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VOLTAGE FLICKER MITIGATION USING GTO-BASED STATCOM TO IMPROVE POWER QUALITY OF A MULTI MACHINE SYSTEM

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Abstract- **Transmission networks of modern power systems are becoming increasingly stressed because of growing demand and restrictions on building new lines. One of the consequences of such a stressed system is the threat of losing stability following a disturbance. Flexible ac transmission system (FACTS) devices are found to be very effective in a transmission network for better utilization of its existing facilities without sacrificing the desired stability margin. FACTS such as Static Synchronous Compensator (STATCOM), employ the latest technology of power electronic switching devices in electric power transmission systems to control voltage and power flow. The STATCOM adjusts voltage at its terminal by managing the amount of reactive power injected into or absorbed from the power supply. When the system voltage is low, STATCOM creates reactive power; when the system voltage is high, STATCOM absorbs reactive power. In this paper STATCOM controllers are designed for improving transient stability of multi machine systems. Proposed controllers are implemented under MATLAB/SIMULNK environment. Results of PI based controllers installed with multi machine system is found to be better on comparison with conventional system.**

Keywords: **Automatic voltage control, Capacitors, FACTS devices, multilevel converter, Power quality, power system stability, Reactive power, STATCOM, voltage source converter, GTO based**

I. INTRODUCTION

Modern electric power system is facing many challenges due to day by day increasing complexity in their operation and structure. In the recent past, one of the problems that got wide attention is the power system instability. With the lack of new generation and transmission facilities and over exploitation of the existing facilities geared by increase in load demand make these types of problems more imminent in modern power systems. Demand of electrical power is continuously rising at a very high rate due to rapid industrial development.

To meet this demand, it is essential to raise the transmitted power along with the existing transmission facilities. So, the requirement for power flow regulation in electrical power systems is obvious. With increased transmission line loads, the problem of transient stability following a catastrophic failure might become a transmission power limiting factor. The power system should be adaptable to changing system circumstances; in other words, it should be flexible. In an ac power system, the electrical generation and load must balance at all times up to some extent, the power system is self-regulating. When the generation is less than the load, the voltage and frequency fall, and the load falls to match the generation minus transmission losses. But there are only a few percent margins for such a self-regulation. Hence there is chance of system collapse. Generator excitation controller with only excitation control can improve transient stability for minor faults but it is not sufficient to maintain stability of system for large faults occur near to generator terminals. Thus, this requires a review of traditional methods and the creation of new concepts that emphasize a more efficient use of already existing power system resources without reduction in system stability and security.

II. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

Direct current always has one polarity in a current source converter, and power reversal occurs through reversal of dc voltage polarity in a voltage source converter, whereas dc voltage always has one polarity in a voltage source converter, and power reversal occurs through reversal of dc current polarity. The power semiconductor devices used in current source converters require bidirectional voltage blocking capability, and in order to achieve this, an additional diode must be connected in series with a semiconductor switch, increasing the system cost and making it more expensive than voltage source converters. In high power applications, voltage source converters can function more efficiently.

Because of the above reasons Voltage source converter is Preferred over Current source converter and now these days it act as a basic electronic block of a STATCOM that converts a dc voltage at its input terminals into a three-phase set of ac voltages at fundamental frequency with controllable magnitude and phase angle.

In STATCOM different technologies used dependent upon the power ratings of STATCOM. For higher power STATCOMs GTO based technologies are used while for lower power STATCOMs IGBT based technologies used.

III. METHODOLOGY: MODELLING OF STATCOM

III.I Modelling of Self Excited Induction generator (SEIG)

In the present section a mathematical modelling of SEIG is done for the purpose of analyzing its performance. This task is achieved with the help generalized theory of machine concept.

Clark's Transformation

This transformation is named after the Edith Clarke, an Electrical engineer. According to him any time domain signal can be transformed from a 3-phase system (i_a, i_b, i_c) into balanced 2-phase (i_α, i_β) system, as shown in figure 1:

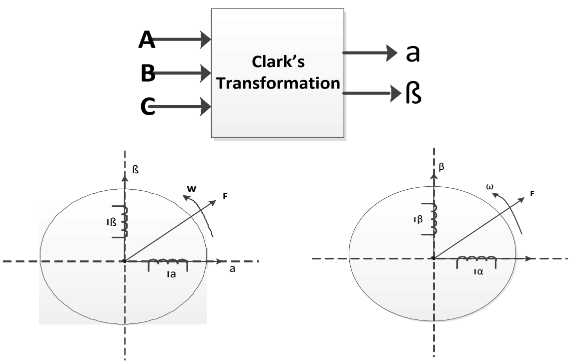

Fig 1 Clark's Transformation

When balanced 3-phase fixed windings and 2-phase symmetry windings bring rotating magnetic field Φ value and speed to equality, the 3-phase windings equivalent with 2-phase windings and the condition of the power invariance is also satisfied by the respective transformation. In order for the transformation to be invertible, a third variable, known as the zero-sequence component, is added. The resulting transformation is:

$$[f_{\alpha\beta o}] = C_T[f_{abc}] \quad \text{... (1)}$$

Where f represents voltage, current, flux linkages or electric charge, C_T is transformation matrix given as:

$$[C_T] = \frac{2}{3}\begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad \text{.... (2)}$$

The transformed voltage equation can be given as below:

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_o \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} \quad \text{.... (3)}$$

Applying Matrix Multiplication, below equations is obtained:

$$V_\alpha = \frac{2}{3} * V_A - \frac{1}{3} * (V_A - V_C) \quad \text{.... (4)}$$

$$V_\beta = \frac{2}{3} * (V_B - V_C) \quad \text{.... (5)}$$

$$V_o = \frac{2}{3} * (V_A + V_B + V_C) \quad \text{.... (6)}$$

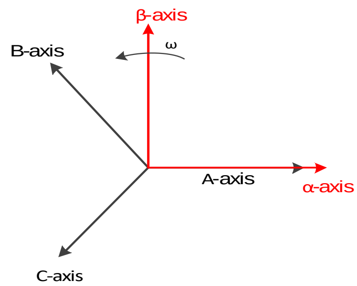

Fig 2 (a-b-c) to (Alpha-Beta) transformation portrayed by trigonometric relation

SEIG Model

The per unit flux-linkages for the stator and rotor circuits of the induction generator described in d- and q- axes are as follows:

$$\dot{\phi}_{ds} = \omega_s(v_{dL} + r_s i_{ds}) + \omega_s.\phi_{qs} \quad \text{.... (7)}$$

$$\dot{\phi}_{qs} = \omega_s\left(v_{qL} + r_s i_{qs}\right) - \omega_s.\phi_{ds} \quad \text{.... (8)}$$

$$\dot{\phi}_{dr} = \omega_s(v_{dr} - r_r i_{dr}) + (\omega_s - \omega_r).\phi_{qr} \quad \text{.... (9)}$$

$$\dot{\phi}_{qr} = \omega_s\left(v_{qr} - r_r i_{qr}\right) - (\omega_s - \omega_r).\phi_{dr} \quad \text{.... (10)}$$

where a synchronous reference frame, rotating at an electrical angular speed ω_s, is adopted. The electromechanical torque in per unit can be written in terms of stator flux linkages and currents as:

$$T_e = \phi_{ds} i_{qs} - \phi_{qs} i_{ds} \quad \text{.... (11)}$$

The corresponding torque balance equation is given by:

$$\dot{\omega}_r^u = \frac{1}{2H_T}(T_m - T_e - D_T\omega_r^u) \quad \text{.... (12)}$$

where T_m is the per unit mechanical torque, andH_T and D_T

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are the equivalent inertia constant and the equivalent damping constant of the isolated induction generator system, respectively.

STATCOM Model

The three-phase STATCOM model can be described in per unit state-space form as follows:

$$\dot{i_{de}} = -\frac{\omega_s r_f}{X_f} i_{de} + \omega_s i_{qe} + \frac{\omega_s}{X_f}(v_{dL} - e_d) \quad .... (13)$$

$$\dot{i_{qe}} = -\frac{\omega_s r_f}{X_f} i_{qe} - \omega_s i_{de} + \frac{\omega_s}{X_f}(v_{qL} - e_q) \quad .... (14)$$

The per unit dc-side circuit equation is

$$\dot{v_{dc}} = \frac{1}{C_{dc}}\left(i_{dc} - \frac{v_{dc}}{r_{dc}}\right) \quad .... (15)$$

where r_{dc} is used to represent the inverter switching loss. The instantaneous powers at the ac and dc sides of the VSI (Voltage Source Inverter) are equal, giving the following power balance equation:

$$v_{dc} i_{dc} = e_d i_{de} + e_q i_{qe} \quad .... (16)$$

Derivations of Active and Reactive Power

The instantaneous active and reactive power, through a coupling path to the STATCOM, at the load bus can be represented as follows:

$$P_e = v_{dL} i_{de} + v_{qL} i_{qe} \quad .... (17)$$

$$Q_e = v_{qL} i_{de} - v_{dL} i_{qe} \quad .... (18)$$

Consider a synchronous reference frame where the d-axis is chosen to coincide with the load bus voltage vector V_L. The above equations become:

$$P_e = v_{dL} i_{de} \quad .... (19)$$

$$Q_e = -v_{dL} i_{qe} \quad .... (20)$$

As Eq. 19 and Eq. 20 show, the d-axis current component i_{de}, accounts for the instantaneous active power and the q-axis current component i_{qe}, is the instantaneous reactive current. Thus, STATCOM control design is simplified to a great extent with this reference frame because the reactive power(Q_e)controlisonly related to the q-axis current [1].

Active and Reactive Current control

Equation 13 clearly shows that the STATCOM input current is induced by its output voltage modulation. Thus, even Eq. 20 concludes that the reactive power can be directly controlled using the reactive current the control coupling with the active current still persists in reality. To obtain a decouple - like control for the reactive and active current, Eq. 13 and Eq. 14 can be modified as:

$$\dot{i_{de}} = -\frac{\omega_s r_f}{X_f} i_{de} + x_d \quad .... (21)$$

$$\dot{i_{qe}} = -\frac{\omega_s r_f}{X_f} i_{qe} + x_q \quad .... (22)$$

where the cross-coupling terms $\omega_s i_{qe}$ and $\omega_s\, i_{de}$ in Eq. 12 and Eq. 13 are collected by the control actions x_d and x_q , respectively.

$$x_d = \omega_s i_{qe} + \frac{\omega_s}{X_f}(v_{dL} - e_d) \quad .... (23)$$

$$x_q = -\omega_s i_{de} - \frac{\omega_s}{X_f} e_q \quad .... (24)$$

Equation 23 shows that an increased active current is induced following the transient increase in x_d. This is also true for the reactive current in Eq. 24. Based on these principles, the control actions and can be expressed as

$$x_d = \left(K_{p1} + \frac{K_{i1}}{s}\right).(i_{de}^* - i_{de}) \quad .... (25)$$

$$x_q = \left(K_{p2} + \frac{K_{i2}}{s}\right).(i_{qe}^* - i_{qe}) \quad .... (26)$$

Where Proportional - Integral regulators are used to control the STATCOM currents. Once the control actions x_d and x_q are determined, the STATCOM output voltage commands e_d^* and e_q^* in Eq. 26 and Eq. 26 can be rearranged as:

$$e_d^* = X_f i_{qe} - x_d + v_{ds} \quad .... (27)$$

$$e_q^* = X_f i_{de} - x_q \quad .... (28)$$

The basic control structure for the STATCOM is detailed in Fig. 3. Since STATCOM control is based on the VSI scheme, the STATCOM output voltage commands can be rebuilt by virtue of Eq. 27 and Eq. 28.

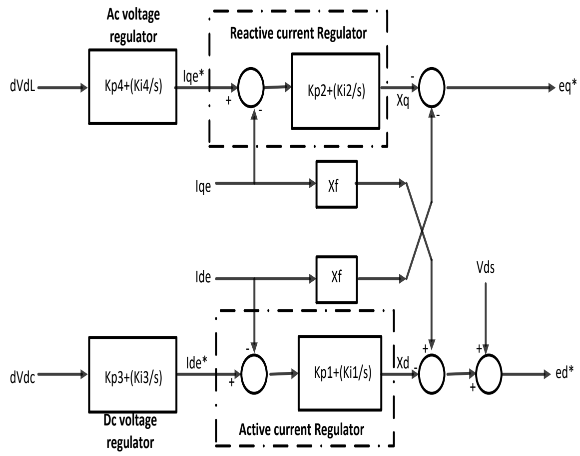

Fig. 3 Basic Control Scheme of STATCOM

In addition, from the fact that Eq.27 and Eq. 28 tell the STATCOM active and reactive power control apart from the STATCOM currents (i_{de} and i_{qe}), the active current command i_{de}^* , accounting for the dc voltage regulation, can be generated directly using a PI controller with the dc-link voltage deviation as the input.

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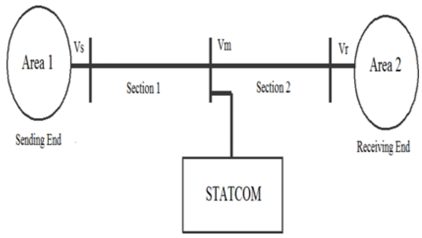
IV. RESULTS AND DISCUSSION

IV.I Multi Machine Systems

Figure 4 shows single line diagram of two area system (area 1 & area 2). Area1 connected to Area 2 through 500 kV, 455 km transmission line.



1Fig.4 Single Line Diagram of Two Area Interconnected System

All plants fed to a load center, modelled by 500 MW resistive load. In order to maintain system stability Static synchronous compensator of 100 MVA is connected to transmission line. By connecting it the power transfers capability of system increases significantly.

IV.II Simulation Model of Multi Machine System

Simulink Model of multi machine system installed with STATCOM controllers are shown in Figure. Each machine equipped with a Governor, excitation system and Power system stabilizer. All machine connected through a 500 kV, 455 km long transmission line. Resistive load of 500 MW connected on Machines. GTO based STATCOM having rating of 100 MVA connected to transmissionline.

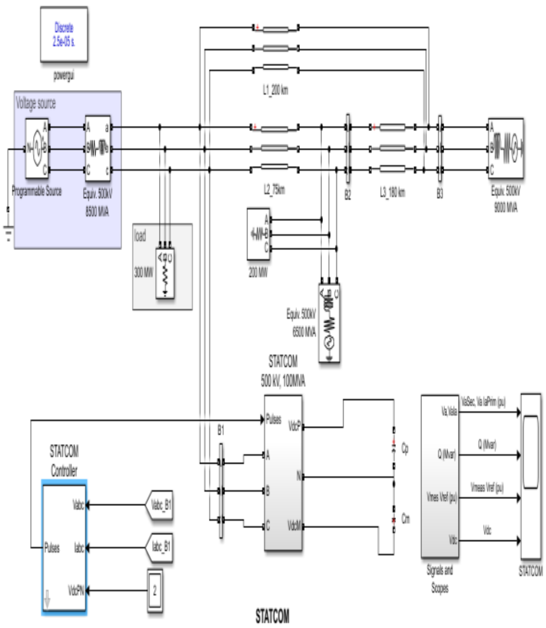


Figure 5simulation model of two machine system installed with STATCOM Controller

IV.III. SIMULATIONRESULTS

A. System without STATCOM

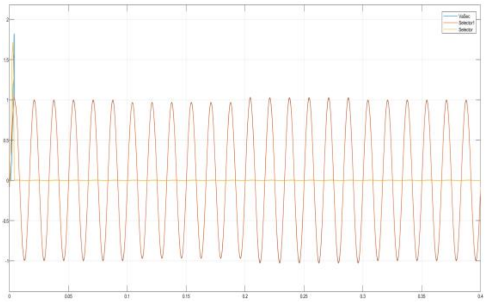


Figure 6 Vasec vs Va vs Ia with time

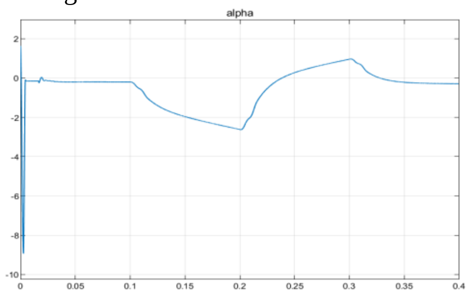


Figure 7 Load angle with time

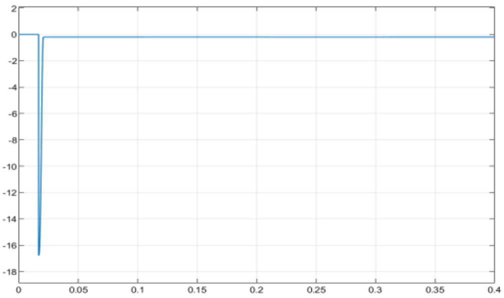


Figure 8 Reactive Power with time

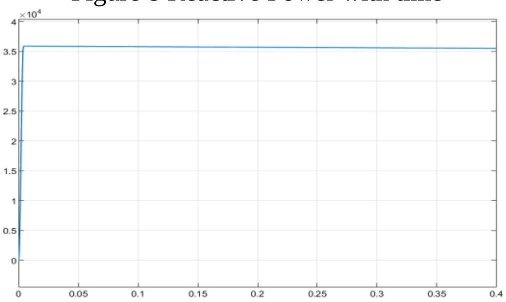


Figure 9 V_{dc} with time

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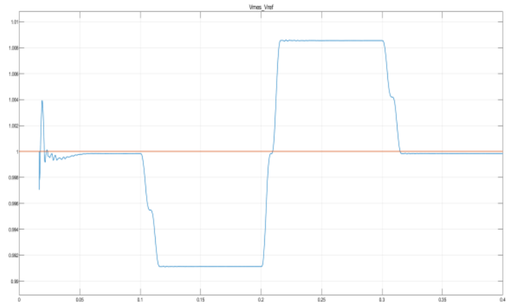


Figure 5.7 Vmeas vs Vref with time

B. System installed with PI based STATCOM
Now System is installed with PI based STATCOM System becomes stable after some time as shown in Figure 10 and Figure 11. Response of different parameters of STATCOM is shown in Figure 12 to Figure14.

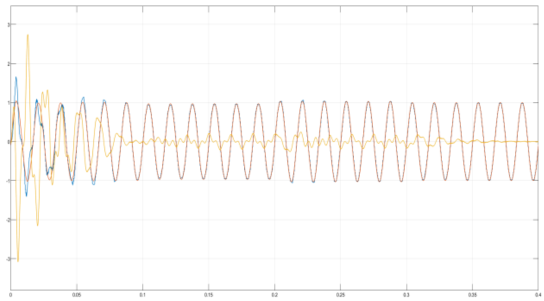


Figure 10 V asec vs Va vs Ia with time

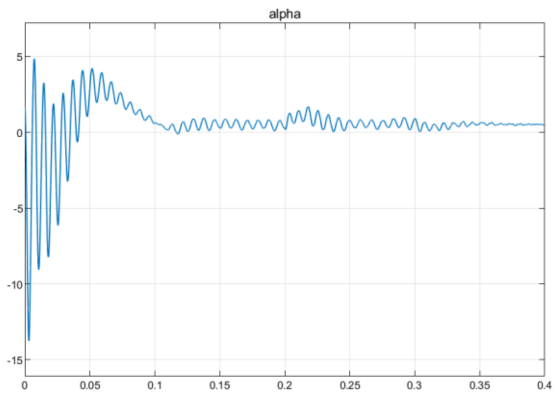


Figure 11 Load angle with time

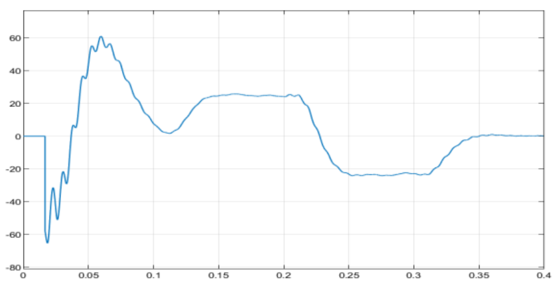
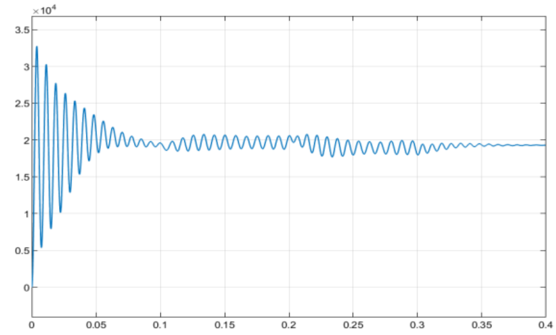


Figure 12 Reactive Power with time



2Figure 13 V_{dc} with time

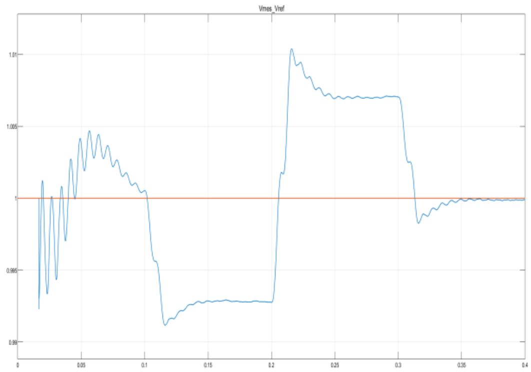


Figure 14 Vmeas vs Vref with time

V. CONCLUSION

In this work, dynamic behavior of multi machine system installed with STATCOM is investigated. PI based STATCOM controller are design to improve the transient stability of the given system. PI based STATCOM controller, error i.e. difference of V_{meas} and V_{ref} and its derivative are taken as input parameters for voltage regulator similarly for current regulator difference of I_q and I_{q_ref} and its derivative are taken as input while K_p and K_i are taken as output parameters. Proposed controllers are implemented using

MATLAB/SIMULINK. PI based STATCOM controller is compared with non-STATCOM controller. Simulation results indicate that the STATCOM controller installed with multi machine system provides better damping characteristics as compared to non- STATCOM controller model and provides improved transient stability.

VI. REFERENCES

[1]. V. Titwaniya and R. Nagar, "Voltage Flicker Mitigation Using STATCOM: A Review", IJRESM, vol. 7, no. 9, pp. 34–37, Sep. 2024, Accessed: Sep. 19, 2024. [Online]. Available: https://journal.ijresm.com/index.php/ijresm/article/view/3171

[2]. R. Nagar, S. K. Bhatt, "A Comparative analysis of a Conventional and cross phase UPQC for enhancing the Power Quality," vol. 7, no. 7. IJSHRE, 2018.

[3]. A. Marmat and R. Nagar, "Appropriateness of Parametric Bootstrap System for Appraise Mean Time to Failure of a Problematical System",IJRESM, vol. 3, no. 12, pp. 161–163, Dec. 2020.

[4]. N. R. Merritt, C. Chakraborty, and P. Bajpai, "An E-STATCOM Based Solution for Smoothing Photovoltaic and Wind Power Fluctuations In a Microgrid Under Unbalanced Conditions," IEEE Transactions on Power Systems, vol. 37, no. 2, pp. 1482–1494, Mar. 2022, doi: 10.1109/TPWRS.2021.3106859.

[5]. N. Prabhu, R. Thirumalaivasan, and M. Janaki, "Enhancement of Transient Response of Statcom and VSC Based HVDC with GA and PSO Based Controllers," in Intelligent Renewable Energy Systems, John Wiley & Sons, Ltd, 2022, pp. 345–390. doi: 10.1002/9781119786306.ch13.

[6]. P. Khatavkar and S. P. Diwan, "Collation of Controllers for the 48-Pulse VSC STATCOM for Reactive Power Mitigation and Voltage Regulation," in 2021 International Conference on Smart Generation Computing, Communication and Networking (SMART GENCON), Oct. 2021, pp. 1–8. doi: 10.1109/SMARTGENCON51891.2021.9645898.

[7]. R. S. Kadam and M. P. Thakre, "Assessment of an Improved Voltage Flicker Remediation Treatment Method Employing VSC-Based STATCOM," in 2021 5th International Conference on Trends in Electronics and Informatics (ICOEI), Jun. 2021, pp. 267–272. doi: 10.1109/ICOEI51242.2021.9452840.

[8]. B. Panigrahy, R. Saha, B. Arif, K. Dutt, and R. Panchal, "Design and Modeling of a Filter Assisted 6-Pulse VSC-IGBT Based D-Statcom for Reactive Power Compensation," in 2021 Asian Conference on Innovation in Technology (ASIANCON), Aug. 2021, pp. 1–7. doi: 10.1109/ASIANCON51346.2021.9544618.

[9]. T. Ahmed et al., "Energy management of a battery storage and D-STATCOM integrated power system using the fractional order sliding mode control," CSEE Journal of Power and Energy Systems, vol. 7, no. 5, pp. 996–1010, Sep. 2021, doi: 10.17775/CSEEJPES.2020.02530.

[10]. K. Abaci, V. Yamaçli, and Z. Chen, "Voltage stability improvement with coordinated ULTC–STATCOM controller and VSC-HVDC in high wind penetration cases," Electr Eng, vol. 103, no. 2, pp. 837–851, Apr. 2021, doi: 10.1007/s00202-020-01127-y.

[11]. H. Zhang, C. Yang, Y. Xue, and X.-P. Zhang, "Adaptive Direct Output Voltage Control of STATCOM for Dynamic Voltage Support," in 2021 IEEE Sustainable Power and Energy Conference (iSPEC), Dec. 2021, pp. 3361–3367. doi: 10.1109/iSPEC53008.2021.9735445.

[12]. B. Behera, K. C. Rout, and R. N. Dash, "Voltage Flicker Mitigation Using VSC-Based STATCOM to Improve Power Quality," in 2021 1st International Conference on Power Electronics and Energy (ICPEE), Jan. 2021, pp. 1–5. doi: 10.1109/ICPEE50452.2021.9358667.

[13]. S. Karmakar and B. Singh, "Fundamental Frequency Switched VSC with PV-STATCOM Feature for Large-Scale Solar PV Plant," in 2020 International Conference on Power, Instrumentation, Control and Computing (PICC), Dec. 2020, pp. 1–6. doi: 10.1109/PICC51425.2020.9362429.

[14]. S. Karmakar and B. Singh, "Fundamental Frequency Switched NPC-PST Based 24-Pulse VSC with PV-STATCOM Feature for Large-Scale Solar PV Plant," in 2020 IEEE 7th Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON), Nov. 2020, pp. 1–7. doi: 10.1109/UPCON50219.2020.9376422.

[15]. M. M. Almelian et al., "Improvement of Performance and Response Time of Cascaded Five-Level VSC STATCOM Using ANN Controller and SVPWM During Period of Voltage Sag," in InECCE2019, Singapore, 2020, pp. 655–668. doi: 10.1007/978-981-15-2317-5_55.

[16]. E. Karami, G. B. Gharehpetian, H. Moradi CheshmehBeigi, and K. Rouzbehi, "A hybrid active load and ideal synchronous condenser-based model for STATCOM applied to power flow studies," IET Energy Systems Integration, vol. 1, no. 4, pp. 229–235, 2019, doi: 10.1049/iet-esi.2019.0031.

[17]. M. a. h. Rafi, T. Vo, and P. h. Nguyen, "Effective integration of large-scale wind power using PV-STATCOM," The Journal of Engineering, vol. 2019, no. 18, pp. 5303–5307, 2019, doi: 10.1049/joe.2018.9232.

[18]. O. Diene, F. P. Rocha, C. F. Nascimento, and E. H. Watanabe, "Model Predictive Control of Grid-Connected Voltage-Source Converters Operating as STATCOM with Unbalanced Loads," in 2019 IEEE 13th International Conference on Power Electronics and Drive Systems (PEDS), Jul. 2019, pp. 1–6. doi: 10.1109/PEDS44367.2019.8998962.

[19]. D. S. Nikam and V. N. Kalkhambkar, “STATCOM and Multilevel VSC Topology: A Review,” in 2018 International Conference on Current Trends towards Converging Technologies (ICCTCT), Mar. 2018, pp. 1–7. doi: 10.1109/ICCTCT.2018.8551170.

[20]. P. K. Singh and A. K. Dahiya, “Analysis Modelling & Simulation of VSC based D-Statcom for Reactive VAR Compensation,” in 2018 International Conference on Current Trends towards Converging Technologies (ICCTCT), Mar. 2018, pp. 1–6. doi: 10.1109/ICCTCT.2018.8550871.

[21]. R. K. Varma and E. M. Siavashi, “PV-STATCOM: A New Smart Inverter for Voltage Control in Distribution Systems,” IEEE Transactions on Sustainable Energy, vol. 9, no. 4, pp. 1681–1691, Oct. 2018, doi: 10.1109/TSTE.2018.2808601.

[22]. Hingorani and N.G.Gyungi – “Understanding Facts Devices”- IEEE Press,2000.

[23]. X.P.Zhang and B.Pal, “Flexible AC Transmissions systems : Modelling and Control”, Springer Berlin Heidelberg, NewYork.

[24]. Priya Kankane, Rishabh Shukla andAnula Khare, "Damping Power SystemOscillations in Single-Machine Infinite-BusPower System Using a PSO based STATCOM", International Journal of Electrical, Electronics and Computer Engineering 3(2): 101-106 (2014)