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STABILITY IMPROVEMENT OF STACOM SYSTEM USING FRACTIONAL-ORDER PROPORTIONAL INTEGRAL (FOPI) BASED CONTROL STRATEGIES

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Abstract: *Proportional (P) controllers are widely adopted in static compensator (STATCOM) systems for their simplicity and fast dynamic response. However, under transient conditions, P controllers exhibit limitations in accurately tracking voltage and current variations, often leading to significant ripples and suboptimal performance. To address this, Fractional Order Proportional-Integral (FOPI) controllers are proposed, leveraging their ability to introduce a fractional-order integrator that provides enhanced tuning flexibility and robustness. The added degree of freedom in FOPI controllers allows for improved handling of non-linear STATCOM dynamics, particularly in mitigating outer-loop capacitor voltage fluctuations and inner-loop current variations. This paper presents a FOPI-based control approach implemented with decoupled current control for enhanced STATCOM performance during transients. The current control is developed assuming steady-state operating conditions to counteract variations induced ripples. While conventional PI controllers must operate at low bandwidths to preserve system stability, this method effectively improves for feedback limitations through positive gains, and non-integer integral gain leading to improved transient responses. Moreover, further studies can consider other methods such a feed forward compensation to handle the non-linearity issues of the STATCOM within same bandwidth. Simulation results using MATLAB simulink demonstrate a substantial reduction in ripple amplitude and improved settling time. The proposed method achieves approximately 70% reduction in load current ripple (from 0.15 A to 0.015 A), and an 80% faster settling time (from 1.2 s to 0.2 s) compared to the conventional P controllers. Additionally, the stability margin improves significantly, with phase margin increasing from -180° to +0.167°. These findings highlight the efficacy of the FOPI-based control scheme in enhancing STATCOM system performance, particularly in mitigating ripple and improving transient response speed*

Key words: Reactive loads, power quality, STATCOM, FOPI, control, Reactive current control

1 Introduction

Electric power system is the backbone of modern society, in which supply reliability is associated to the development power systems. However, as more non-linear loads and inverter-based resources are connected to the power grid, the issue of reliable and power quality (PQ) problems arise. The power quality problems include harmonic distortion, voltage fluctuation, voltage sag, and voltage swell (Sharma et al., 2024), and the PQ issues greatly affect the reliability and quality of power supplied. The voltage, which is tied to reactive power, is one of the main indices which ensure reliable power supply, when there is a challenge with it, power system results into having power quality issue especially when non-linear loads are involved. FACTS (Flexible Alternating Current Transmission System) devices are employed mostly to provide reactive power via compensation in order to increase the reliability of power supply. FACTS devices can be divided into four categories (Sharma et al., 2024): Series FACTS devices, Shunt FACTS devices, Series-Series FACTS devices and Series-Shunt FACTS devices. Series FACTS devices include Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Series Reactor (TCSR), Thyristor Switched Series Capacitor (TSSC) and the Static Synchronous Series Compensator (SSSC). The shunt FACTS devices are the Static VAR Compensator (SVC), Thyristor Controller Reactor (TCR), Thyristor Switched Capacitor (TSC), Thyristor Switched Reactor (TSR), and the Static Synchronous Compensator (STATCOM). The Interline Power Flow Controller (IPFC) are Series-Series FACTS devices while Unified Power Flow Controller (UPFC) are series-shunt FACTS devices.

The operating principle of a STATCOM as a shunt FACT device is related to the operating principle of rotary synchronous compensators or generators, in which behaviour varies similar to a synchronous motor, capacitive when overexcited and inductive when under excited by changing the voltage angle (Engelbrecht et al., 2023), (Lawan et al., 2019a) to supply the desired reactive current while deploying STATCOMs.

Some of the related work on FACTs and STATCOM include, as highlighted in reference (Donga et al., 2023), that gives the impact of increasing interconnection of large-scale power grids that presents a growing challenge for maintaining power quality and transient stability. Hence the need for improvements in the controllability and reliability of the power systems. As a result, VAR compensators such as flexible AC transmission system (FACTS) devices were developed for effective reactive power management (Sri Ram et al., 2023). STATCOM being of the prominent and versatile FACTS controllers offers a wide range of control capabilities (Lawan et al., 2019a). STATCOM which can be an inverter-based Static VAR Compensator, is an important modern device used for reactive power compensation (Sri Ram et al., 2023), a sensing system is required to monitor the ac system condition, and adjust this angle in order to supply reactive power to the system or absorb reactive power from the system, so as to regulate the bus voltage as reported by (Lawan et al., 2019a).

Cascaded Multilevel Converters Topology (CMCT) have attracted substantial interest in recent years for their capacity to produce high-quality output waveforms, enhance voltage control, power factor correction and grid stability (Xiao et al., 2023). A voltage source converter based STATCOM proposed by Morati et al. (2016) for improved voltage flicker mitigation, employs both active and reactive compensating current components without the need for filter oversizing. A feedforward control strategy as described by Jung et al., (2017), implemented in a delta-connected cascaded H-bridge converter-based STATCOM, demonstrated by this approach is its ability in maintaining stable DC cell capacitor voltages, especially during grid faults and load imbalances, furthermore, it shows a significant improvement in suppressing zero-sequence circulating currents.

The authors in (Lawan et al., 2019a, Lawan et al., 2019b) improves the transient response of modular multilevel converter (MMC) based STATCOM system in which compensation concept based on virtual impedance to minimize variations was employed. The STATCOM system uses two switching methods, i.e. fundamental frequency switching (FFS) and pulse width modulation (PWM) (Lawan et al., 2019a, Chen and Ooi, 1999, Srndovic et al., 2016). Furthermore, the PWM method can be used where high frequency of switching is required (Lawan et al., 2019b). However, the choice of converter affects the choice of control. CHB STATCOM such as that reported in (Chen et al., 2023), uses a detection method based on carrier phase-shifted SPWM technique that shows effectiveness in balancing the capacitor voltage. Highlighted by (Simonetti et al., 2023) is a hybrid controller composed of TCR, TSC, and STATCOM acts as a reactive power and harmonic compensator. (Roy et al., 2023) published a report on the mitigation of unbalanced voltage and power factor correction was conducted using hybrid controllers based STATCOM for a high voltage distribution system.

Furthermore, Xiao et al. (2023), proposed is a dual-layer modulated model predictive control scheme for STATCOM that turns out to be very effective in achieving controlled current and voltage balance. An innovative point-of-common coupling (PCC) voltage controller for STATCOM as highlighted in a reported by Ahmadi et al., (2021), This approach aims to reduce imbalances in voltage and damping of oscillation. Exhibited in (Simonetti et al., 2023) is a proposal on a neural network-based approach for the STATCOM controller, in other to shows its capability to reduce the computational burden of the conventional control scheme.

The evidence of a reduction in torsional damping by the use of STATCOM is tested with a French line commutated converter and a new Electro link modular multilevel converter interacting with a grave lines generator (Kovacevic et al., 2023).

In reference (Mohanty et al., 2023), a direct control was used for sub-cycle response nonlinear control based on feedback linearization and has been with both direct and indirect control similar to References (Sri Ram et al., 2023), (Lawan et al., 2019a, Lawan et al., 2019b) that also used decoupled control. The decoupled control d-q reference frame simplifies the operation because d component is neglected in the reactive power while the use of average capacitance balancing for maintaining the voltages was explored. (Mohanty et al., 2023) presented a reactive power control in which each H-bridge is balanced in a Cascaded H-bridge STATCOM; this provides reactive power and less frequency deviation through virtual synchronous inertial into the system.

Additionally, (Lawan et al., 2019a) presented a decoupled current control strategy, proposed an enhanced control approach for a MMC-based STATCOM system. The methodology applied uses PI-controller. However, PI-controllers have some drawbacks such as leaving steady-state error making their output not to effectively match the setpoint. However, the integration of Fractional-Order Controllers into systems can demonstrate potential to enhance robustness, adaptability, and dynamic response (Dastjerdi et al., 2019, George et al., 2022,). Hybrid topologies have been developed to improve the performance of converters by combining several advantages, such as improved efficiency, enhanced performance and control, flexibility with cost effective. Different hybrid structures have been reviewed by (Venkataramanaiah et al, 2017). However, despite the advantages associated with hybrids, challenges such as complexities in control result to reduced performance.

Despite advantages of CB-PWM modulation in-terms of reasonable reduction of harmonics, smaller coupling filter size and faster dynamic response to grid, other disadvantages such as increased switching losses, ripples, noise, electromagnetic interference, difficulty in tuning controller results to coupling effects, and control interaction among inner current loops and the PLL dynamics in the STATCOM system, the coupling effects results of the current controller results to negative effects of PLL information processing, which results to poor compensation, transient instability and steady state error even at steady state in the power system with inductive and capacitive reactive loads.

The concept of conventional control (A.U Lawan et al, 2024) for voltage source inverter based on proportional control and weak grid scenario can further allow the consideration and use of STATCOM control dynamics with FOPI controllers for improved performance.

The proposed control scheme improves the stability of the STATCOM system within the required bandwidth of the current controller at the low switching frequency of CB-PWM while the FOPI with fractional tuning range is adopted to further enhance and minimize the coupling effects and control interaction among control loops in STATCOM system for improved compensation of reactive current. The main contribution of the work includes:

1. A FOPI-based control approach implemented with decoupled current control for enhanced STATCOM performance during transients. The current control is developed assuming steady-state operating conditions to counteract variations induced ripples while further minimizing the coupling effects and control interactions of different control loops in STATCOM system, therefore the compensation capability of STATCOM is enhanced;
2. Employment of CHI topology for STATCOM results in few components required for retrofitting, less power loss which further reduces stress and improves reliability therefore cost-effectiveness is achieved;
3. The PI controllers plugged in with fractional order employed has advantage of replacing the integer-order integral with a fractional-order $S^{-\lambda}$ where $\lambda \in (0,1]$, allowing finer control through tuning flexibility over the STATCOM system dynamics such as the capacitor voltage variation in the outer-loop and the inner-loop ac current variation resulting in suppressed ripples and better output AC voltage of the STATCOM at the point of coupling to the grid, thus, improving power quality.

The rest of the paper is organized as follows: Section 2 introduces the STATCOM system description, the methodology for conventional and proposed methods, Section 3 describes the simulation and Section 4 presents discussion of results, and finally section 5 concludes the paper.

2 Conventional Methodology using Proportional Controller

The conventional system employs a Static Synchronous Compensator (STATCOM) based on a five-level cascaded H-bridge inverter, which generates phase voltages V_C by synthesizing outputs from individual H-bridge modules (Ahmadi et al., 2021, Law Kah Haw et al, 2015).

Each phase leg of the inverter is constructed using series-connected Insulated Gate Bipolar Transistors (IGBTs). To ensure system stability and prevent short circuits across the DC-link, these IGBTs are controlled in a complementary fashion, allowing for precise voltage synthesis while safeguarding the integrity of the overall system.

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In Figure 1, a STATCOM is connected in shunt with the power system at the Point of common coupling (PCC) via a series coupling inductor L_f (Lawan et al., 2019a, Lawan et al., 2019b). This shunt connection strategy aims to mitigate voltage drops across the source impedance Z_s, consequently enhancing the transmissible power capacity of the transmission line.The reactive current i_C flowing through the coupling inductor L_f is determined by the impedance ratio, expressed as $\tan^{-1}\left[\frac{j\omega L_f}{R_f}\right]$ (Ahmadi et al., 2021).

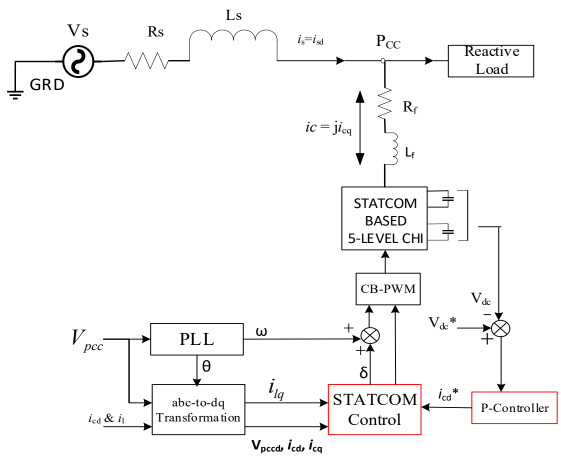

Figure 1: Block diagram of the STATCOM with the control scheme [Law Kah Haw et al, 2015]

This current is proportional to the voltage difference between the grid voltage at the PCC (V_{pcc}) and the STATCOM's AC output voltage. Through modulation of the DC-link capacitor voltage (V_{DC}), both the magnitude and the phase angle (δ) of the Static Synchronous Compensator (STATCOM) output voltage (V_C) can be regulated with respect to the grid voltage (V_{pcc}). This can be achieved by controlling the total DC-link capacitor voltage V_{DC}, which regulates the converter output voltage and its phase angle δ relative to the grid, as shown in Equation (1):

$$i_c = \frac{V_{pcc} - V_c\angle\delta^{o}}{Z_f\angle\left(\tan^{-1}\frac{j\omega L_f}{R_f}\right)} = \pm\, ji_{cq} \qquad (1)$$

Where δ the phase difference between V_{pcc} and V_c. L_f is the coupling inductance with ϕ as the (PF angle) i.e. phase difference between i_c and V_{pcc}.

The PLL determines the reference phase angle δ of the grid voltage V_{pcc}, which is used to transformation to dq component, and the STATCOM terminal output voltage V_C, and the current i_C is decoupled into dq vectors based on park transformation. The STATCOM current i_C in Equation (1) is transformed into the transfer function (Equation (3)) of the inverter in dq-coordinates and it is given by Equation (3), where $i_{cq}{}^{*}$ can be modeled as load reactive current i_{lq} for STATCOM reactive current control as:

$$i_{cq}^{*} = i_{lq} \qquad (2)$$

$$\begin{bmatrix} V_{cd} \\ V_{cq} \end{bmatrix} = \begin{bmatrix} V_{pccd} \\ V_{pccq} \end{bmatrix} - R_f \begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} - L_f \frac{d}{dt}\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} + \omega L_f \begin{bmatrix} i_{cq} \\ -i_{cd} \end{bmatrix} \qquad (3)$$

The sum of the DC voltage levels V_{DC} is regulated according to the system requirement determined by the active current reference from the DC-link i_{cd}^{*} in a voltage loop control using a fractional order PI-controller with as given in Equation (4). Since only the d-axis current component is predominant and required for charging and discharging the DC-link capacitors, hence all the q-axis can be neglected.

$$I_{DC\_dq} = C\frac{dV_{DC\_dq}}{dt} \qquad (4)$$

$$I_{DC\_d} = C\frac{dV_{DC\_d}}{dt} \qquad (5)$$

Where I_{DC_dq} is the measured current flowing its reference dc current i_{cd}^{*} going through the MCHI as an output of the outer-loop of the the p-controller given in Figure 2 with a gain, K_P given in (6) and C is the total DC capacitance of the H-bridges.

$$K_{P\_vd} = \frac{C_{DC}}{T_{vd}} \qquad (6)$$

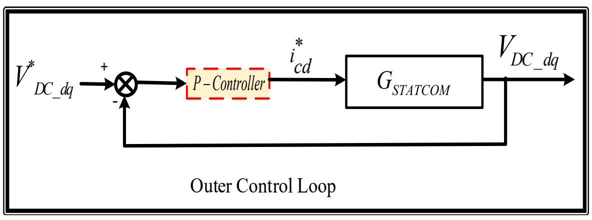

Figure 2. Outer loop control of DC link voltage (Law Kah Haw et al, 2015)

3 Proposed Fractional-Order PI controller (FOPI)

The proposed current control is derived assuming no voltage variations based on the relationship between the command voltage V_{cc}^* and the d-axis grid voltage at PCC, V_{pccd} as shown in Figure 3, the phasor diagram of STATCOM operating in region under steady state condition (Lawan et al, 2024), this steady state assumes that the measured output reactive and active current of the STATCOM i_{cq} and i_{cd} follows and become the desired compensating reference currents i_{cq}^* and i_{cd}^* respectively where the transient component are all zeros. That is steady state is reached and at this stage the STATCOM is assumed to be ideal, thus, Equation (3) is neglecting the q-axis voltage at point of coupling V_{pccq} as given in Equation (7) as shown in the phasor diagram of Figure 3 (Lawan et al, 2024). Equation (7) can further be split to form Equation (8) and (9).

$$\begin{bmatrix} V_{cd} \\ V_{cq} \end{bmatrix} = \begin{bmatrix} V_{pccd} \\ 0 \end{bmatrix} + \omega L_f \begin{bmatrix} i_{lq} \\ -i_{cd} \end{bmatrix} \quad (7)$$

Equations (8) through (9) are derived based on the characteristics (Lawan et al, 2024) where $i_{cq\_com}^*$ and $i_{cd\_com}^*$ are the reference reactive and active currents respectively under compensation period.

$$V_{ccd}^* = V_{pccd} + \omega L_f i_{cq\_com}^* \quad (8)$$

$$V_{ccq}^* = -\omega L_f i_{cd\_com}^* \quad (9)$$

And the resultant STATCOM desired voltage becomes resultant unity voltage under compensation with ideal voltage drop. This enables better shaping of the open-loop frequency response when plugged in with the fractional-order controller, resulting in improved phase and gain margins, enhanced robustness to parameter variations, and reduced overshoot.

Although the PI-controller has zero static error in tracking the dc-current reference for Equation (2) at the expense of overshoots, its impact in suppressing the harmonics due to the dc voltage variation of Equation (5) in form of ripple can be improved even at steady-state as the PI-controlled dc current is reported to exhibit limited presence of harmonics, (Lawan et al., 2018). In order to improve the suppression of these harmonics in the outer loop dc current at any specified frequency, controllers of high gain at frequencies of the harmonics have to be used within the bandwidth frequency. The PI controllers plugged in with fractional order as given in Figure 2 has advantage of replacing the integer-order integral with a fractional-order $S^{-\lambda}$ where $\lambda \in (0,1]$ allowing finer control through tuning flexibility over the STATCOM system dynamics such as the capacitor voltage variation in the outer-loop and the inner-loop ac voltage variation due to the inner loop current control (Lawan et al., 2018, Lawan et al, 2019a, law kah haw et al, 2015). This added degree of freedom enables enhanced robustness of the non-linear STATCOM system leading to improved transient and steady-state response. Furthermore, the current PI-controller plugged-in fractional order PI (FOPI) controller can here be selected with low bandwidth to preserve the robustness and stability of the system (Lawan et al., 2018). This will extend the improved use of the power electrnic devices for applications in STATCOMs and converts (Lawan, A.U., Almurib, H.A.F., & Khor, J.G. (2019)- Magaji, N., Mustafa, M.W., Dan-Isa, A., & Lawan, A.U. (2013).

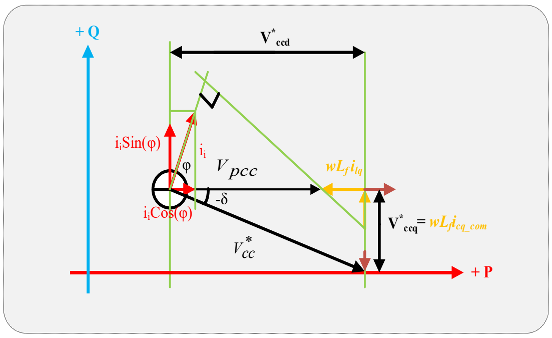

Figure 3: Phasor diagram of the inverter with STATCOM characteristics (Law Kah Haw et al, 2015)

Thus, Equation (14) gives the system voltage Equations employed with the fractional order controller and the newly proposed $i_{cq\_new}^*$ and Figure 4 depicts the STATCOM output ac current and outer-loop DC link voltage controls using FOPI controllers as a cascade control while Figure 5 gives the overall control diagram.

$$\begin{cases} V_{cd}^* = V_{pccd} - \left(i_{cd}^* - i_{cd}\right) G_{FOPI} + \omega L_f i_{cq} \\ V_{cq}^* = V_{pccq} - \left(i_{cq\_new}^* - i_{cq}\right) G_{FOPI} - \omega L_f \left(i_{cd}^* - i_{cd}\right) \end{cases} \quad (14)$$

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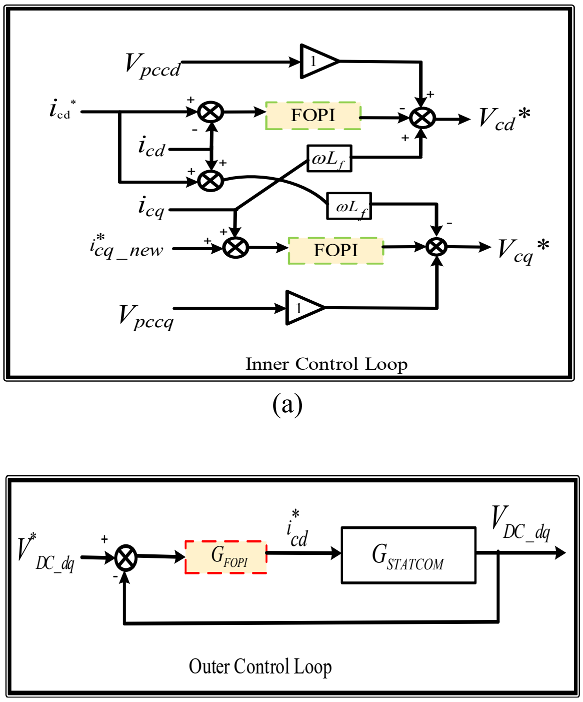

Figure 4: Proposed control of (a) inner loop ac current of the STATCOM (b) outer-loop DC link voltage

For stability analysis, the STATCOM system will be model as combination of controller $\left(G_{controller}\right)$, the PLL model $\left(G_{pll}\right)$, the CB-PWM will be model as a gain while the inductive and capacitive load are modelled as RL and RC load respectively.

Equations (15) through (17) are the models of the respective system component, with load considered as parallel RL and RC load. Where k_p, k_i, λ and k_{cbpwm} are controller gains, fractional-order integral term and switching gain respectively, ω_{pll} and ξ are PLL bandwidth and damping ratio of PLL. R, L and C are resistance, inductance and capacitance of the load.

$$G_{FOPI}(s) = k_p + \frac{ki}{s^{\lambda}} \qquad (15)$$

$$G_{pll}(s) = \frac{2\xi\omega_{pll}s + \omega_{pll}^2}{s^2 + 2\xi\omega_{pll}s + \omega_{pll}^2} \qquad (16)$$

$$G_P(s) = k_p \qquad (17)$$

For the STATCOM system under study, the system is stable when (GM) and ϕ_M are greater than zero i.e. $\left(GM\ f\ 0, \phi_M\ f\ 0\right)$,while the system is unstable when (GM) is less than zero, or the ϕ_M is less than zero or both are less than zero i.e. $\left(GM\ p\ 0, \phi_M\ p\ 0\right)$

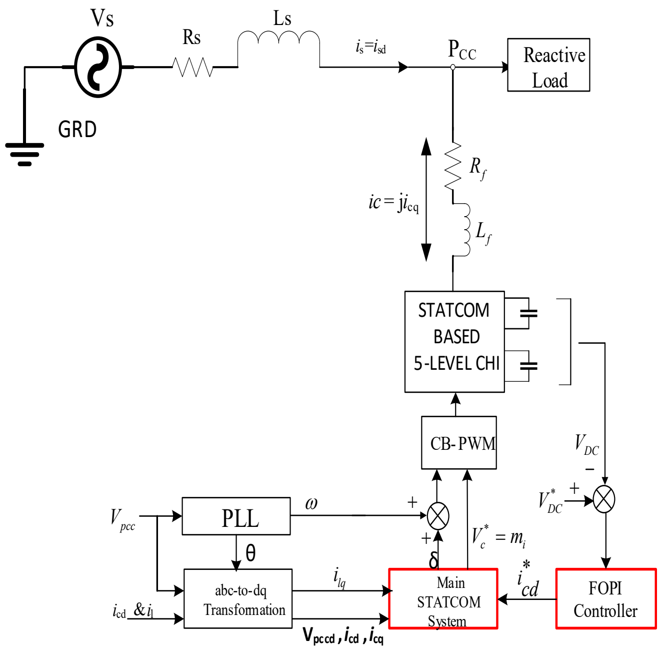

Figure 5: Block diagram of the STATCOM with the Proposed control scheme.

4 Results and discussion

To investigate the behaviour of the STATCOM system, detailed time domain simulation was conducted in MATLAB/Simulink using both the conventional proportional (P) based current controllers and the proposed fractional-order (FOPI) based PI controllers. The simulation study investigates the transient performance, steady state performance, and reactive current compensation capability of the STATCOM for both methods.

To simulate diverse operating scenarios, two operating conditions of the STATCOM were considered based on reactive RL inductive load (with lagging power factor) and reactive RC capacitive (with leading power factor). Under scenario 1, the STATCOMM system absorbs the desired reactive current under the inductive load, while under scenario 2, the capacitive load the STATCOM inject the reactive current. The simulation time was set to 2s using automatic variable step solver in Simulink with auto parameters.

From 0.0s to 0.2s, the transient oscillations seen are due to PLL action for processing and computation of the desired angle required for transformation. From 0.2s to 1.0s, the system was set at capacitive mode or scenerio1 and at 1s to 2s the system was transitioned to inductive mode or scenario 2.

In addition, frequency domain analysis is conducted to investigate the stability of the STATCOMM system using both the conventional and proposed method. Step responses of currents with the P and FOPI are depicted in Figure 5a and Figure 5b respectively furthermore, the conventional and proposed control step changes in current are given in Figures 6a and Figure 6b respectively. Simulation results in the proposed method achieves about 70% reduction in load current ripple from 0.15 A to 0.015 A and an 80% faster settling time from 1.2 s to 0.2 s compared to the conventional P controllers as shown in Figure 7. Thus, at scenario 1, the transient instability, steady state error and poor compensation decreases with the conventional control as compared with P control only for both scenarios.

The voltage response of the individual capacitors and total DC link capacitors for the conventional control and proposed control are depicted in figures 7a and b for both scenarios, respectively. It can be observed from Figure 7b that the DC voltage level across each DC-link capacitor is balanced as the steady state error becomes minimal. The ripples due to transient instability is reduced, while Figure 8 gives the corresponding 5-level CHI based STATCOM output ac voltages with their dips during transitions.

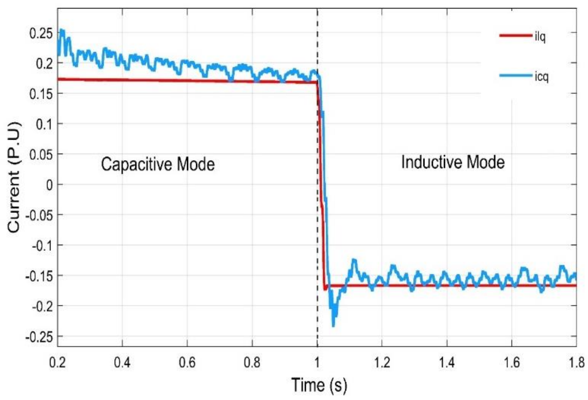

Figure 6a : Current response with P controller.

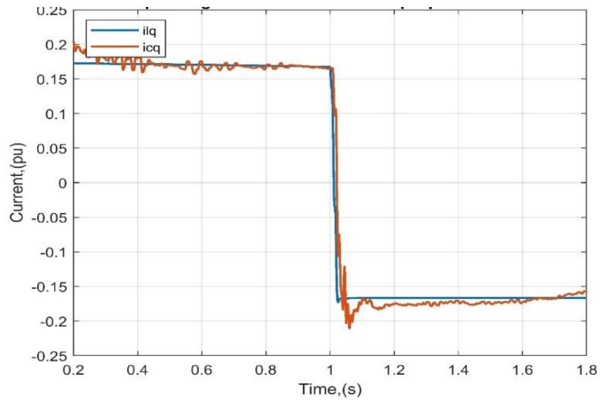

Figure 6b Current response with FOPI controller

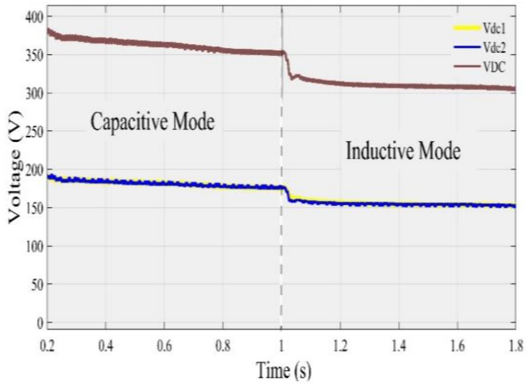

Figure 7a DC link capacitor voltage response with conventional control P-controller

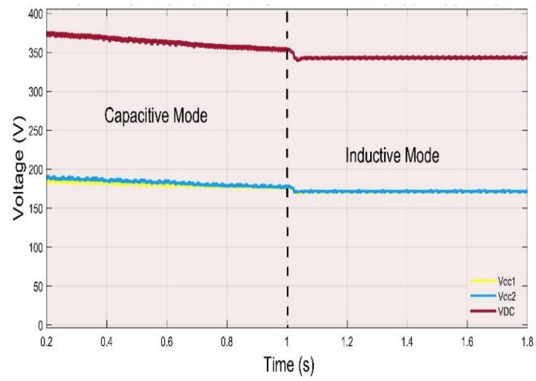

Figure 7b DC link capacitor voltage response with proposed FOPI-control.

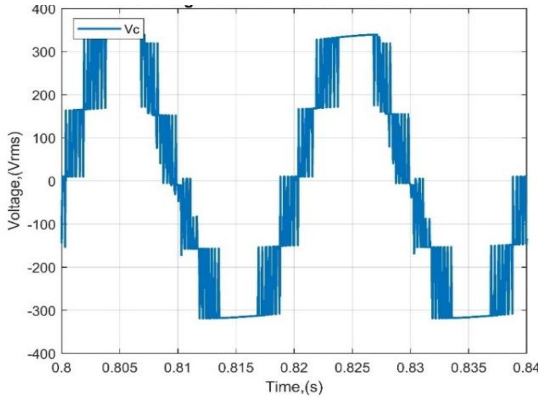

Figure 8a 5LC voltage waveform with conventional control PI-Control

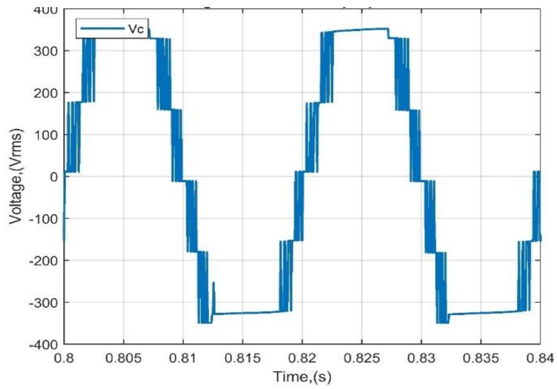

Figure 8b 5LC voltage waveform with the proposed FOPI-control

Table 2: System response parameters for different cases

Load condition	GM (dB)	$PM\ (^{O})$
P	Inf	-180
FOPI (base)	Inf	0.617
-75%	262	3.27
-50%	265	2.18
-25%	220	1.09
+75%	Inf	7.62
+50%	Inf	6.50
+25%	Inf	5.45

Frequency stability analysis was conducted for both the conventional and proposed methods. To evaluate the robustness of the proposed control strategy, various load conditions were considered. The stability analysis was conducted using the parameters in Table 1 and the closed-loop transfer function from Figure 2. The analysis was performed for both the P and FOPI controllers under base-case condition

Additionally, to test the robustness of the proposed control, the load parameter was varied decreasing the base value by 25% and increasing it by 25% in steps of up to three increments as given in Table 2.

The frequency response of the system for the conventional and proposed control methods is shown in Figure 9a, while the responses for the decreased and increased load conditions are depicted in Figures 9b and 9c, respectively. The GM (Gain Margin) and PM (Phase Margin) of the system are also given in Table 2. The system is unstable with the conventional P-controller method, whereas the proposed FOPI-based method ensures stability, as both the GM and PM are positive in both cases. An infinite or larger GM indicates greater robustness against variations, while the smaller PM is due to the oscillatory nature of the load and its response settling time, as discussed in the time-domain simulations. Hence, in practical implementations, an online-adjustable controller gain tuning, a phase delay compensator, or a lead compensator may be employed. Conclusively, the FOPI has helped improves the stability of the system by mitigating the variations of the STATCOM nonlinearities.

5 Conclusion

As investigated via time domain simulation and frequency stability analysis using Table 2, the conventional P reactive currents algorithm does not affectively tackle the disturbance and non-linearity in

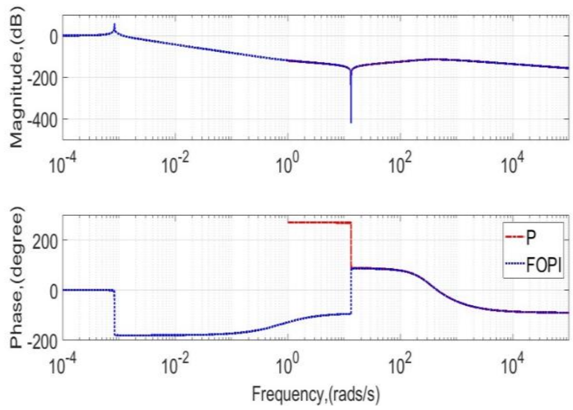

Figure. 9a Frequency response with P and FOPI controllers.

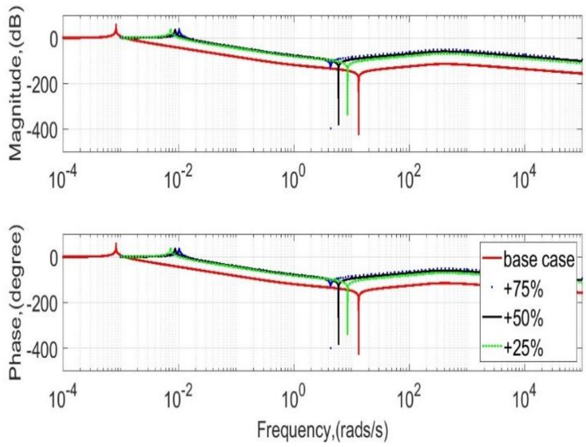

Figure 9b Frequency response of the proposed control with increasing load

the STATCOM system, resulting to transient instability, poor steady state performance, uneven or poor compensation and ripples in the reactive currents while the proposed method achieves approximately 70% reduction in load current ripple and an 80% faster settling time compared to the conventional P controllers. Additionally, the stability margin improves significantly, with phase margin increasing from -180° to +0.167°. These findings highlight the efficacy of the FOPI-based control scheme in enhancing STATCOM system performance, particularly in mitigating ripple and improving transient response speed.

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