

Voltage Flicker Mitigation Using PI-STATCOM controller to Improve Power Quality

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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.

1. Introduction

Modern electrical power systems are facing numerous operational and structural challenges due to the continuous rise in electricity demand. A significant concern that has garnered increasing attention in recent years is the issue of power system instability. The absence of sufficient expansion in generation and transmission infrastructure, combined with the intensive use of existing facilities, exacerbates this problem in contemporary power networks. Rapid industrial growth has led to a steep increase in energy consumption, necessitating the delivery of more power through the current transmission system.

To accommodate this growing demand, it becomes imperative to enhance power transfer capabilities using the existing transmission network. Consequently, the ability to regulate power flow becomes a critical requirement. As transmission lines approach their loading limits, the system's vulnerability to transient instability—especially following severe disturbances—becomes a limiting factor in power transfer. A modern power system must exhibit flexibility and adaptability to varying operational conditions. Although power systems possess a limited degree of self-regulation (where load and generation attempt to rebalance through changes in voltage and frequency), this margin is typically narrow. Therefore, the system faces the risk of collapse under significant disturbances.

Traditional generator excitation systems, using excitation control alone, can provide improved transient stability for minor faults. However, they often fall short in maintaining overall system stability during large faults, particularly those occurring near generator terminals. As a result, it is

essential to re-evaluate conventional control methods and develop innovative approaches that ensure effective utilization of existing resources without compromising the system's stability and security.

2. Static Synchronous Compensator (STATCOM)

In power electronics, the distinction between current source and voltage source converters is fundamental. In a current source converter, direct current maintains a constant polarity, and power flow direction is reversed by inverting the DC voltage polarity. Conversely, in a voltage source converter (VSC), the DC voltage retains a fixed polarity while power flow reversal is achieved by changing the direction of the DC current. The power semiconductor devices employed in current source converters must possess bidirectional voltage-blocking capability, often necessitating the use of an additional series diode with each switch. This design increases both the cost and complexity of current source converters, making them less favorable than voltage source converters for many applications.

Due to their superior efficiency in high-power applications and simpler topology, voltage source converters are generally preferred. In STATCOM systems, the VSC acts as the core electronic unit, converting DC voltage at the input into a set of three-phase AC voltages at the system's fundamental frequency. These AC voltages are generated with controllable magnitude and phase angle, enabling dynamic voltage regulation and reactive power compensation.

STATCOM devices employ different semiconductor technologies based on their power ratings. For high-power applications, Gate Turn-Off Thyristor (GTO)-based converters are commonly used, while Insulated Gate Bipolar Transistor (IGBT)-based converters are preferred in lower power systems. This selection ensures that STATCOM can deliver fast and precise reactive power support across various scales of power system operations.

3. Methodology: Modelling Of Statcom

3.1 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:

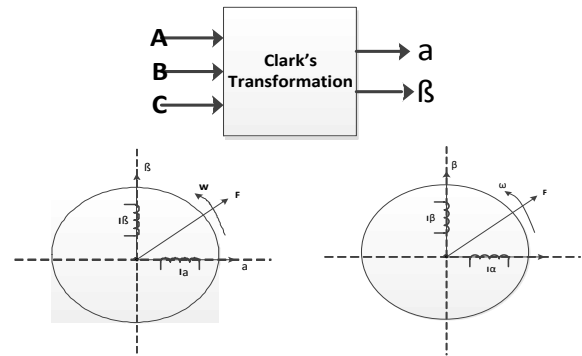


Fig 1 Clark's Transformation

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:

$$[f_{\alpha\beta 0}] = C_T [f_{abc}] \quad \dots (1)$$

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

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

The transformed voltage equation can be given as below:

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} \quad \dots (3)$$

Applying Matrix Multiplication, below equations is obtained:

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

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

$$V_0 = \frac{2}{3} * (V_A + V_B + V_C) \quad \dots (6)$$

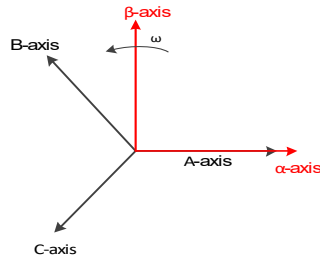


Fig 2 (a-b-c) to (Alpha-Beta) transformation portrayed by trigonometric relation

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:

$$\dot{\Phi}_{ds} = \omega_s(v_{dL} + r_s i_{ds}) + \omega_s \cdot \Phi_{qs} \quad \dots (7)$$

$$\dot{\Phi}_{qs} = \omega_s(v_{qL} + r_s i_{qs}) - \omega_s \cdot \Phi_{ds} \quad \dots (8)$$

$$\dot{\Phi}_{dr} = \omega_s(v_{dr} - r_r i_{dr}) + (\omega_s - \omega_r) \cdot \Phi_{qr} \quad \dots (9)$$

$$\dot{\Phi}_{qr} = \omega_s(v_{qr} - r_r i_{qr}) - (\omega_s - \omega_r) \cdot \Phi_{dr} \quad \dots (10)$$

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:

$$T_e = \Phi_{ds} i_{qs} - \Phi_{qs} i_{ds} \quad \dots (11)$$

The corresponding torque balance equation is given by:

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

where T_m is the per unit mechanical torque, and H_T and D_T 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:

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

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

The per unit dc-side circuit equation is

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

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:

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

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:

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

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

3.2 PI Controller Design

PID (proportional integral derivative) control is one of the prior control techniques. Its initial execution was in pneumatic gadgets, trailed by vacuum and solid-state analog electronics, before showing up at the present computerized usage of microchips. It has a basic control structure which was comprehended by plant administrators and which they discovered generally simple to tune. It is a conventional control circle input instrument and utilized as a criticism controller. PI's working guideline is that it computes a mistake an incentive from the handled estimated esteem and the ideal reference point. Crafted by the controller is to limit the mistake by changing in the contributions of the framework. In the event that the framework or plant isn't unmistakably known, at that point applying the PI controller gives the best outcomes in the event that it is tuned appropriately by keeping boundaries of the framework as per the idea of the framework. [13]

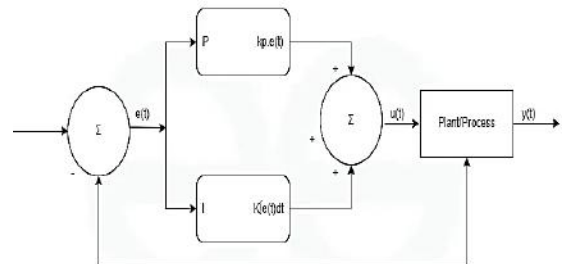


Figure 4.1 Block Diagram of the PI controller

The PI estimation relies on two boundaries which are called proportional (P) and the integral (I). For the P part, it decides the response to the current mistake. I part decide the response to the entirety of as of late showed up mistakes. A derivative activity is delicate to clamor so for the most part the controller is PI controller as opposed to PI as it is unimaginable a framework without the aggravations. The integral part causes the framework to reach onto its objective worthwhile the P part is incrementing overshoot. [13] proportional, integral, and the derivative term is given by:

$$P = K_p e(t) \quad (19)$$

$$I = K_i \int_0^t e(t) dt \quad (20)$$

$$\therefore PI = K_p e(t) + K_i \int_0^t e(t) dt \quad (21)$$

Proportional Gain (K_p)

Bigger qualities commonly mean quicker reaction since the bigger the blunder, the bigger the Proportional expression remuneration. An unnecessarily enormous proportional increase will prompt procedure flimsiness and wavering.

Integral Gain (K_i)

Bigger qualities infer consistent state blunders are wiped out more rapidly. The exchange off is bigger overshoot: any negative blunder incorporated during transient reaction must be coordinated away by positive mistake before we arrive at a consistent state.

4. Results And Discussion

4.1 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.

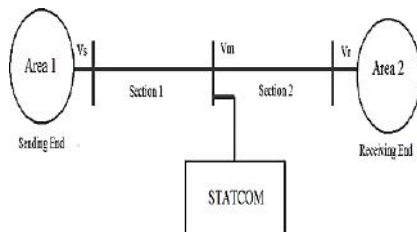


Figure 4 Single Line Diagram of Two Area Interconnected System

All generating units supply power to a common load center, which is modeled as a 500 MW resistive load. To enhance system stability and improve the power transfer capability of the network, a Static Synchronous Compensator (STATCOM) rated at 100 MVA is integrated into the transmission line. The inclusion of the STATCOM leads to a significant improvement in the system's ability to transfer power while maintaining voltage stability.

4.2 Simulation Model of Multi-Machine System

The Simulink model representing the multi-machine power system equipped with STATCOM controllers is illustrated in Figure 5. Each synchronous machine

in the system is configured with a governor, excitation system, and power system stabilizer (PSS) to ensure dynamic control and improved damping. The machines are interconnected through a 500 kV transmission line with a total length of 455 km. A resistive load of 500 MW is connected to the generating units to simulate real-world demand. A GTO-based STATCOM with a power rating of 100 MVA is connected to the transmission line, providing reactive power support and enhancing the system's transient stability under various loading conditions.

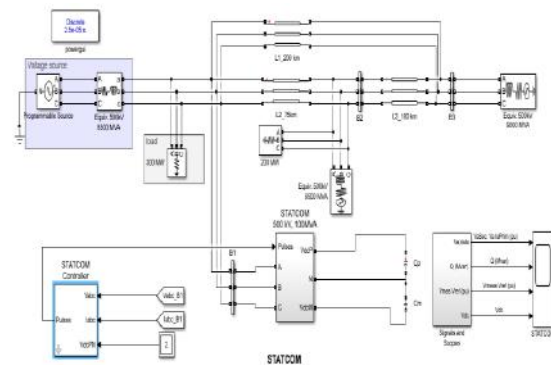


Figure 5 simulation model of two machine system installed with STATCOM Controller

4.3 Simulation Results

4.3.1 System without STATCOM

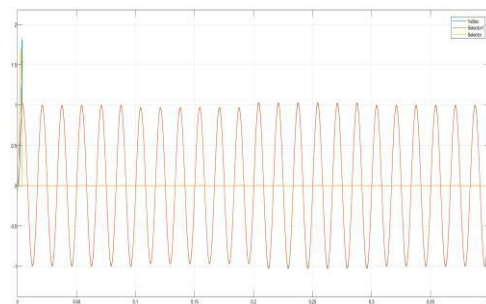


Figure 6 V_{asec} vs V_a vs I_a with time

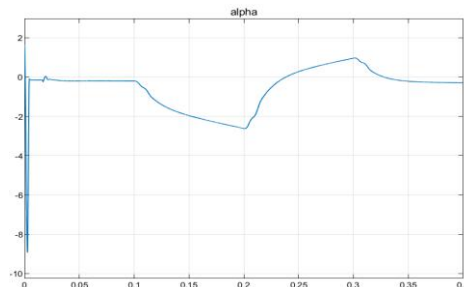


Figure 7 Load angle with time

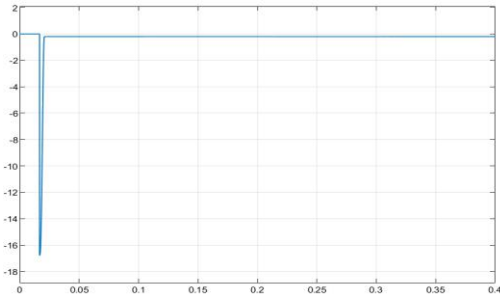


Figure 8 Reactive Power with time

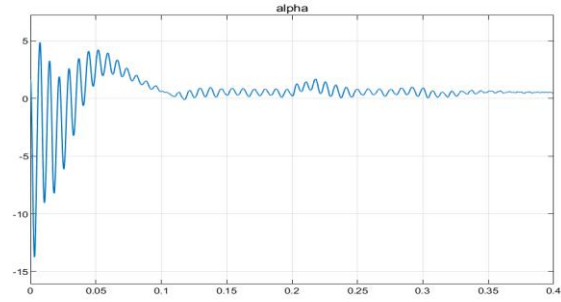


Figure 11 Load angle with time

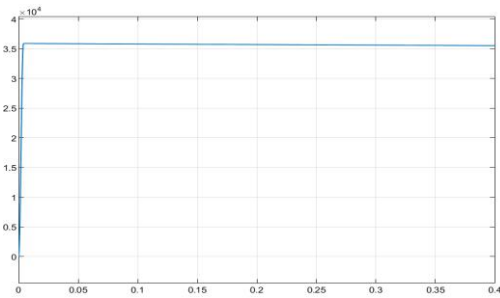


Figure 9 V_{dc} with time

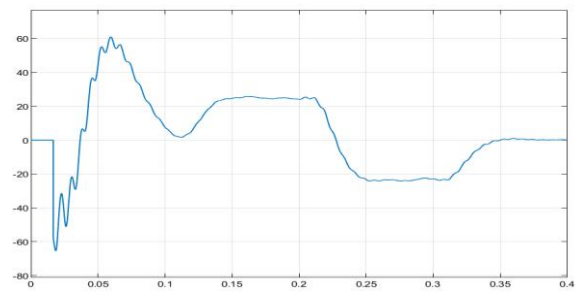


Figure 12 Reactive Power with time

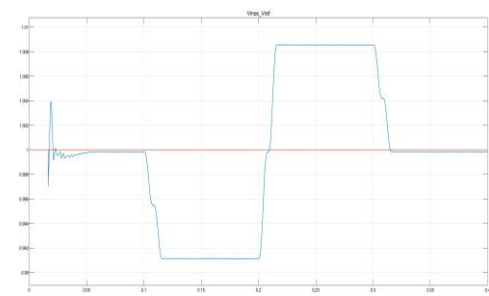
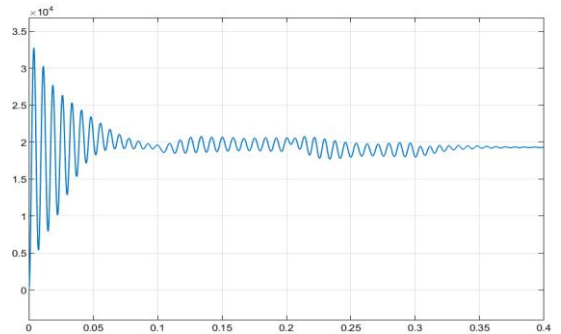


Figure 5.7 V_{meas} vs V_{ref} with time



2Figure 13 V_{dc} with time

4.3.2 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 Figure 14.

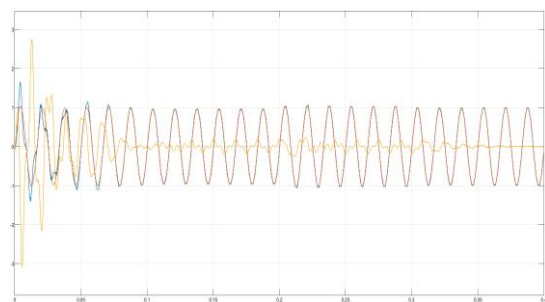


Figure 10 V_{asec} vs V_a vs I_a with time

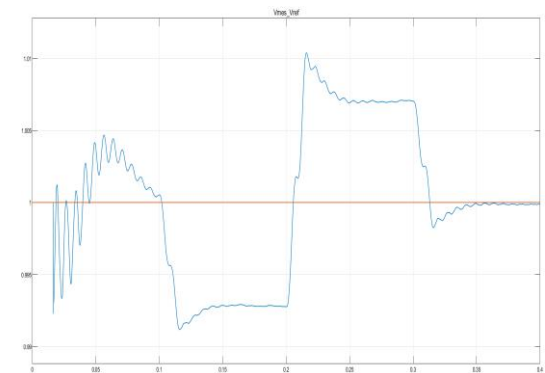


Figure 14 V_{meas} vs V_{ref} with time

5. Conclusion

In this study, the dynamic performance of a multi-machine power system integrated with a STATCOM is analyzed. A PI-based STATCOM controller is designed to enhance the transient stability of the system. The voltage regulator of the STATCOM controller uses the error between the measured voltage (V_{meas}) and the reference voltage (V_{ref}), along with its derivative, as input signals. Similarly, for the current regulator, the error between the actual quadrature current (I_q) and its reference value ($I_{q,ref}$), along with its derivative, is used as input. The proportional (K_p) and integral (K_i) gains serve as the controller outputs.

The proposed control scheme is implemented in the MATLAB/Simulink environment. The performance of the system equipped with the PI-based STATCOM controller is compared against a system operating without STATCOM compensation. Simulation results demonstrate that the inclusion of the STATCOM significantly improves system damping and enhances transient stability, thereby validating the effectiveness of the proposed control strategy.

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