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Design and Tuning of Genetic algorithm based Robust Fractional Order Controller for Autonomous Micro-grid VSC System

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Abstract: *A robust controller design for the voltage control of an autonomous three-phase voltage source converter (VSC) is pro-posed. As compared with the conventional proportional plus integral (PI) controllers and fractional order controllers, Genetic Algorithm based FOPI (GAFOPI) controller make the VSC system robust due to their fractional characteristics. This work proposes GAFOPI controller for VSC, the parameters of voltage controller of VSC are tuned with the proposed method. The effectiveness of the proposed method is compared with conventional PI and FOPI controllers on standard test system. Results demonstrated that the proposed method is better in performance compared with conventional and FOPI controllers.*

Keywords: *Genetic Algorithm based Fractional order PI controller (GAFOPI), Fractional order PI controller (FOPI), Voltage source converter (VSC).*

I.INTRODUCTION

Distributed power generation systems are increasingly being deployed in low-voltage networks for “cleaner” and “smarter” power supply. As these are located close to the customer loads, the power supply is cost effective with enhanced reliability of supply [1]. The local interconnections of these distributed generators, loads, and storages are integrated through a network to form micro-grids. Various types of distributed generation like fuel cells, photovoltaic, biomass, and micro turbines are connected to the system through power electronic converters [2]–[5]. The power electronic converters that interface the sources make the system more flexible, robust, and fast as compared to conventional synchronous generators [6]. In autonomous mode of operation, the voltage source converter (VSC’s) are expected operate as similar to uninterrupted power supply system’s [7], and are expected to regulate output voltage through a cascaded control loop [8].

In micro-grid mode of operation, the VSC’s are usually operated in a droop mode where the frequency and voltages are drooped so as to achieve the proportional power sharing [9]. Even under the micro-grid mode, the VSC controllers are used to regulate the voltage and frequency similar to autonomous mode [10], [11]. The typical VSC control scheme consists of the outer voltage controller that ensures tracking of the ac reference voltage, and the inner current controller that is responsible for fast dynamic mitigation of system disturbances [12]. LC filters are used to filter the switching ripples developed due to VSC switching. The inherent resonance of the LC filters can lead to oscillations and unstable dynamic response [13]. Passive and active dampings are widely used in order to damp such oscillations. Conventionally multiple proportional plus integral (PI) feed-back controllers are used in VSC, and are controlled using the rotating synchronous frame (dq frame) for output voltage control [8].

The PI controllers are tuned using simplified approaches such as linear weighted mean square error minimization, Zigler–Nicholas method, etc., with linear assumptions. However, it should be noted that the integrator in a PI controller may introduce saturation and reduce the overall stability margin due to additional phase lag. These controllers are also sensitive to parameter variation and operating conditions [14]. Apart from the conventional PI controllers many other control strategies have been used for the inner control of the VSC such as predictive control [15], table-based control [16], repetitive control [17], intelligent control [18], and neural-network-based control [19].Different control schemes have their own benefits and drawbacks with respect to variations in system parameters and operating points. The predictive control requires precise system parameters for implementation [20]. The table-based control and intelligent control schemes have variable switching frequency, which may result in undesired harmonics in the system and also complicates the design of inverter filter. The repetitive control method has a sluggish dynamics, whereas the neural-network-based control scheme requires a complex training process with high computational burden [20].

In [20], mixed control scheme is proposed in which a sliding mode control is used for the inner current control and outer voltage control is achieved using is mixed nonlinear H2/H∞ using state feedback control law is proposed. In this the designer should be aware of the infinity norm or uniform norm of the system so as to ensure the robustness of the system. But the calculation of uniform of the system is complex. Fractional order control schemes have gained impetus due to their flexibility and effectiveness resulting from higher degrees of freedom [21]. A few studies have been conducted on the applicability of fractional order controllers for power system such design of automatic voltage regulator and load frequency control where it has been shown to give better performance over the PI controllers. They have also been implemented for two area frequency control [22], distributed energy resources control [23] and maximum photovoltaic power tracking controller in micro-grids [24].

In recent, this control is applied in autonomous micro-grid in [25] but the tuning details are not provided clearly. In this paper, a fractional order proportional integral and derivative (FOPID) controller is implemented for the control of VSC in autonomous micro-grid system addressing the drawbacks of [25]. This work proposes Genetic algorithm based fractional order proportional plus integral (GAFOPI) controller, in which the parameters of voltage control loop are obtained using genetic algorithm. This work proposes Genetic algorithm based fractional order proportional plus integral (GAFOPI) controller, in which the parameters of voltage control loop are obtained using genetic algorithm

II.SCHEMATIC MODEL OF VSC

A simplified schematic model of a VSC that supplies an autonomous distribution network along with a local load is shown in Fig. 1(a). The VSC is connected to the micro-grid network with a line having impedance R, L, through a LC filter circuit. The Lf , Cf represent per phase inductance and capacitance of the filter circuit whereas Rf represents the equivalent resistance that include the ohmic losses of the filter inductor and on-time resistance of the VSC switches. i is the current flowing through the Rf , Lf filter, whereas Vo is the voltage across the load and capacitor. The VSC output current flowing after the capacitor point is i_o . All these current and voltage variables indicate instantaneous three phase quantities of the system. In this paper, the net dc side voltage is supported by the dc energy sources like battery banks, photovoltaic (PV) array, etc., considering negligible dc dynamics. The switching dynamics are also neglected with the considerably high switching frequencies f_{sw} (4–10 kHz), [6].

III .CONTROLLER DESIGN & TUNING

3.1 *INNER CURRENT CONTROLLER*

For designing of the controller the complete detailed modelling of the VSC system dynamics are to be considered. The ac series Lf and Rf filter dynamics of the system shown in Fig. 1 are given by [25]

$$L_f \frac{di_d}{dt} = -R_f i_d + \omega_o L_f i_q + v_{id} - v_{od}$$
$$L_f \frac{di_q}{dt} = -R_f i_q + \omega_o L_f i_q + v_{iq} - v_{oq} \tag{1}$$

Where

$$v_{id} = \frac{v_{dc}}{2} m_d$$
$$v_{iq} = \frac{v_{dc}}{2} m_q \tag{2}$$

where v_{dc} is the dc voltage across the VSC input. Since i_d and i_q are cross coupled in (1), they are needed to decouple so as to control d-axis and q-axis separately. The decoupling can be obtained by using feed forward compensation in the system input m_d and m_q as

$$m_d = \frac{2}{v_{dc}}\left(u_d - L_f \omega_o i_q + v_{od}\right)$$
$$m_d = \frac{2}{v_{dc}}\left(u_q - L_f \omega_o i_d + v_{oq}\right) \tag{3}$$

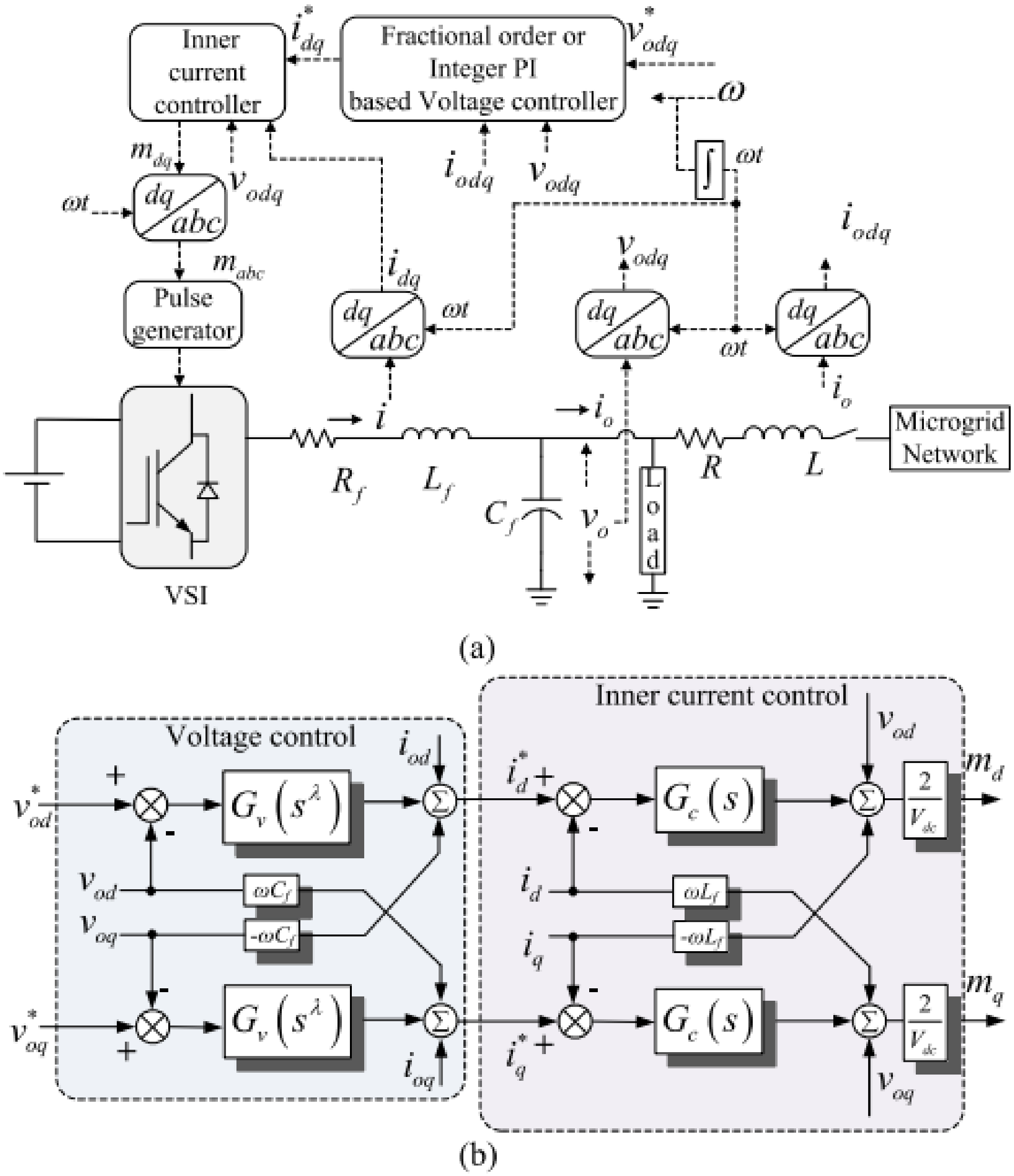


Fig.1. Control schematic of voltage source converter. (a) Schematic of voltage source converter system; (b) Control loop.

$$L_f \frac{di_d}{dt} = -R_f i_d + u_d$$
$$L_f \frac{di_q}{dt} = -R_f i_q + u_q \tag{4}$$

The proportional (k_{pc}) and integral (k_{ic}) gains of inner current control "$G_C(s)$" in Fig. 2 are obtained by using the pole placement for pole-zero cancelation [26], which results in

$$k_{pc} = \frac{L_f}{\tau_c}$$

$$k_{ic} = \frac{R_f}{\tau_c} \tag{5}$$

where τ_c is time constant of the closed-loop system, typically selected as five to ten times of switching time period, i.e., (1/*fs*). Thus, the equivalent closed-loop transfer function of inner current control and series *Lf* and *Rf* filter shown in Fig. 2 is given as

$$G(s) = \frac{1}{\tau_c s + 1} \tag{6}$$

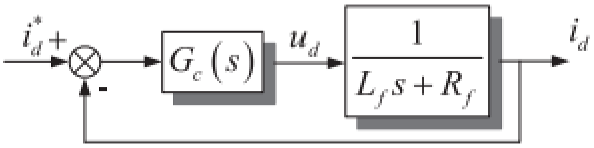


Fig. 2. Simplified VSC current control.

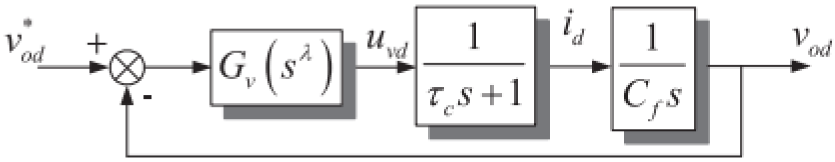


Fig. 3. Simplified voltage control loop of VSC.

3.2 *FRACTIONAL ORDER VOLTAGE CONTROLLER*

The dynamics of the voltage across the filter capacitor in *dq* frame are given by

$$C_f \frac{dv_{od}}{dt} = i_d - i_{od} + C_f \omega_o v_{oq}$$
$$C_f \frac{dv_{oq}}{dt} = i_q - i_{oq} + C_f \omega_o v_{od} \tag{7}$$

As the voltage equations are also cross coupled, the coupling between v_{od} and v_{oq} are eliminated by feed forward compensation similar to the current equations. From (7), the voltage control can be achieved by controlling i_{dq}, since the output current i_{odq} depends on the load and network dynamics.

Considering aforementioned conditions, i_{dq}^* is given by

$$i_d^* = u_{vd} + i_{od} - C_f \omega_o v_{oq}$$
$$i_q^* = u_{vq} + i_{oq} - C_f \omega_o v_{od} \tag{8}$$

IV .PROPOSED METHOD

This paper proposes Genetic algorithm based fractional order PI controller (GAFOPID) for VSC, In which the parameters of voltage controller of VSC are tuned using genetic algorithm. The proposed control method for VSC is shown in fig.4.VSC consists of two controllers first one is voltage controller or outer controller and second one is current controller or inner controller. The outer controller fractional order PI controller values (k_p, k_i and λ) are obtained using genetic algorithm optimization method with the help of voltage error. This voltage error is the error between measured value and reference value. The output of outer controller is the reference current and this acts as an input to the inner controller, based on this value inner controller generates a signal which controls the firing pulses to VSI or VSC.

The genetic algorithm flow chart is shown in fig.5. For acquiring better performance, number of generations, population size, crossover rate and mutation rate is chosen 100, 150, 0.97 and 0.08, respectively. 100 iterations are taken for getting better performance.

$$fitness = \frac{1}{10 * ITAE}$$

$$ITAE = \int_0^t t(|V_{error}|)dt$$

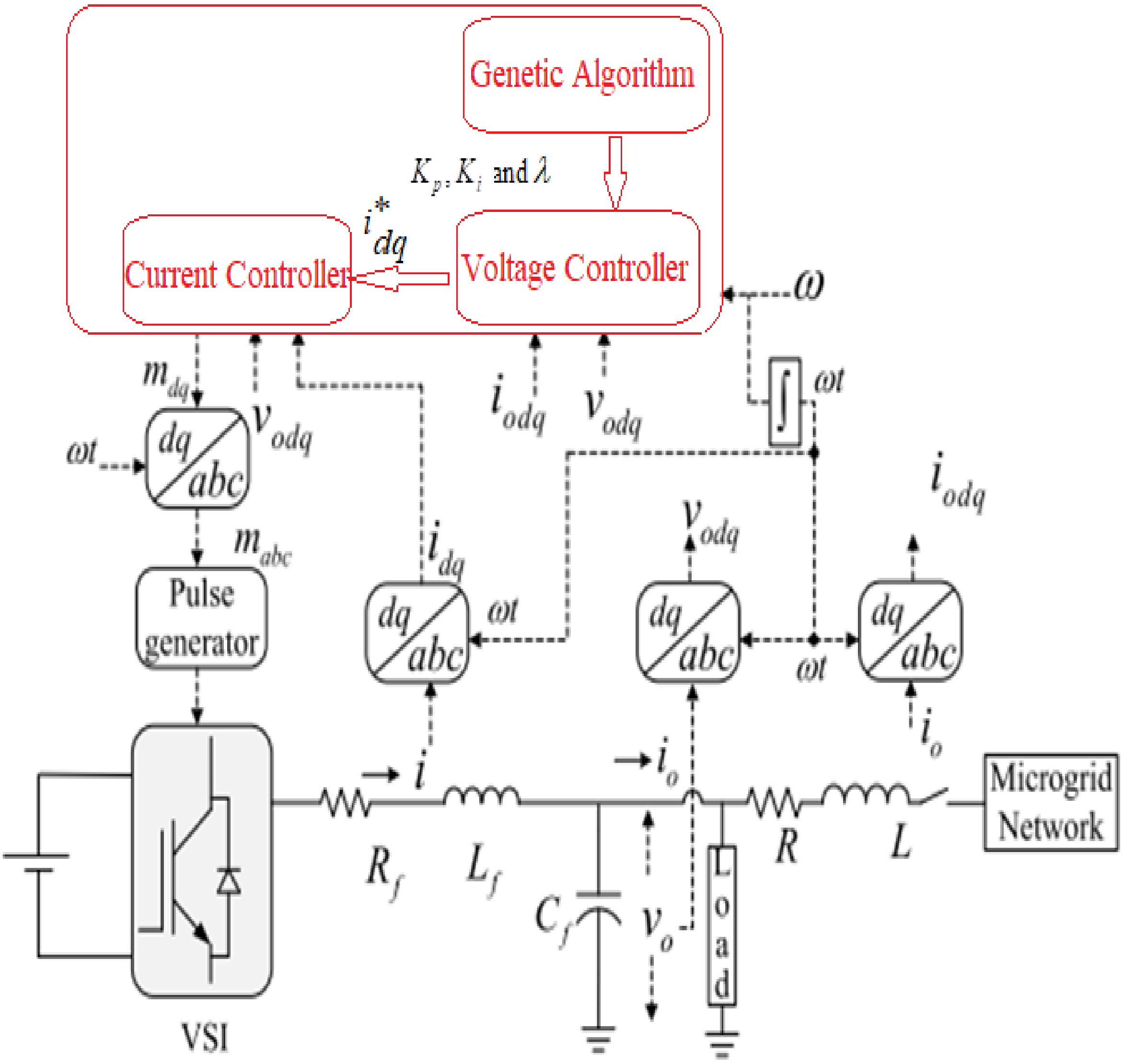


Fig.4. Proposed Control schematic of voltage source converter.

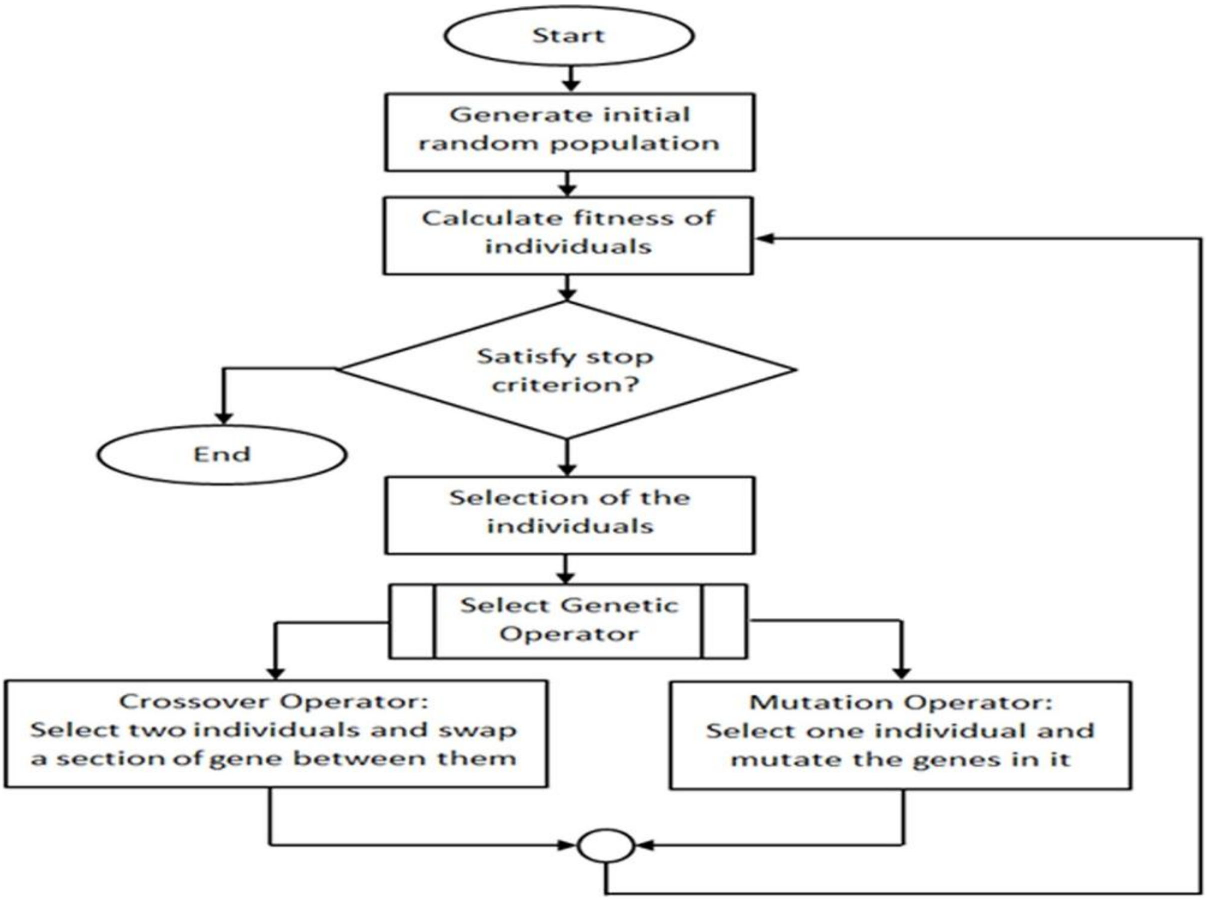


Fig.5. Proposed method Flow chart (Genetic algorithm).

V . TEST SYSTEM & RESULTS

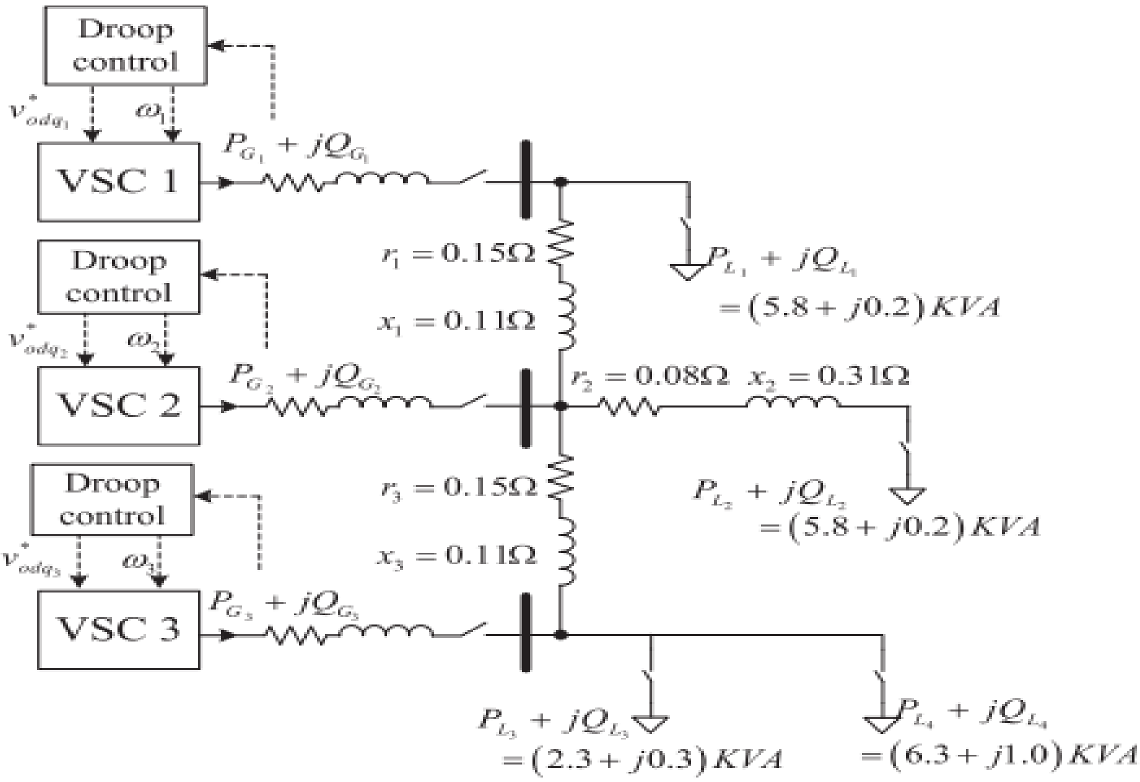


Fig.6. Test system.

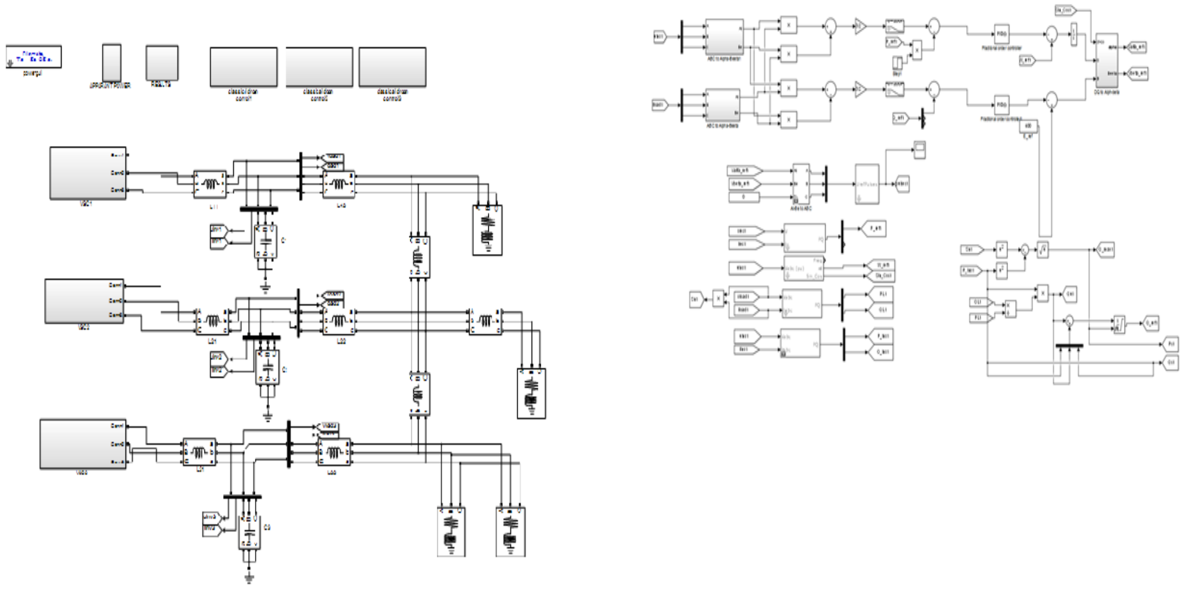
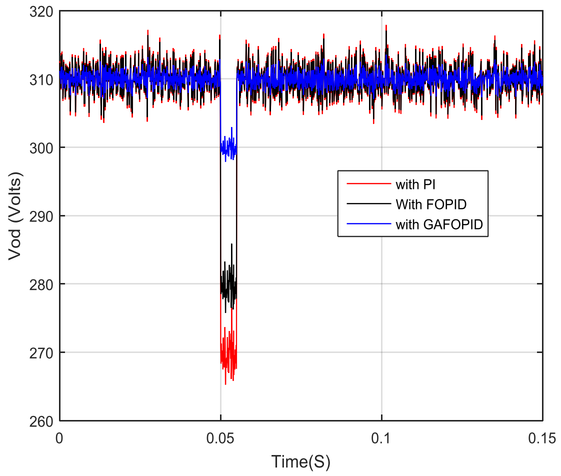


Fig.7. Simulation diagram of proposed method.



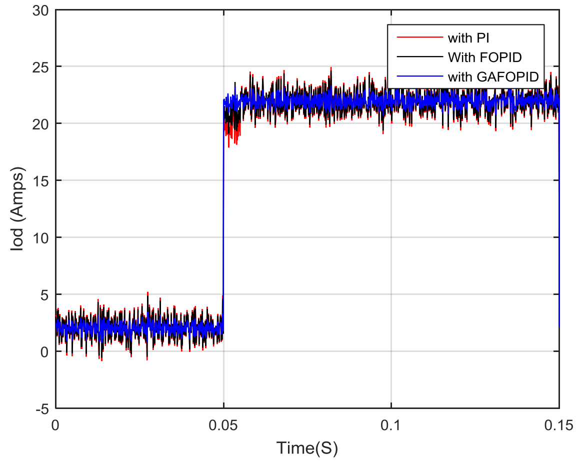


Fig. 8 VSC Response for High resistive loads (voltage & current waveforms)

Test system and its implementation on MATLAB with proposed controller are shown in Figs. 6 & 7 respectively. The simulation done in MATLAB/SIMULINK with three types of controllers for voltage controller of VSC system. First controller is conventional PI, second controller is FOPI and third controller is GAFOPI. Results obtained in three cases, in first case VSC response with high resistive loads, in second case VSC tracking response and the last case is VSC response with parameter variations.

Fig.8 shows the performance of VSC with high resistive loads with PI controller, FOPI controller and GAFOPI controllers. Here the proposed controller reducing the oscillations and also peak overshoots effectively as compared with PI and FOPI controllers.

Fig.9 shows VSC system tracking response with PI controller, FOPI controller and GAFOPI controllers. Here the proposed controller reducing the oscillations and also peak overshoots effectively as compared with PI and FOPI controllers.

Fig.10 shows VSC system robustness with parameter variations with PI controller, FOPI controller and GAFOPI controllers. Here the proposed controller reducing the oscillations and also peak overshoots effectively as compared with PI and FOPI controllers.

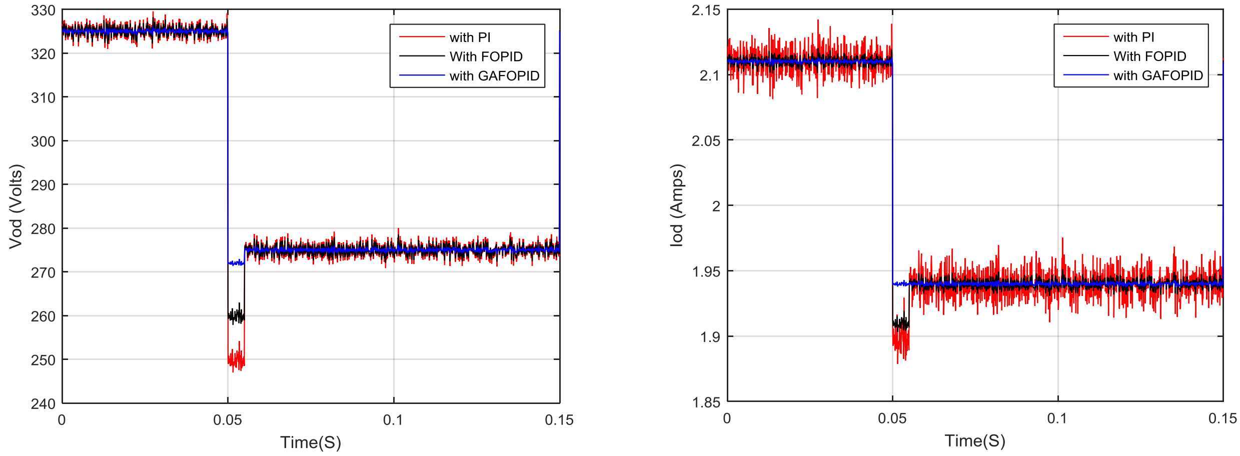


Fig. 9 VSC Reference Tracking Response (voltage & current waveforms)

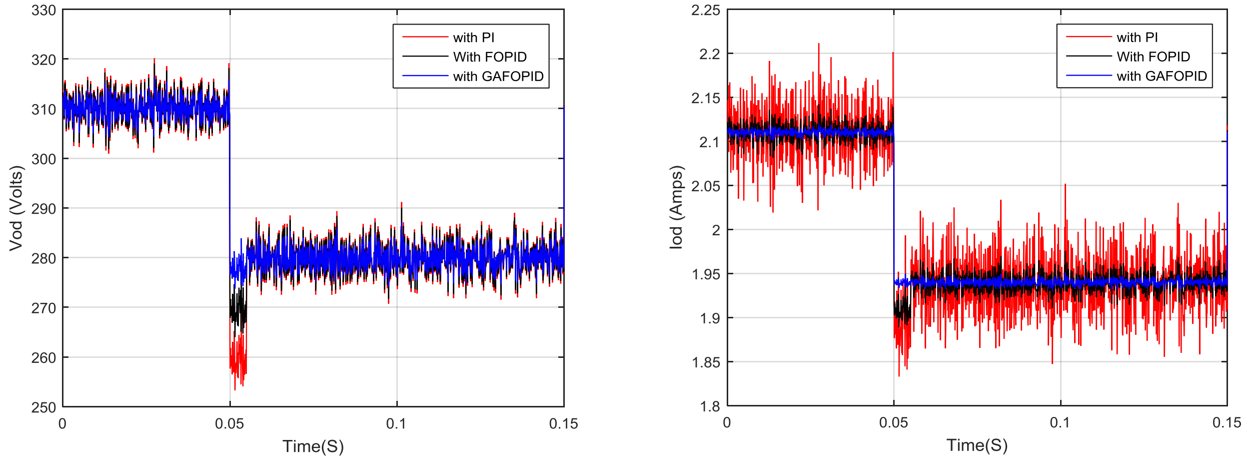


Fig. 10 VSC System Robustness under parameter variations (voltage & current waveforms)

V . CONCLUSIONS

Detailed designing and tuning of a robust fractional order control is presented for the voltage control of VSC systems. The time response of the proposed controller was also observed for both linear (step response) and nonlinear system simulations in MATLAB/Simulink. When compared to a conventional PI controller and FOPID controllers, GAFOPID controller shows marked improvement in performance, specifically reducing the peak overshoot, improved response time, and oscillation damping capability.

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