. 49, pp.1747-1765

36) C. Barbier, A. Maloyd, and G. Putrus, *"Embedded Controller for LV Network with Distributed Generation,"* DTI project, URN number: 07/921. Contract number: K/EL/00334/00/00, UK, 2007.

37) T. Yun and D. Kirschen, *"Impact on the Power System of a Large Penetration of Photovoltaic Generation,"* Power Engineering Society General Meeting, 2007. IEEE, pp.1-8.

38) S. Ali, N. Pearsall and G. Putrus, '*Impact of High Penetration Level of Grid-Connected Photovoltaic Systems on the UK Low Voltage Distribution Network',* RE&PQJ, Vol.1, No.10, April 2012.

39) M. Karimi a , H. Mokhlis a,b,n , K. Naidu a , S. Uddin c , A.H.A. Bakar b, *'Photovoltaic penetration issues and impacts in distribution network – A review',* M. Karimi et al. / Renewable and Sustainable Energy Reviews 53 (2016) 594–605.

40) B. Belcher, B.J. Petry, T. Davis, K. Hatipoglu, '*The effects of major solar integration on a 21-Bus system*': technology review and PSAT simulations, Conf. Proc. - IEEE SOUTHEASTCON (2017)