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Fuzzy Sliding Mode based PI Controlled UPFC for optimized WECS dynamics during fault ride through

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Abstract:

This study presents a comparative study of transient stability and reactive power compensation issues in an autonomous wind energy conversion system (WECS) using robust fuzzy-sliding mode based unified power flow controller (UPFC). It is noted from the simulation results that the performance of UPFC is superior to static VAR compensator and static synchronous compensator in improving the voltage profile of the WECS. Further, fuzzy and fuzzy-sliding mode based UPFC controller is designed in order to improve the transient performance. Simulation results reflect the robustness of the proposed fuzzy-sliding mode controller for better reactive power management to improve the voltage stability in comparison with the conventional PI and fuzzy-PI controllers. In addition to this, system stability analysis is performed based on Eigen value, bode and Popov for supporting the robustness of the proposed controller.

This paper presents a nonlinear controller based on the fuzzy sliding-mode control technique to improve the transient stability of the power system. The rapid response of a controller is very desirable to damp transient power oscillation in the power system which is achieved with this control technique by shifting the sliding surface closer to the error trajectory using fuzzy logic. By this the sliding mode control unit need not wait for the state errors to strike the sliding surface. This modification enhances the performance of sliding mode control and also avoids the chattering effect. To validate the sturdiness of the controller computer simulation has been done by inducing transient disturbance at three different operating points and its performance has been compared with conventional PI controller. Following a transient disturbance, the range of deflection in rotor angle is competently delimited by this nonlinear controller to maintain the generator in synchronism. The effectiveness of this nonlinear controller has been found to be independent of the operating point of power system.

Introduction

Ever since AC power system has appeared its stability has always remained as a concern for power system engineers. Among different types of stabilities transient stability is the most precarious one to be dealt with as it involves sudden large disturbances in the system. So in order to ensure the transient stability of the power system one needs to provide fast and sufficient damping to the power oscillations.

This can be achieved by application of fast acting power electronics based FACTS devices and among them. Unified Power Flow Controller (UPFC) is the most versatile one. In order to enable these FACTS devices to provide very rapid and sufficient damping effect we also need control mechanism with very rapid response. The conventional controllers such as PI control, are optimized only for single operating points and their performances are prone to parameter variations. The nonlinear characteristics of power

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system have great impact on the transient stability of the system and UPFC is also a highly nonlinear device, so a nonlinear control technique would be better to improve transient stability using UPFC.Sliding mode control (SMC) is nonlinear control technique which shows rapid response and immunity against operating point variations, and this control mechanism has been tested for UPFC to improve power oscillation damping, but it exhibits chattering effect and has been tested only for single operating point. The chattering effect caused by the SMC results in decreased control over the system and thermal losses in the electrical system.Keeping above points into consideration, this paper proposes the combination of fuzzy logic and SMC to achieve very fast control at every operating point without facing chattering effect. Recently also sliding mode controller has been implemented in UPFC to improve the power flow capability of power system in terminal sliding mode control as well as asymptotically sliding mode control has been proposed for power flow control, however this paper is silent about the variation of rotor angle under transient conditions.

Unified power flow controller (UPFC)

A **Unified Power Flow Controller** (or UPFC) is an electrical device for providing fast-acting reactive power compensation on high-voltage electricity transm ission networks. It uses a pair of three-phase control able bridges to produce current that is injected into a transmission line using a series transformer. The controller can control active and reactive power flows in a transmission line. The UPFC uses solid state devices, which provide functional flexibility, generally not attainable by conventional thruster controlled systems. The UPFC is a combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) coupled via a common DC voltage link. The main advantage of the UPFC is to control the active and reactive power flows in the transmission line. If there are any disturbances or faults in the source side, the UPFC will not work. The UPFC operates only under balanced sine wave source. The controllable parameters of the UPFC are reactance in the line, phase angle and voltage. The UPFC concept was described in 1995 by L. Gyugyi of Westinghouse. The UPFC allows a secondary but important function such as stability control to suppress power system oscillations improving the transient stability of power system.

II. MODELLING OF SMIB WITH UPFC

Fig. 1 shows the UPFC connected with the single machine infinite bus (SMIB) system Voltage at the generator terminal is $V_1\angle\delta$, impedance of the tieline and series connecting transformer is $r_{se}+jx_{se}$, impedance of shunt connecting transformer is r_s+jx_s, and voltage at the bus is $V_b\angle\theta$. Current from the generator is I_{se}, current exchanged by shunt converter is Isand current flowing through series converter is I b respective subscripts d and q represents the direct and quadrature axis components.Fig. 2 shows the vector diagram of different voltages in d-qreference frame. The mathematical structure of SMIB with UPFC used in the paper is based on dq0 reference frame. With the higher modeling of synchronous generator, the accuracy of the system increases, but it also increases the system complexity.

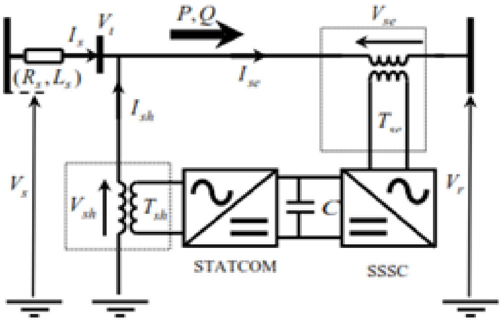

Fig. 1 Basic power system with UPFC

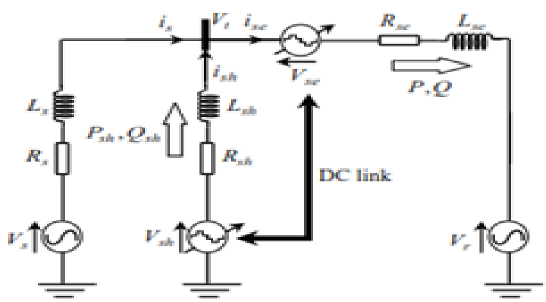

Fig. 2 Single phase equivalent circuit of UPFC

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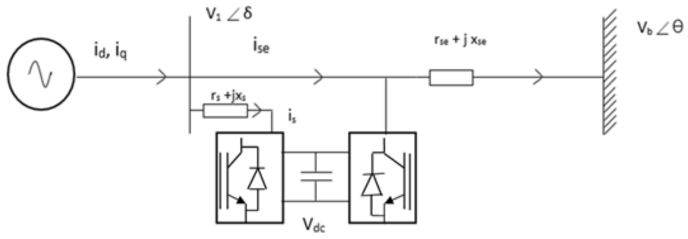

Figure 1: Single Machine Infinite Bus System with UPFC

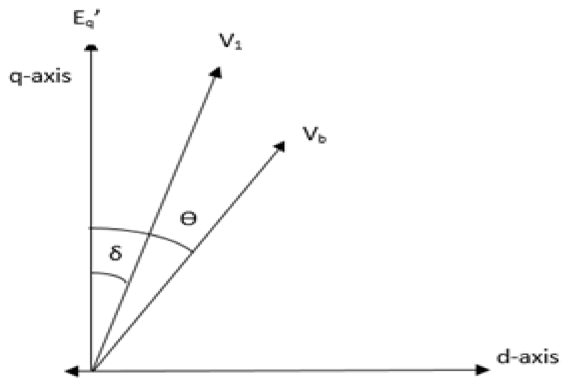

Fig. 2. Vector diagram of voltages in d-q reference frame

With the higher modeling of synchronous generator the accuracy of the system increases, but it also increases the system complexity. So to maintain the required accuracy and avoid system complexities we have used fourth order model of synchronous generator, by neglecting the effect of the damper winding as illustrated in reference [10]. The generator data is taken from reference [11]. The expressions describing the behavior of the synchronous generator are given as follows:

$$\dot{\delta} = \Delta\omega \tag{1a}$$

$$\dot{\omega} = \frac{\pi f_0}{H}(P_m - P_e) \tag{1b}$$

$$\dot{E_q'} = \frac{E_{fd0} + \Delta E_{fd} - E_q' - (x_d - x_d')i_d}{\tau_{d0}'} \tag{1c}$$

$$\Delta \dot{E}_{fd} = \frac{-\Delta E_{fd} + K_e(V_{ref} - V_1)}{\tau} \tag{1d}$$

The UPFC is modeled with two voltage source converters(VSC) one in shunt and other in series with the tie line, both the converters are linked through a DC link capacitor, in order to maintain voltage support for the converters and provide independent control for real and reactive powers by the two converters.In UPFC both the converters are able to exchange real and reactive power with the power system, but in our system we have used series converter to exchange the real and reactive power and shunt converter has been used to exchange the real power demanded or absorbed by the series converter to keep the DC link capacitor voltage constant. The mathematical structure for the UPFC has been used as described in reference [12] and is given as follows:

Shunt Converter

$$\frac{d}{dt}\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = \begin{bmatrix} \frac{-r_s}{L_s} & \omega \\ -\omega & \frac{-r_s}{L_s} \end{bmatrix}\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_s} & 0 \\ 0 & \frac{1}{L_s} \end{bmatrix}\begin{bmatrix} V_d - e_{sd} \\ V_q - e_{sq} \end{bmatrix} \tag{2}$$

Series Converter

$$\frac{d}{dt}\begin{bmatrix} i_{sed} \\ i_{seq} \end{bmatrix} = \begin{bmatrix} \frac{-r_{se}}{L_{se}} & \omega \\ -\omega & \frac{-r_{se}}{L_{se}} \end{bmatrix}\begin{bmatrix} i_{sed} \\ i_{seq} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_{se}} & 0 \\ 0 & \frac{1}{L_{se}} \end{bmatrix}\begin{bmatrix} V_d + e_{sed} - V_{bd} \\ V_q + e_{seq} - V_{bq} \end{bmatrix} \tag{3}$$

Where $i_d = i_{sd} + i_{sed}$ and $i_q = i_{sq} + i_{seq}$ (4)

The DC link capacitor voltage dynamics has been established on the basis of power balance on the DC side of the converters. The net real power exchanged by both the converters through DC side should be zero to keep the capacitor voltage constant.

The voltage dynamics across the capacitor is given as:

$$\frac{d\dot{V}_{dc}}{dt} = \frac{(V_d * i_{sd} + V_q * i_{sq}) - (e_{sed} * i_{sed} + e_{seq} * i_{seq})}{C * V_{dc}} \tag{5}$$

Steady state equations used in the system are:

$$E_q' = V_q + X_d' * i_d \tag{6}$$

$$E_{fd} = E_q' + (x_d - x_d') * i_d \tag{7}$$

$$i_{sd} = i_s \cos\delta \tag{8a}$$

$$i_{sq} = i_s \sin\delta \tag{8b}$$

$$\delta = \tan^{-1}(V_d / V_q) \tag{9}$$

$$V_{bd} = e_{sed} + (x_q + x_{se}) * i_q - x_{se} * i_{sq} \tag{10a}$$

$$V_{bq} = e_{seq} + E_q' - (x_d' + x_{se}) * i_d + x_{se} * i_{sd} \tag{10b}$$

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A. Sliding Mode Control

The sliding mode control is popular nonlinear control technique which is known for its robustness against parameter variations. The SMC based controller brings the system to steady state by sliding the state trajectory along the sliding surface and reducing the error value to zero, when the state trajectory reaches to origin. This sliding surface is usually defined by using the error and its derivative as in (12).

$$e = y_{ref} - y_{actual} \quad (11)$$

$$s = e + k\dot{e} \quad (12)$$

To get obtain an attractive surface the dynamics usually chosen is

$$\dot{s} = m.\mathrm{sign}(s) \quad (13)$$

Since, the switching caused by the *signum* function is hard one we replace it by tanh function to make the controller outputsmoother [13] as shown in the Fig. 3.

$$\tanh(x) = \begin{cases} \mathrm{sign}(x) \text{ if } |x| \geq 1 \\ x|x| + 2x \text{ if } |x| \langle 1 \end{cases} \quad (14)$$

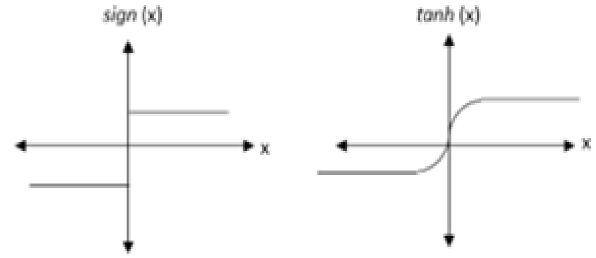


Fig. 3. Outputs of signum and tanh function.

So the controller output would be:

$$u = m.\tanh(s) \quad (15)$$

B. Fuzzy-Sliding Mode Controller

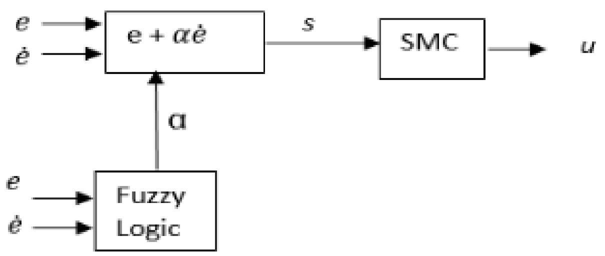
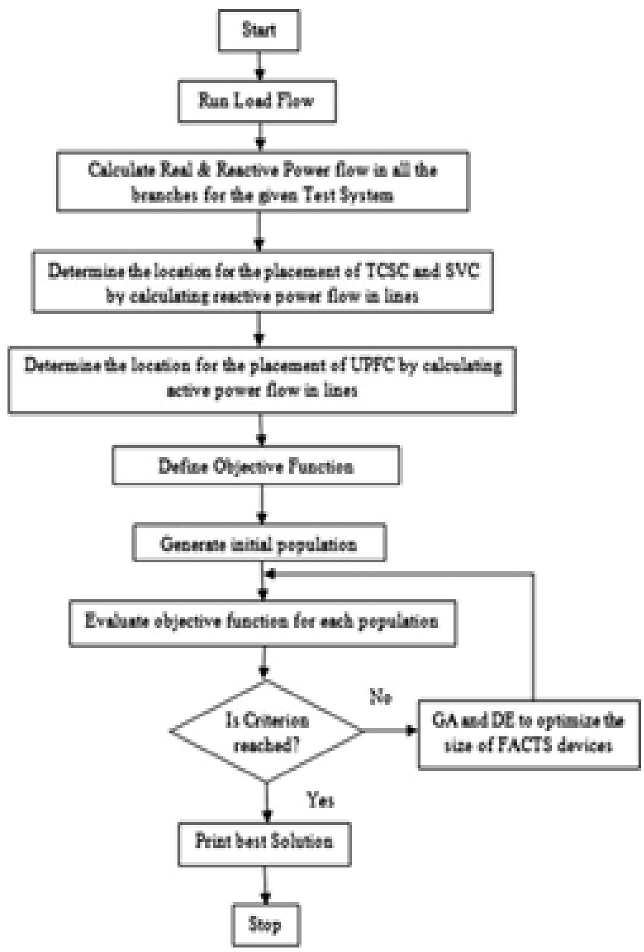


Fig. 4. Control structure for the Fuzzy-Sliding Mode Controller

The fuzzy logic component of the controller works to alter the slope of the sliding surface in accordance with the state errors to make the response faster and bring the system to steady state rapidly [7].In this way the controller need not to wait for the state error to reach the sliding surface rather the sliding surface moves towards the state error, so that the errors only need to slide over the surface and reach zero. Once the Fuzzy logic has done its job the SMC unit makes the state errors to slide along the surface to reach zero. The fuzzy logic unit takes state error e and its derivative with respect to time, to determine the position of the state error relative to the sliding surface and output of the fuzzy logic is the required updated slope (a) for the sliding surface. As the SMC unit does not bring the state error far from its original position, so the SMC controller gain is not very high, which helps in preventing chattering effect?

Algorithm



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A. Real Power Flow Control

The real power control is achieved by the series converter of the UPFC, to stabilize the real power flow through generator; controller takes the rotor speed deviation as error during sudden transients. Corresponding to this error the FSMC controls quadrature axis component of the voltage injected by the series converter, which in turn enhances the real power flow in the line.

B. Reactive Power Flow Control

The reactive power control is achieved by the series converter of the UPFC, to stabilize the reactive power flow through generator; controller takes the deviation of reactive power flow from the reference value as error during sudden transients. Corresponding to this error the FSMC controls direct axis component of the voltage injected by the series converter, which in turn manages the reactive power flow in the line.

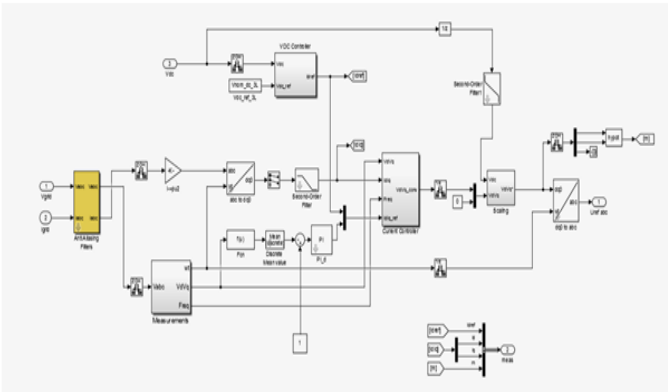
C. DC Capacitor Voltage Control

The DC link capacitor voltage is maintained at a constant value by the shunt converter. It absorbs or supplies the real power to the DC capacitor as needed by the series converter to maintain the power balance on the DC side. It takes the deviation of the capacitor voltage from the reference value as error and corresponding to this error the FSMC regulates the current exchanged by the shunt converter.

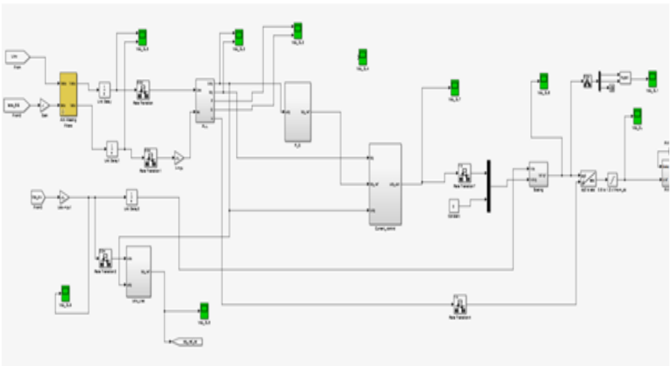
IV. SIMULATION AND RESULT

The ability of the Fuzzy Sliding Mode Controller with UPFC to damp the transient power oscillation is analyzed by inducing three phase fault near the generator terminal for 120milliseconds. This assess ment has been carried out for three different power levels to establish the robustness of the controller. Due to the fault the voltage reduces to a critical value and the power flow in the system is hindered which leads to the transient oscillation in the power system. All the values are taken in per unit system during modeling and simulation.

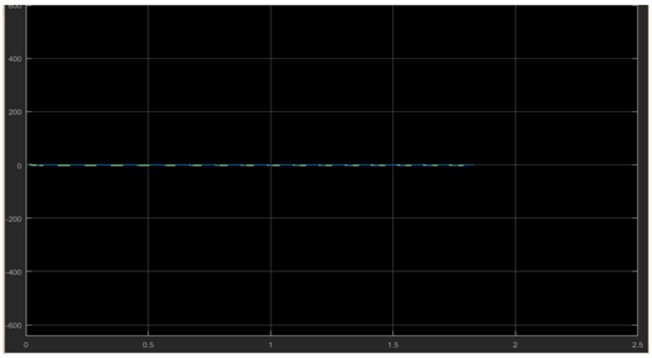
The project has been implemented using Mat lab& Simulink



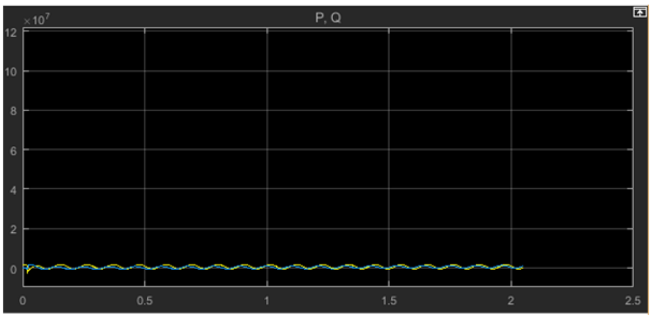
SEC Control System



REC Control System



Vdc_3LggH



PQ_Grid

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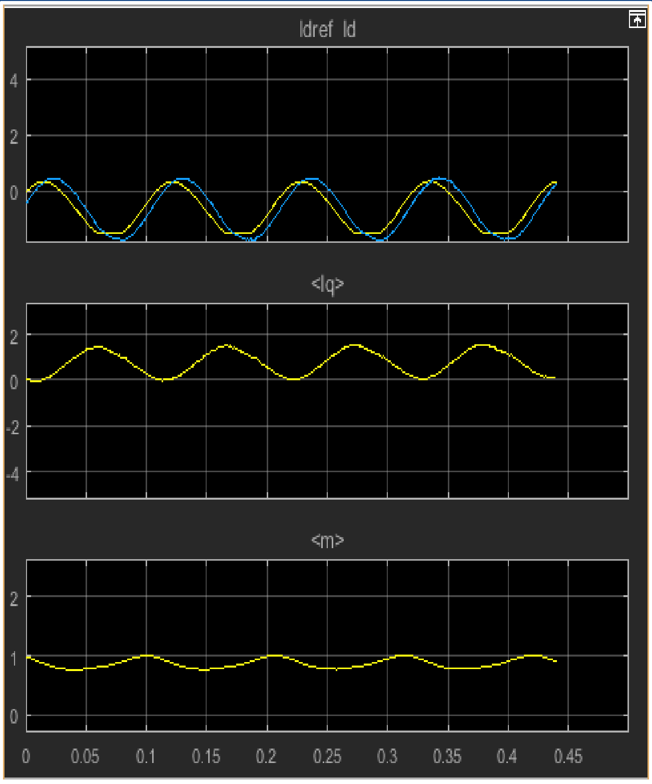
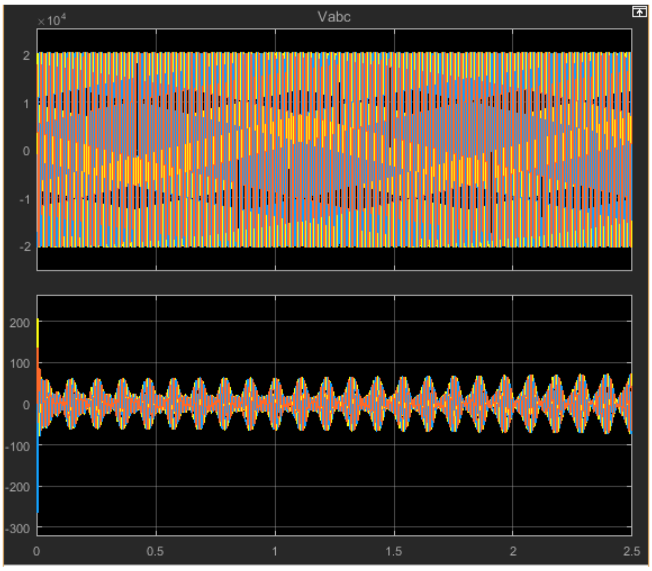
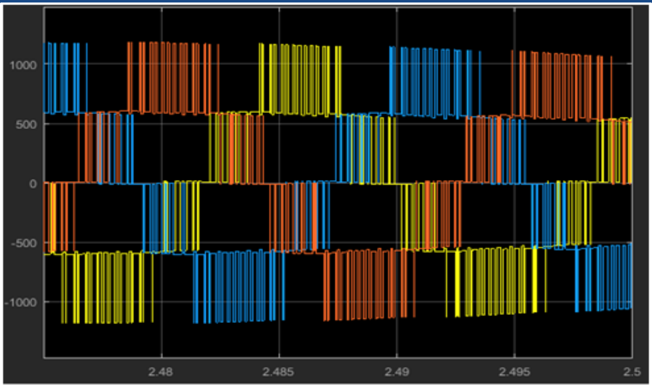


3L_Rectifier control



VI Grid



VSec 3l

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