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A STATCOM with a Fuzzy Controller Improves Voltage Stability in a Microgrid-Connected PV System

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Abstract

The Modern distributed power systems incorporate renewable energy sources, which may be used to meet energy demands. Therefore, microgrid-connected renewable energy systems will satisfy grid demand and lower carbon emissions, which will reduce global warming. In this study, a solar photovoltaic (PV) system for grid-connected applications is proposed. The new microgrid codes address many power quality concerns such as harmonics, transients, voltage fluctuations, flicker, voltage stability, and reliability when PV systems are linked with the grid. Voltage dips, imbalanced voltage, and negative sequence voltage are the primary sources of power quality difficulties in the grid. Disturbances in the grid, such as frequency changes, voltage sag, swell, and especially failures, have an impact on the performance of PV. The increase in the use of solar photovoltaics will have a substantial impact on the Indian electricity system. The primary goal of this research is to evaluate the performance of a microgrid-connected PV system employing STATCOM that employs dynamic reactive power compensation & voltage stability. A STATCOM can improve the quality and stability of the voltage by reducing the sag and swell in a PV system that is linked to the grid. This study uses a STATCOM to investigate balanced and unbalanced voltage sags and swells in a microgrid-connected PV system. A STATCOM is recommended to adjust for both positive and negative voltage sequences in order to improve voltage stability and quality.

Keywords- Microgrid; STATCOM; Voltage Stability; Power Quality; Fuzzy controller; Voltage Sag and Voltage Swell.

1. Introduction

The advantages of renewable energy, particularly solar power generation, have drawn attention from all over the world in response to the deterioration of the global environment. Pollution-free, simple, and environmentally friendly installation [1]. Large-scale grid-connected PV is expected to overtake other photovoltaic power production technologies in the next years, according to the progressive expansion of solar power producing distributed generation systems from the island to the integrated grid [2]. A converter connects solar power generation equipment to a low voltage distribution network, allowing load electricity to be delivered [3]. It is capable of supplying power to neighbouring local loads at higher light intensities. Local loads are supplied by the power supply when the light intensity is low. A large number of non-resistive loads connected to a power grid may result in voltage distortion at the end of the power grid, three-phase imbalance, reactive power, as well as undesirable distribution network conditions [4]. Changes in the power grid and load, advanced electronic gadgets, and fresh problems related to the use of power electronics technology all play a role. The conventional approach to reactive power compensation uses a STATCOM-style device to fix reactive power, which necessitates extra power equipment expenditure to increase the voltage stability of the grid's terminals [5]. The study's conclusions show that a solar inverter and d-STATCOM have fundamental architectures that are entirely compatible, allowing for the installation of a photovoltaic power generation system in the distribution system of terminals that deliver reactive power.

Due to an increase in sensitive loads, power quality is presently viewed as a serious problem in the industrial sectors. Power quality concerns, in general, have a considerable influence on the distribution side, causing sensitive loads to malfunction and fail. Nonlinear loads and harmonic imbalances are the main causes of power quality issues. The primary power quality concerns that have a substantial detrimental impact on the power distribution system include voltage sag/swell, harmonic distortions, spikes and surges, and transient interruptions [6]. It uses an innovative strategy to deal with the voltage sag problem, however the power quality problem is not entirely handled because it only accounts for some of the sag. STATCOM, an outstanding FACTS device, is employed in this study to improve power quality and voltage stability by increasing sag/swell control, dynamic voltage control, real and reactive power regulation, and so on [7], [8]. As a consequence of advanced technology, the power generation and distribution networks are undergoing significant changes, including the adoption of large-scale distributed renewable producing, enhanced communication and control methods, and increased storage capacity. Solar PV dependent energy producing systems are extensively utilized for the generation of electricity by various renewable resources because to their static design, compact size, and low maintenance needs [9]. Due to the intermittent nature of solar PV output, energy storage systems & other renewable energy sources are linked with PV systems to offer dependable operation. This is done by parallelizing the DC-DC converters and PV panel [10], [11]. A DC-DC converter is required between the inverter and the PV panel to avoid connecting several PV panels in series. This converter is required for the PV system's power generation process in order to ensure electrical isolation.

The Static Synchronous Compensator (STATCOM), a highly developed FACTS regulating device that operates independently of other system components, is one of the many FACTS family devices. The flow of reactive power across the system may be controlled using FACTs. STATCOM switches the instantaneous reactive power across phases to supply reactive power [12], [13]. Within the power system, the STATCOM's primary duties include controlling fundamental reactive power exchange and giving buses voltage support. Bus voltages are modified during dynamic disturbances to enhance transient characteristics, expand transient stability margins, and decrease system fluctuations brought on by these disturbances [14].

2. Statcom System Outline

Reactive power can be supplied or absorbed by the Static Synchronous Compensator (STATCOM), a parallel-connected reactive compensation system. Its output can be altered to maintain control of various electrical power system characteristics. STATCOM performs similarly to a spinning synchronous compensator in the absence of mechanical inertia [15]. The three phase voltages in the STATCOM system may be quickly controlled in terms of amplitude and phase angle thanks to the solid-state power switching components. A three-phase IGBT or GTO, Voltage Source Inverter (VSI), DC capacitor, and step-down transformer with leaky reactance make up the majority of the STATCOM [16], [17]. The AC potential difference across the leaky reactance provides reactive power exchange among the power system and the STATCOM, enabling STATCOM to regulate the AC voltage at the bus bar and improve the voltage profile of the power system.

In order to increase transmittable power while also strengthening steady-state transmission characteristics and system stability, a power system's voltage can be controlled via STATCOM. The controller lowers or eliminates line overvoltage when there is a light load; nevertheless, when there is a strong load, STATCOM is employed to maintain precise voltage levels.

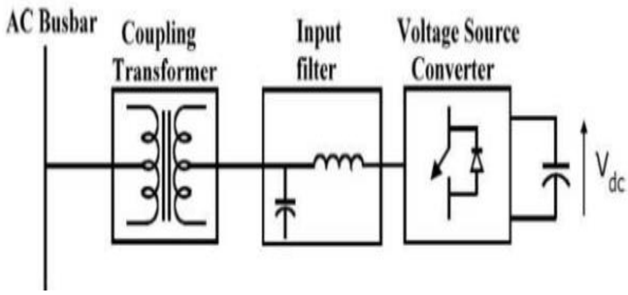

Figure 1. STATCOM & AC-bus bar Connection

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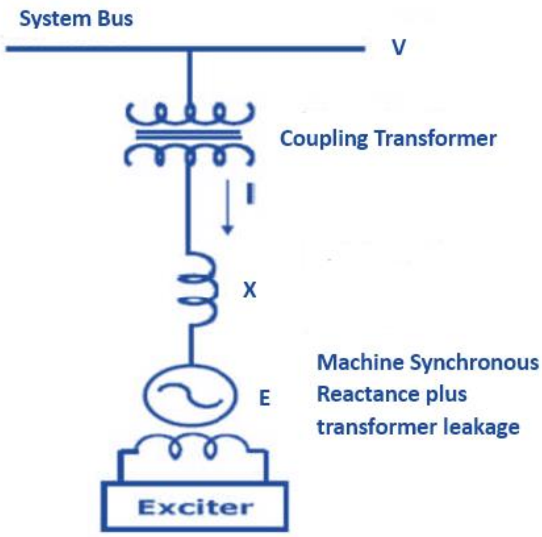

Figure 2. STATCOM and AC bus bar Connection

The input filter, coupling transformer, controller, and voltage source converter make up STATCOM. In Figure 1, the STATCOM connection to the AC bus is depicted. When two AC sources with the same frequency are wired in series, the active power moves from the leading source to the trailing source, while the reactive power moves from the leading source to the lower voltage source. Active power flow is determined by the phase angle difference between the two sources, whereas reactive power flow is determined by the voltage amplitude difference between the two sources

The inner current controllers & voltage controller of a rotating dq reference frame with grid voltage orientation in STATCOM define a proportional-integral (PI) controller. Equation for the fuzzy PI controller is

A PI controller was used by Dannehl et al. (2009) to construct the inner current loop in STATCOM for both negative and positive sequence current. Based on the power rating, the voltage source converter level configuration for the STATCOM is selected. Two-level voltage source converters are utilized for low power applications, whereas multi-level topologies are used for high power applications.

3. Integration of Statcom with PV System

An LC filter, a STATCOM connected to the grid, and a PV power supply make up the recommended system. PV panels, the MPPT algorithm, a DC-DC buck-boost converter, a three-phase inverter with a filter, and the PV power system are the components of the PV power system. In reaction to changes in irradiance, a PV panel's output voltage changes. DC-DC converters equipped with MPPT technology create consistent DC voltage. When output filters are used with three-phase inverters, they provide pure sinusoidal output when converting regulated DC current into three-phase AC. The PV sinusoidal voltage is linked to the grid after the transformer. STATCOM is currently linked via the LCL filter at this time. PV systems only increase the utility grid's active power, which might change the system's reactive power flow. Higher voltages on nearby buses might result from a lack of reactive power. The utility and consumer sides of the PV system's functioning may be negatively impacted by the over-voltage it generates. To regulate the voltage in a PV grid-connected system, STATCOM must be included. STATCOM also regulates voltage flickers and undesirable voltage variations brought on by over- and under-loading. The imbalanced kind of grid faults predominates

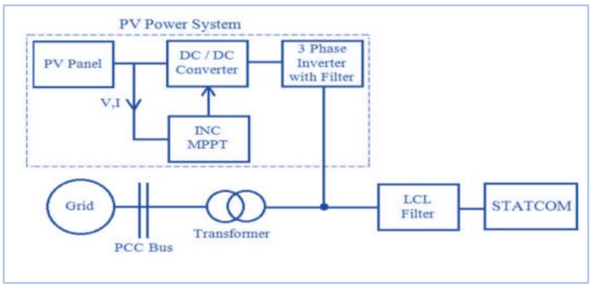

Figure 3. Block representation of the suggested system

4. Results & Discussions

4.1 A STATCOM simulation analysis for a grid connected type PV system

The system under investigation is a 1MW PV power system connected to the grid. The STATCOM is located close to the grid & the PV system. The STATCOM is modelled as controlled voltage sources. The same low voltage bus, which connects both devices, is attached to the medium voltage bus by a transformer. Through a second transformer, the high voltage level is linked to the medium voltage level. The STATCOM and PV systems' total output is what both transformers are rated for, and they each have a series impedance of 5% as well as 10% The high voltage level of the grid is thought to be where the problem with the grid is.

4.2 Integration of STATCOM with PV-System

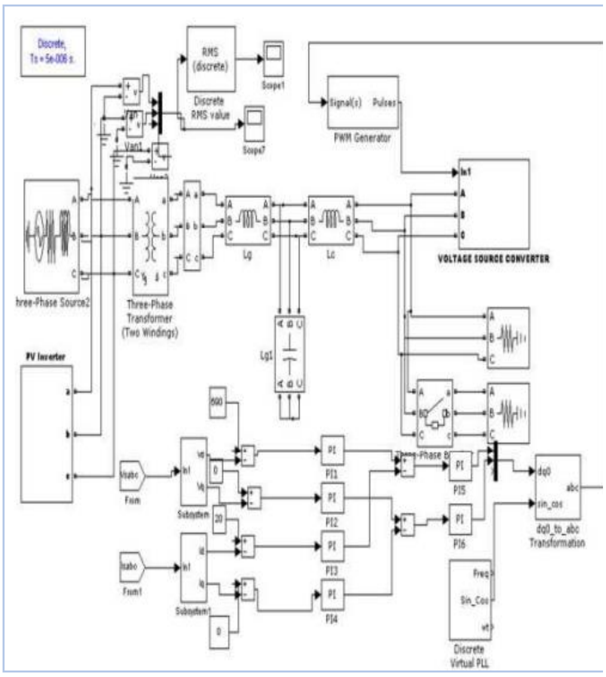

Figure 4. Block representation of the suggested system.

MATLAB and Simulink are used to simulate the complete system. Analysis of the PV system's performance using STATCOM is done with various balanced and unbalanced loads on the grid. Grid voltage will sag and swell when there are abrupt variations in the load on the system. Figure 3 depicts the system's simulation model using PI

4.3 Sag Control:

Voltage and current control in this model are handled by fuzzy based- PI controllers. The initial load balance causes the system to droop. Figure 5 depicts the three phases of the sag brought on by an abrupt increase in load.

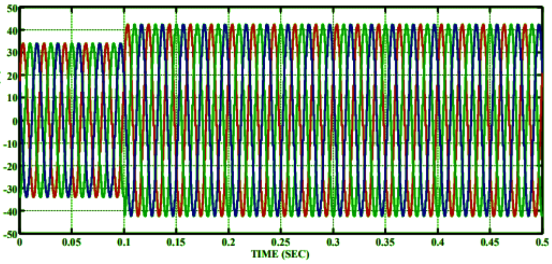

Figure 5 a). Grid Current with a 28% variation in load

Figure 5 (c) illustrates how well STATCOM adjusts for voltage sag, and it can be seen from this that it does so without causing a change in frequency. Figure 5(d) and (e) illustrate STATCOM's performance in the aspect of frequency for the identical 28 % sag scenario.

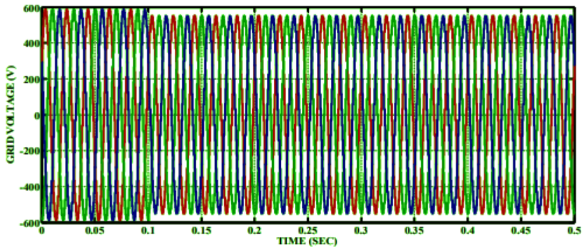

Figure 5 b). Uncompensated grid voltage by a 28% load variation

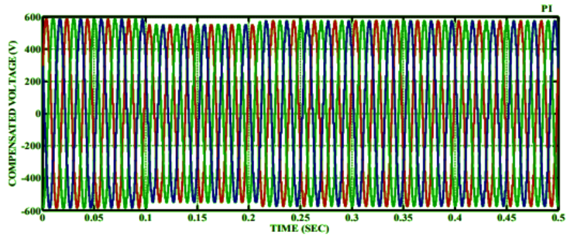

Figure 5 c). Sag corrected grid voltage by 28% load variation

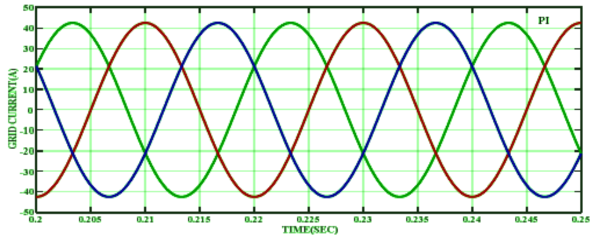

Figure 5 d). Grid Current two cycles with a 28% load change

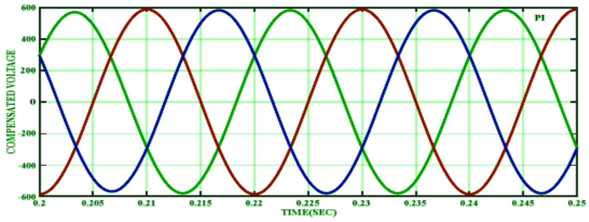

Figure 5 e). grid voltage was reduced by 28% throughout two cycles of sag compensation

4.4 Swell Control

Swell control is also used to examine the system. Voltage increases as a result of the quick decrease in load. 28% of the load is lowered at 0.1 seconds for the analysis. Grid current and its impact on grid voltage are depicted in Figure 6.

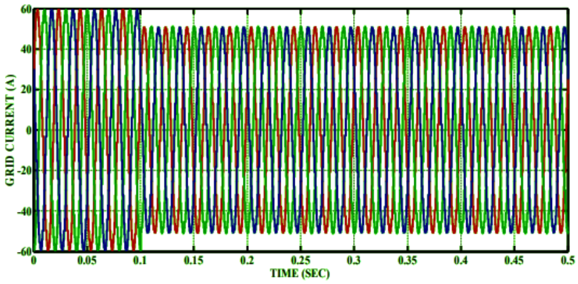

Figure 6 a). 28% load variation in grid current

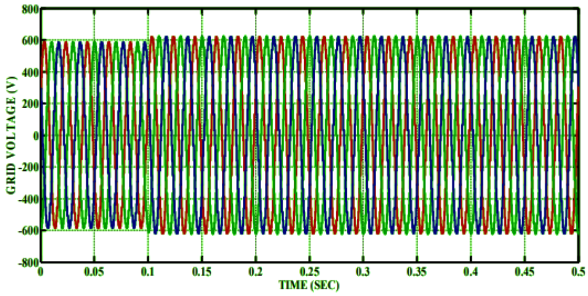

Figure 6 b). uncompensated 28% load variation in the grid voltage

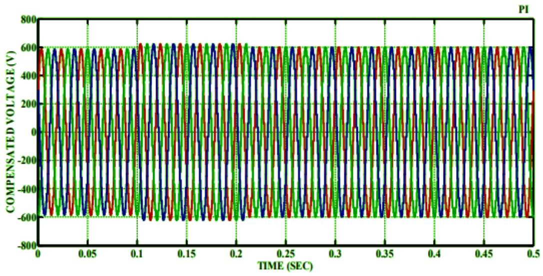

Figure 6 c). Swell compensated grid voltage by 28% load change

Figure 6 (d) and (e) depict STATCOM's performance in the aspect of frequency under the identical 28% swell situation.

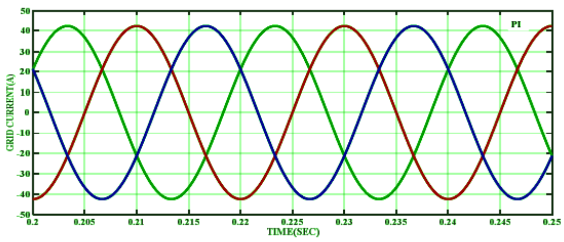

Figure 6 d). Grid Current with a 28% load change over two cycles results in swelling.

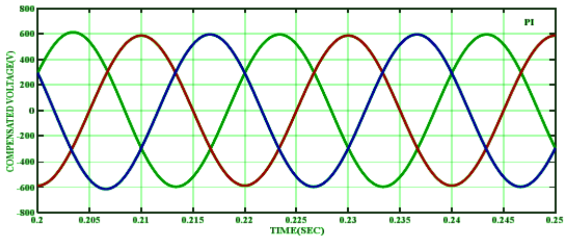

Figure 6 e). Swell compensated the grid voltage two cycles by a 28% load change.

Figures 5 a and 5 b demonstrate how a quick shift in grid current generates changes in voltage such as sag and swell. When the load changes without STATCOM, the voltage fluctuates, resulting in lower-quality electricity. It can be seen from figures 5 (d) and (e) and 6 (d) and (e) that the frequency of the grid's voltage and current is kept constant. By compensating for voltage sags and swells, STATCOM enhances power quality. It is clear from this investigation that the effectiveness of voltage stability and reactive power correction depends on the voltage controller employed.

5. Conclusion

The primary goal of the research project was to provide techniques for fuzzy logic controller implementation for PV STATCOM and to offer a control strategy for enhanced improvement of voltage stability. The introductory portion included a brief overview of the modulation technique and controller that could be analysed from the literature. When the load changes without STATCOM, the voltage fluctuates, resulting in lower-quality electricity. The STATCOM is used in this work to analyse balanced and unbalanced voltage sags and swells in a microgrid-connected PV system. It is suggested to utilize a STATCOM that takes into account both the advantageous adverse sequences of voltage in order to boost the voltage's stability and quality. The simulation findings demonstrate that the STATCOM effectively corrects for voltage variations and maintains the grid system's power quality.

References

[1] A. Luo, C. Tang, Z. Shuai, J. Tang, X. Y. Xu, and D. Chen, "Fuzzy-PI-based direct-output-voltage control strategy for the STATCOM used in utility distribution systems," *IEEE Transactions on Industrial Electronics*, vol. 56, no. 7, pp. 2401–2411, 2009, doi: 10.1109/TIE.2009.2021172.

[2] E. S. Percis, A. Nalini, S. T. Rama, S. Bhuvaneswari, J. Jayarajan, and T. Jenish, "Reactive Power Compensation Using Fuzzy Logic Controlled UPFC in a Hybrid Microgrid," in *2019 Second International Conference on Advanced Computational and Communication Paradigms (ICACCP)*, IEEE, Feb. 2019, pp. 1–5. doi: 10.1109/ICACCP.2019.8882998.

[3] A. Q. Al-Shetwi, M. A. Hannan, K. P. Jern, M. Mansur, and T. M. I. Mahlia, "Grid-connected renewable energy sources: Review of the recent integration requirements and control methods," *J Clean Prod*, vol. 253, p. 119831, Apr. 2020, doi: 10.1016/j.jclepro.2019.119831.

[4] H. Li, I. Member, and Y. Huang, "Reactive Power Compensation and DC link Voltage Control using

Fuzzy-PIon Grid-connected PV System with d-STATCOM.”

[5] A. Iqbal *et al.*, “Stability assessment and performance analysis of new controller for power quality conditioning in microgrids,” *International Transactions on Electrical Energy Systems*, vol. 31, no. 6, Jun. 2021, doi: 10.1002/2050-7038.12891.

[6] R. V and M. Ebenezer, “Power Quality Enhancement Techniques in Microgrid-A Review,” in *2023 International Conference on Control, Communication and Computing (ICCC)*, IEEE, May 2023, pp. 1–7. doi: 10.1109/ICCC57789.2023.10165147.

[7] A. Oymak, M. R. Tur, and E. Hossain, “Modeling of STATCOM Connected System to Microgrid,” in *2022 Global Energy Conference (GEC)*, IEEE, Oct. 2022, pp. 202–207. doi: 10.1109/GEC55014.2022.9986624.

[8] N. Hosseinzadeh, A. Aziz, A. Mahmud, A. Gargoom, and M. Rabbani, “Voltage Stability of Power Systems with Renewable-Energy Inverter-Based Generators: A Review,” *Electronics (Basel)*, vol. 10, no. 2, p. 115, Jan. 2021, doi: 10.3390/electronics10020115.

[9] A. M. Mohammed, S. N. H. Alalwan, A. Taşcıkaraoğlu, and J. P. S. Catalão, “Sliding mode-based control of an electric vehicle fast charging station in a DC microgrid,” *Sustainable Energy, Grids and Networks*, vol. 32, p. 100820, Dec. 2022, doi: 10.1016/j.segan.2022.100820.

[10] M. T. L. Gayatri, Alivelu. M. Parimi, and A. V. Pavan Kumar, “A review of reactive power compensation techniques in microgrids,” *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 1030–1036, Jan. 2018, doi: 10.1016/j.rser.2017.08.006.

[11] K. Zhou, X. Qiu, Y. Song, Q. Jin, and Z. Mo, “Research on Coordinated DC voltage Control Strategy of DC Microgrid based on Photovoltaic Power Generation System,” *J Phys Conf Ser*, vol. 2246, no. 1, p. 012066, Apr. 2022, doi: 10.1088/1742-6596/2246/1/012066.

[12] F. H. Gandoman, A. M. Sharaf, S. H. E. Abdel Aleem, and F. Jurado, “Distributed FACTS stabilization scheme for efficient utilization of distributed wind energy systems,” *International Transactions on Electrical Energy Systems*, vol. 27, no. 11, p. e2391, Nov. 2017, doi: 10.1002/etep.2391.

[13] H. A. Gabbar and A. A. Abdelsalam, “Microgrid energy management in grid-connected and islanding modes based on SVC,” *Energy Convers Manag*, vol. 86, pp. 964–972, Oct. 2014, doi: 10.1016/j.enconman.2014.06.070.

[14] F. H. M. Rafi, M. J. Hossain, D. Leskarac, and J. Lu, “Reactive power management of a AC/DC microgrid system using a smart PV inverter,” in *2015 IEEE Power & Energy Society General Meeting*, IEEE, Jul. 2015, pp. 1–5. doi: 10.1109/PESGM.2015.7286080.

[15] K. Al-Haddad, R. Saha, A. Chandra, and B. Singh, “Static synchronous compensators (STATCOM): a review,” *IET Power Electronics*, vol. 2, no. 4, pp. 297–324, Jul. 2009, doi: 10.1049/iet-pel.2008.0034.

[16] L. E. Christian, L. M. Putranto, and S. P. Hadi, “Design of Microgrid with Distribution Static Synchronous Compensator (D-STATCOM) for Regulating the Voltage Fluctuation,” in *2019 IEEE 7th International Conference on Smart Energy Grid Engineering (SEGE)*, IEEE, Aug. 2019, pp. 48–52. doi: 10.1109/SEGE.2019.8859860.

[17] M. R. Zaidan and S. I. Toos, “Optimal Location of Static Var Compensator to Regulate Voltage in Power System,” *IETE J Res*, vol. 69, no. 4, pp. 2177–2185, May 2023, doi: 10.1080/03772063.2021.1886877.