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Power System Oscillation Damping and Stability Enhancement using Static Synchronous Series Compensator (SSSC)

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Abstract: In modern power system network power oscillation is a major source of concern for power utilities. Because of the enormous demand on power system has initiated the system to load heavily which leads to voltage unbalance conditions. The static synchronous series compensator (SSSC) is capable of delivering a compensating voltage with an inductive and capacitive range. SSSC is a FACTS device which is used to increase the power system capacity and system stability. SSSC has a voltage source converter, dc capacitor and a series transformer which injects voltage in series with the transmission line. SSSC-based power oscillation damping (POD) controller is proposed to eliminate the power oscillation damping in power system and enhance the transient stability. Also, controller used here for controlling SSSC is hysteresis controller and lead lag controller to enhance the dynamic response of the system. A multi machine bus system with SSSC and POD controller is simulated in MATLAB/Simulink software. Simulation results show the effectiveness of this controller with SSSC for power system stability enhancement under different fault conditions.
Keywords: Static synchronous series compensator (SSSC), Power oscillations, Flexible AC transmission system (FACTS), Power oscillation damping (POD).

I. INTRODUCTION

A power system is becoming more complex and heavily loaded day by day. Earlier electric power systems were small and localized. Thus, real and reactive power compensation in transmission line is necessary which will improve the stability of the power system. Due to high non-linear characteristics of modern power system, the operating parameters changes continuously. Unwanted power differences and increasing load over the transmission lines also result in power oscillation in the system. The power systems must be able to withstand all these variations. Due to such characteristics, oscillations last for few seconds (3-20 sec.) in a power system after a severe fault occur. It becomes important to damp out these oscillations as soon as possible. These unnecessary oscillations may cause huge power quality disturbances in power plant and power system stability problems. Considering the stability conditions the power transfer capability is limited in long transmission. The FACTS devices are more advantageous in controlling the power in the transmission lines. Because of the presence of the FACTS controller the power system stability has been improved under different fault conditions and also improved voltage stability, reactive power compensation and oscillation damping. In this paper, static synchronous series compensator (SSSC), one of the types of FACTS controllers is examined. A Static Synchronous Series Compensator (SSSC) is a series controller of FACTS family is connected in series with the transmission lines and used to improve stability and performance of the system.

The SSSC controller mainly depends on the output amplitude of voltage source converter (VSC) with several semiconductor and thyristor switches. The SSSC circuit model has a voltage source converter (VSC), DC capacitor and a series coupling transformer. Coupling transformer are connected in series with power system which couples the SSSC with the transmission line. Primarily shunt compensation is utilized mainly to maintain the required voltage profile in the transmission line. Whereas Series compensator can primarily operate over the steady state power transmission, maximum power transmission capability, voltage stability and transient stability. These series controllers are more productive in compensation of reactive power and active power exchange as compare to shunt controller. Also, this series compensation provides most cost-effective mean to maintain stability of power system.

FACTS controllers are classified in four main categories: shunt controller, series controller, series-series controller and series-shunt controller. Series connected FACTS devices can directly control active power flow control by changing its line reactance in transmission line. GCSC, SSSC, TCSC are the series FACTS devices.

The purpose of series controller is to increase or decrease the overall reactance of the transmission line in order to control the reactive voltage drop across the line and thereby controlling the transmission line electric power.

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This paper proposes how SSSC can be utilized for enhancing stability of power system by providing reactive power compensation. SSSC has its own control unit and we can also provide external control to it. There are many controllers such as proportion integral (PI), proportional integral derivative (PID), hysteresis control. Amongst which hysteresis controller is used because of its simplicity and faster response. This controller also gives beneficial and reliable ratio between costs to performance.

II. STATIC SYNCRONOUS SERIES COMPENSATOR

SSSC circuit model consists of solid-state voltage source converter (VSC), which feeds sinusoidal voltage of variable magnitude in series with transmission line. Voltage injected in the line is in quadrature with the line converter. A small part of voltage which got injected in phase with the line current is considered as a loss in the inverter. Voltage injected in quadrature of line current is considered as inductive or capacitive reactance in series with the transmission line, which affects the power transfer capability of transmission line.

The transformer is connected to voltage source converter. VSC has a DC capacitor, here DC capacitor is assumed as energy storage device. Depending upon the control circuit the SSSC works along with the transient change. The DC capacitor produces a voltage which is given as input to VSC and then it finally converts the DC form to ac form and injects the AC voltage through the coupling transformer and injects voltage from SSSC to the line. For controlling the power flow, current voltage and reactive powers in d-q references are calculated and compared to produce the error signal. This error signal is given as input to the PI controllers. The main purpose of PI controller is to reduce or eliminate steady state error.

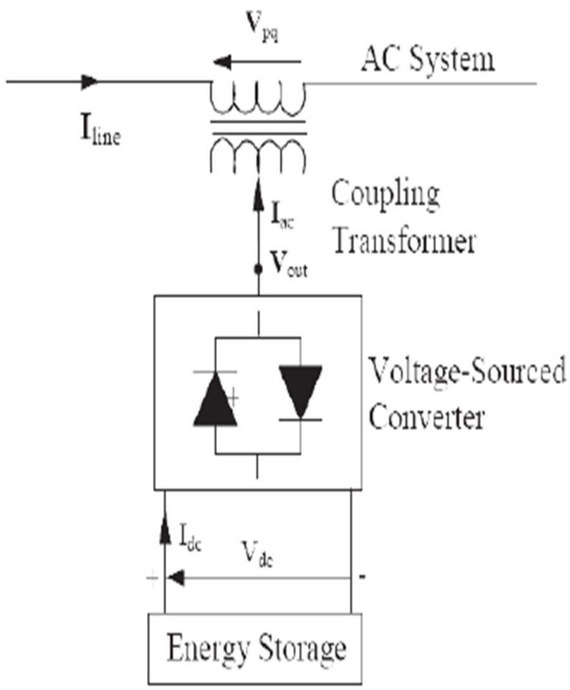

Fig 1. Basic SSSC configuration

SSSC can be used as an ideal synchronous voltage source which produces three-phase AC voltages of desired fundamental frequency with controlled amplitude and phase angle. This injected voltage is nearly sinusoidal ac voltage with variable magnitude and phase angle. SSSC provides advantage over TCSC that if removes gigantic passive component of reactors and capacitor. An expression for injected voltage by SSSC is given as,

Vsssc = ± j Vsssc(e) (I/I) (1)

Where, Vsssc (0) is value of injected voltage by SSSC at (0 < Vsssc(e) < Vssscmax) by changing phase angle, magnitude of VSSSC can be maintained at required level. SSSC have its own controlling unit which controls the switching action for VSC. In proposed paper a hysteresis controller is provided to internal control system of SSSC. Working and structure of proposed controller is explained further in this paper.

III. INTERNAL CONTROL SYSTEM OF SSSC

As explained earlier SSSC requires controller for its switching action of VSC. A hysteresis controller is proposed in this paper. Hysteresis controller is used separately for each phase and directly creates the switching signals for the switches of the inverter. The error signal is the difference between the reference current and the actual current and if the error current outstrips the top limit of the Hysteresis band, the upper switch of the inverter limb is turned OFF and the lower switch is turn ON. If the error current crosses the foot limit of the Hysteresis band, the lower switch is turn OFF and the upper switch is turned ON.

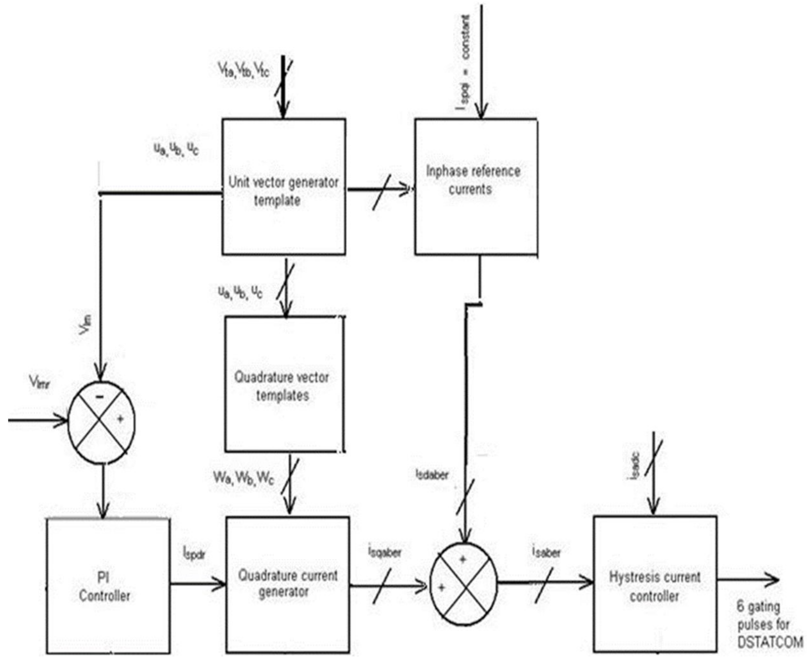

Fig 2. Internal control diagram of SSSC

This method controls the switches of the voltage source inverter asynchronously so that it ramp the current through the inductor up and down and follows the reference current. Hysteresis current control is the simplest control method to execute in the real time. The hysteresis control method enhanced system stability, it has simple implementation and increased response speed and reliability.

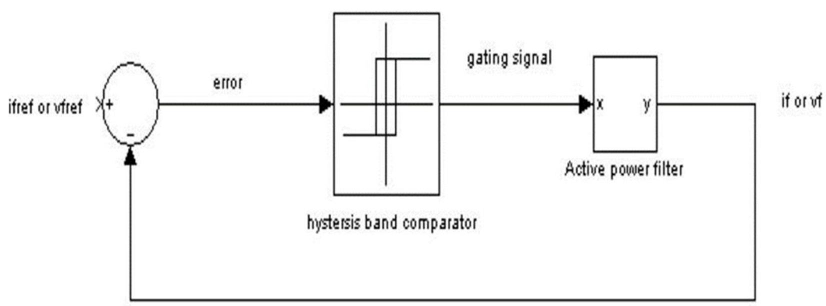

Fig 3. Hysteresis Control

IV. POWER OSCILLATION DAMPING CONTROLLER

POD controller is mainly used to provide an additional input signal to damp out power system oscillations. Some of the commonly used input signals are bus voltage, line current from bus, line power and line reactive power from bus.

A POD controller is proposed as a SSSC-based damping controller to control the injected voltage of SSSC. It consists of a gain block, washout block and two stage lead-lag blocks. The gain block is used to damp out the oscillations. The two-stage lead-lag blocks provide suitable phase-lead characteristics to compensate for the phase lag between input and the output signals and vice versa. The washout block is mainly used for the removal of overshoots and signals which are the below required frequency i.e. it acts as filter and allows signals associated only with oscillations to pass through it.

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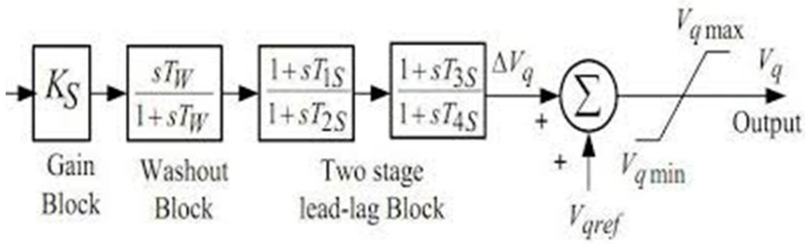

Fig 4. Design Structure of POD Controller

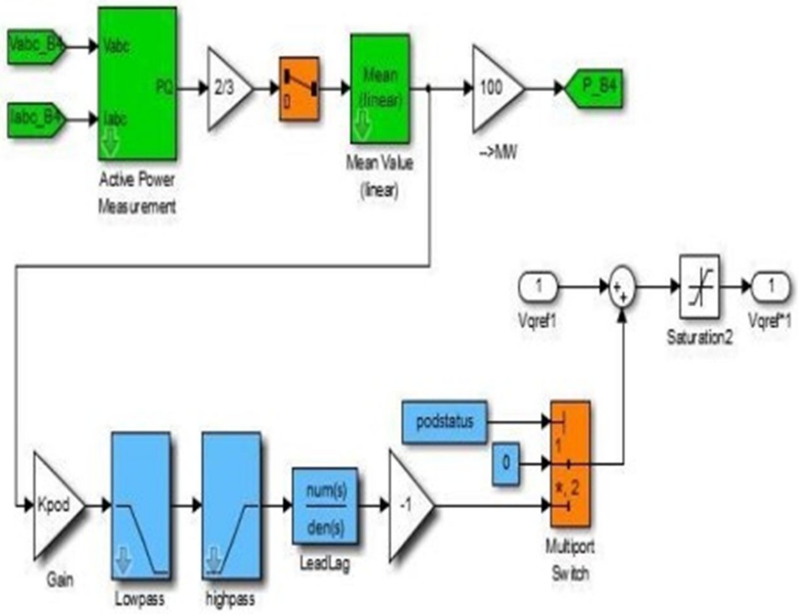

Fig 5. Simulink Design for POD Controller

Under steady state condition Vqref is the desired reference value of the compensation voltage to be injected in transmission line under steady state condition. Resultant value of compensation voltage Vq is obtained by adding the modulated voltage (ΔVq) to the Vqref. This Vq output signal from controller is given to the SSSC internal control system, so that SSSC can provide compensation in order to limit damping and remove oscillation of the system.

Vq = Vqref + ΔVq.

The inputs to the POD controller are the current flowing in line 2 and the voltage at bus no.4. The POD takes input as Vabc, Iabc and it convert it as power. If there is no fault in the system then switch will remains open. But if there is any kind of fault occurs on transmission line then controller becomes closed.

V. TEST SYSTEM DESCRIPTION

The proposed test power system has two generating stations and one major load centre at bus no. 3. The generating station (G1) has a rating of 2100 MVA and the other generating station (G2) which has a rating of 1400 MVA. A dynamic load is connected before bus 3 in transmission line having magnitude of 2200 MW. Both the generators are being followed by two transformers having rating of 2100 MVA and 1400 MVA. The transmission lines are used to connect the load and the machines in the system. One of the generating stations is connected to the load through transmission lines. Line 1 is 280 km long and Line 2 is split into two segments L2-1 150 km and L2-2, 150 km, to simulate a three-phase fault by using a fault breaker at the midpoint of the line. SSSC is connected to bus no. 2 in series with Line 1. The unsymmetrical faults are applied at bus no. 4 of given time period in proposed case the fault will be applied at 1.33 s and will last for 10 cycles. For all fault conditions, variation on power at bus no. 2 is checked by making POD controller ON and OFF. Both results are compared and effectiveness of POD controller can be verified. The results discussed in this section are obtained from MATLAB/Simulink software.

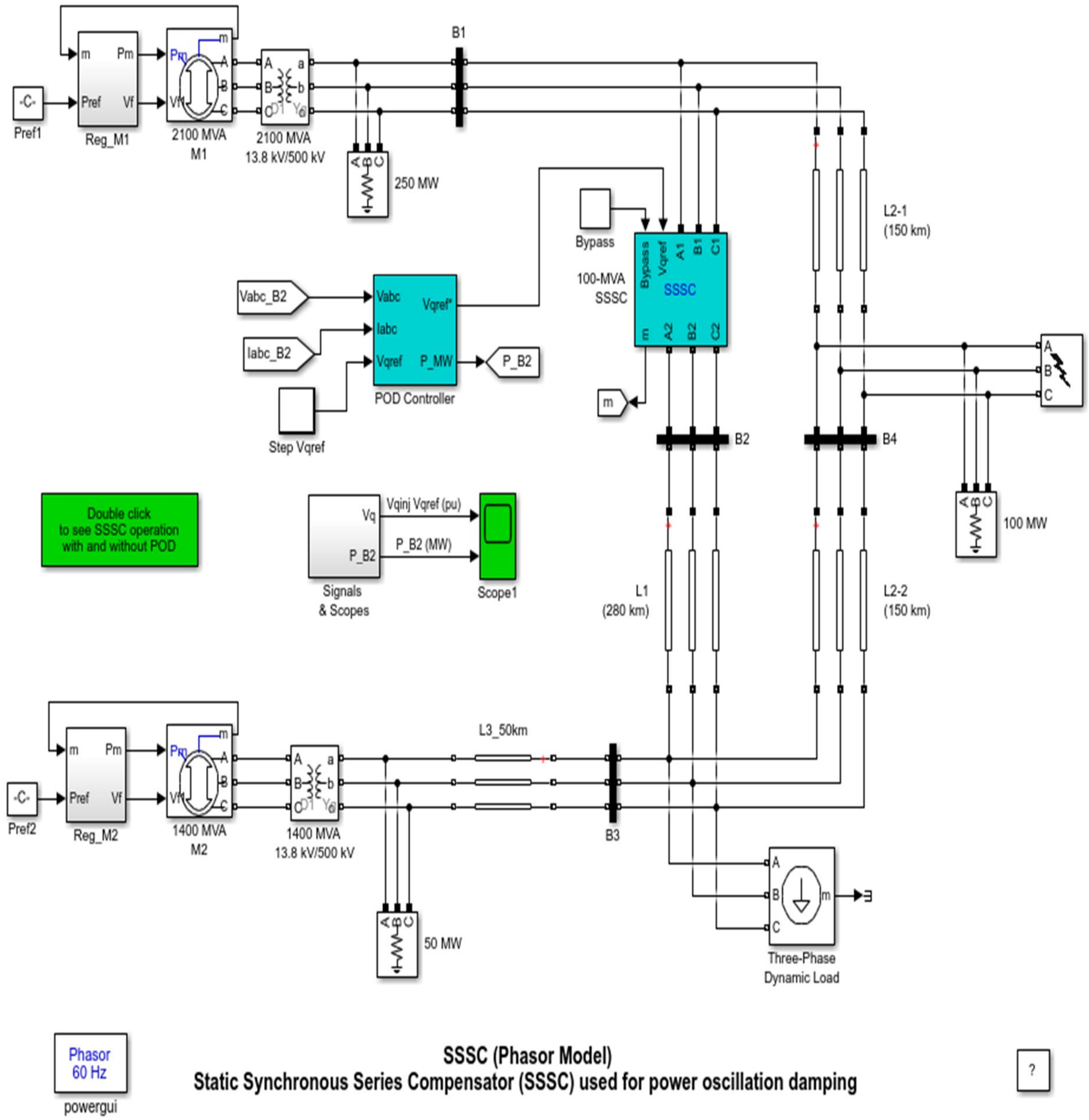

Fig 6.

Different fault conditions such as line to ground fault, double line to ground, and three phase faults are examined through Simulink software, with and without power oscillation damping controller.

VI. SIMULATIONS AND RESULTS

The effect of SSSC based POD controller in damping out power oscillation is analysed for different cases. The unsymmetrical fault is created for three conditions when POD is OFF and second when POD is ON. Simulation results of line power flow and the Vqref and Vqinj for with and without SSSC damping controller under different fault conditions for bus 2 are examined.

A. CASE I. Line to ground fault with and without POD.

In line to ground fault case POD is maintained OFF at first and then made ON. The fault is simulated at the midpoint of transmission line 1. This fault lasts for 10 cycles and gets cleared thereafter. Observation of power and voltage at bus 2 are then recorded.

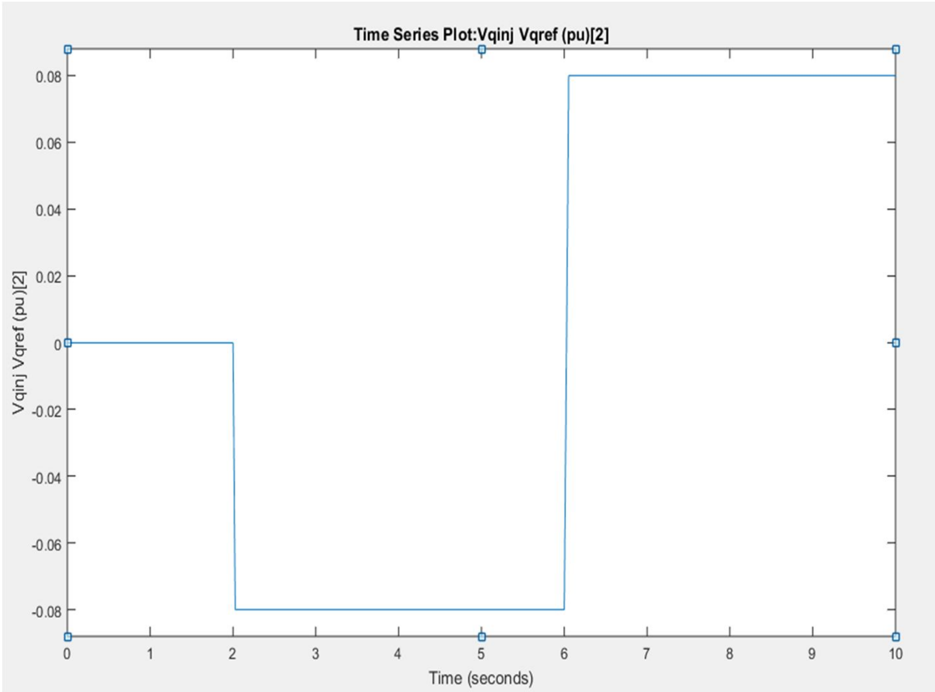

Fig 7 (a)

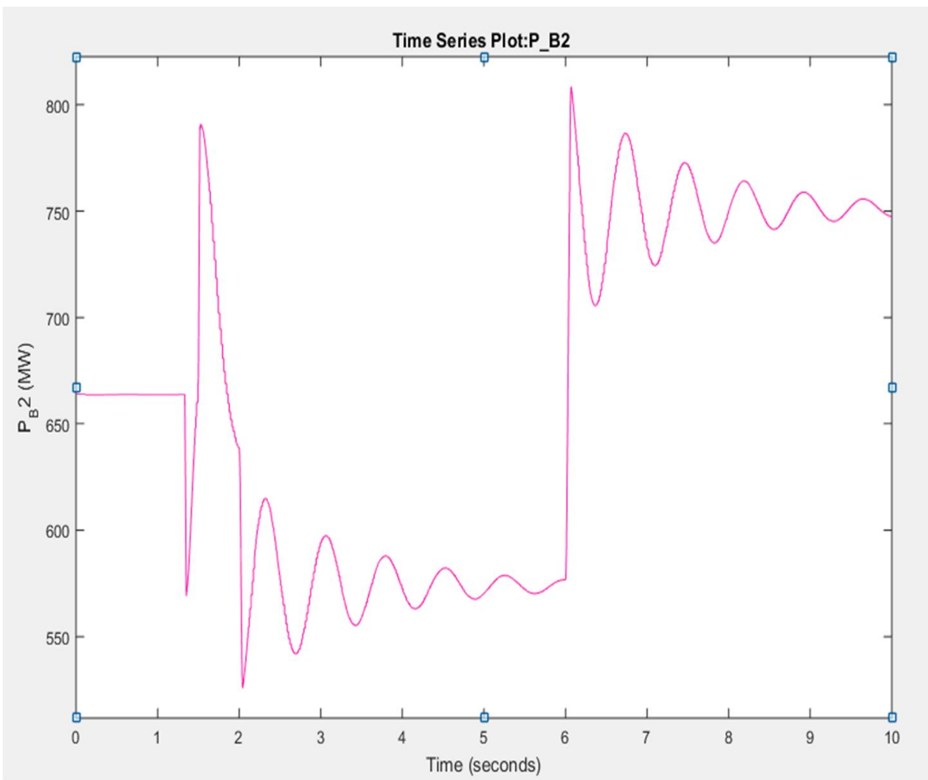

Fig 7 (b) POD is not working

The above simulation results fig 7 (b), shows variation of power at bus 2 with time, as there is fault on transmission line at t = 1.33 sec and disappear after 10 cycle. The line voltage waveform fig7 (a) shows that the injected voltage follows exact same path as reference voltage. After running simulation by making controller 'OFF', then rerun simulation by making controller 'ON'.

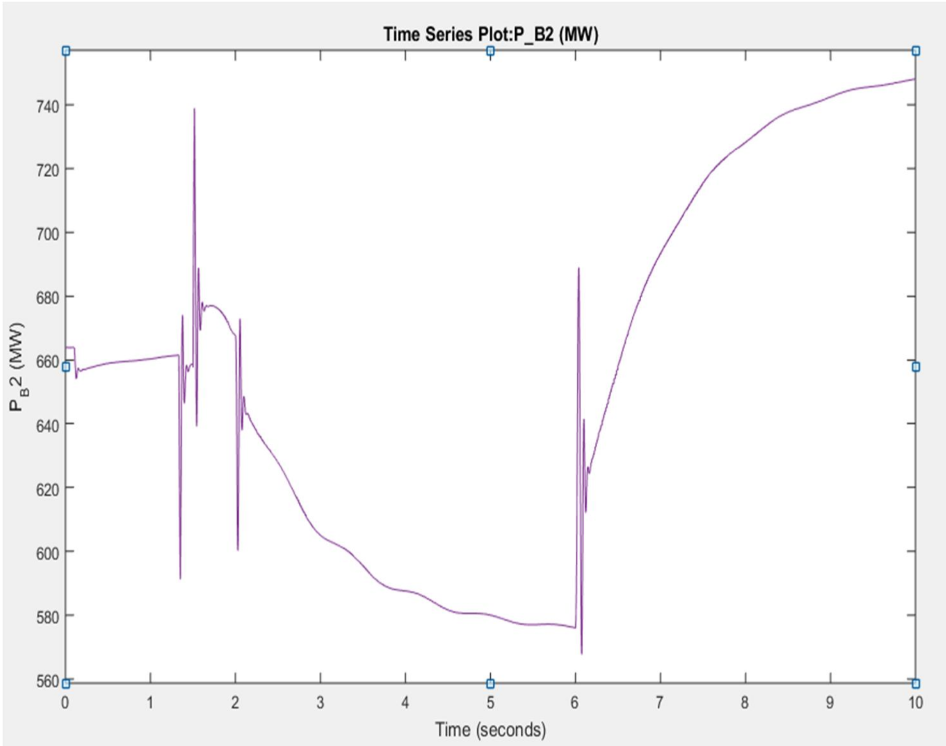

Fig 7 (c) POD is working

The settling time when POD is on is lesser as compared to when the power oscillation damper is off. Also, the graph fig7 (c) indicates that the oscillation in the system are removed when POD turn ON. Both the conditions are compared in below graph fig7(d).

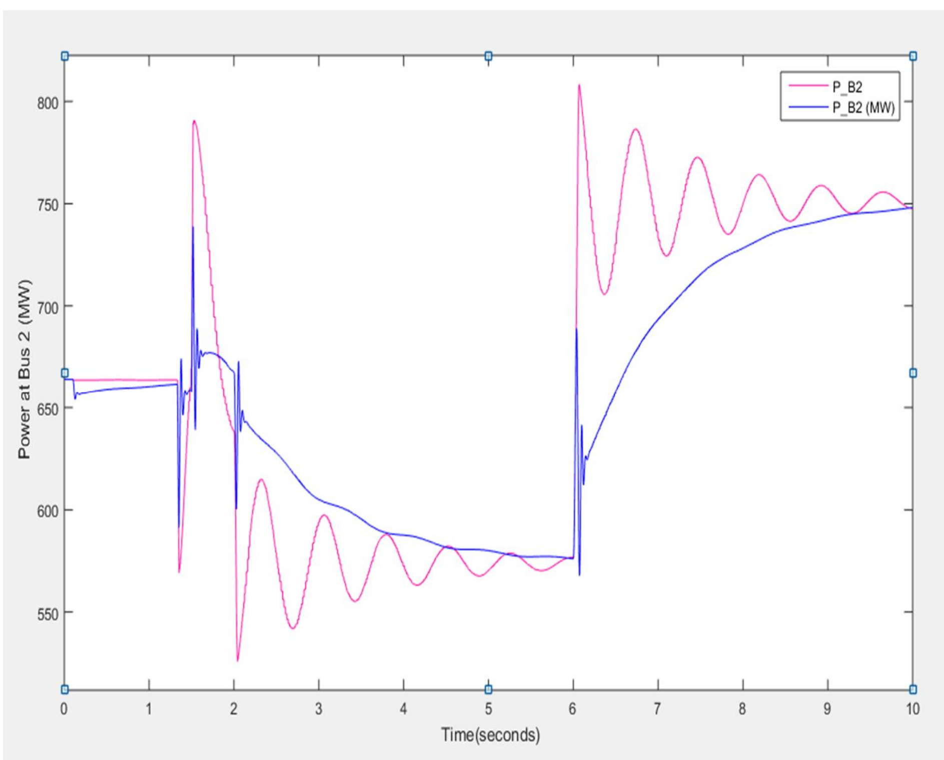

Fig 7 (d)

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B. CASE II. Double line to ground fault with and without POD.

Same like previous case, in double line to ground fault observations are recorded. Simulation is done first when POD controller is not working and secondly when POD controller is working. Fig8(c) shows the comparison between two cases. It is concluded that oscillation remains 6 sec in the system after the fault occurs when the POD is off. And the oscillations damp out in 2 sec when the POD is ON.

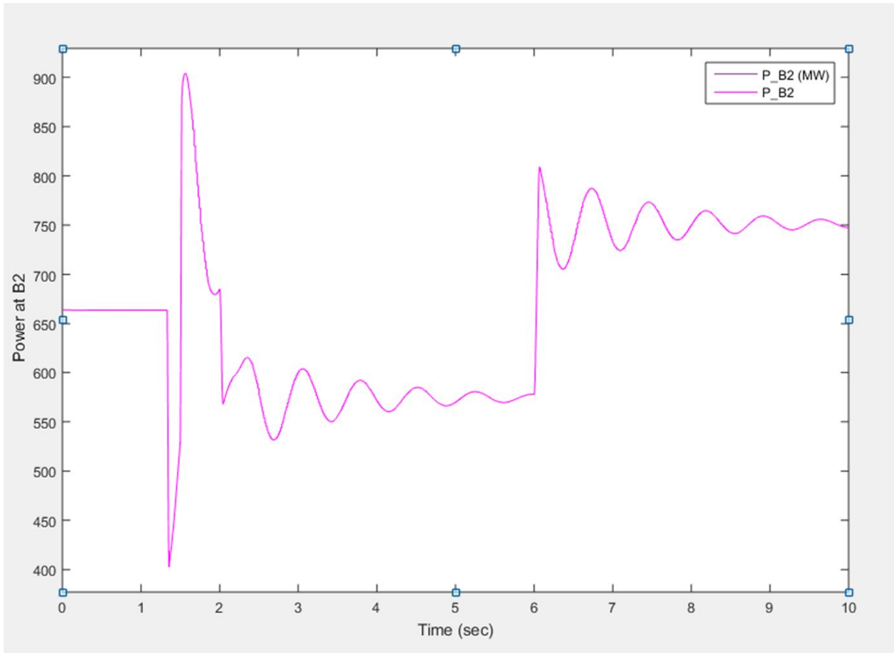

Fig 8(a) POD is not working

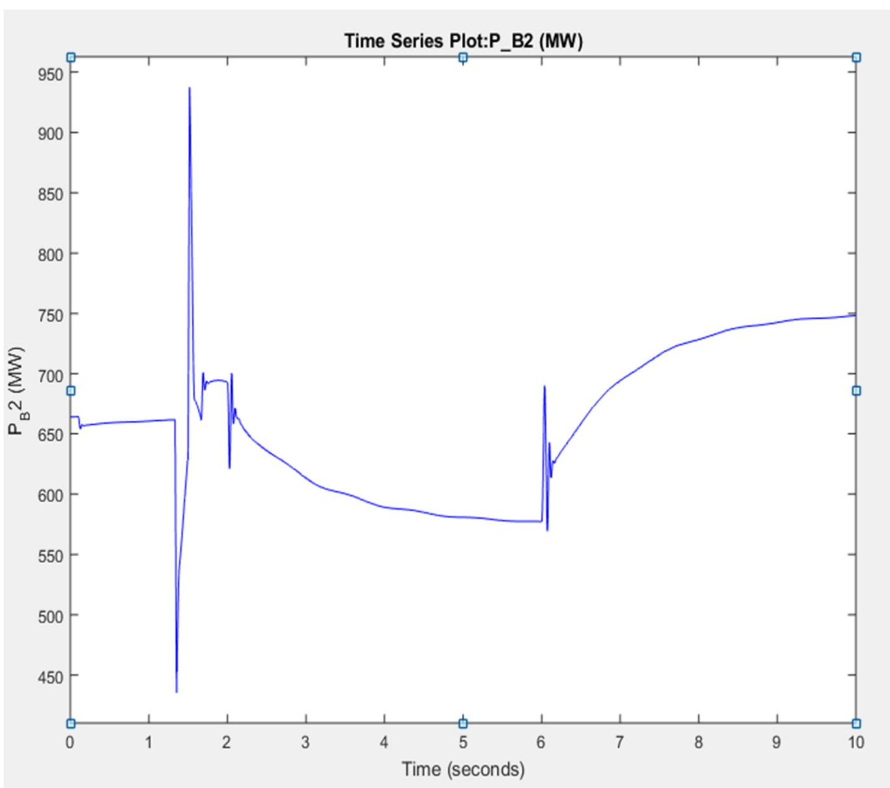

Fig 8(b) POD is working

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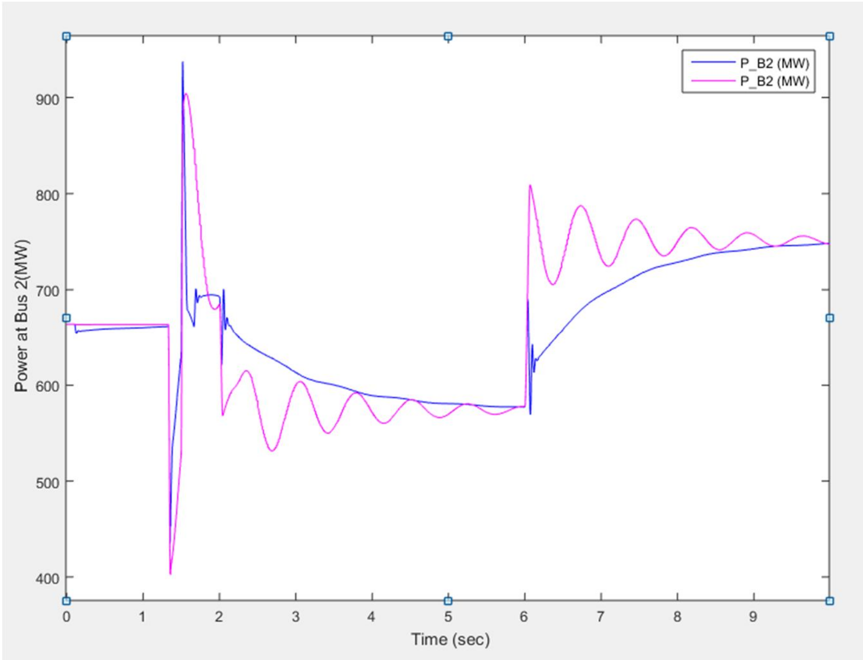

Fig 8(c)

C. CASE III. Three phase fault with and without POD.

In three phase fault case, the value of step Vqref is changed to enhanced the limit of Vqref. First the faut is created in the system when the controller is not working. The fault lasts for 10 cycle and it gain stability after 6.5 sec, shown in graph Fig9(a). Observation are recorded for the variation in the power at bus 2. These oscillations then can be removed from system by making the POD controller ON. The system gains stability at 1.7 sec when POD is on, shown in Fig9(b). The comparison is shown in the graph Fig9(c).

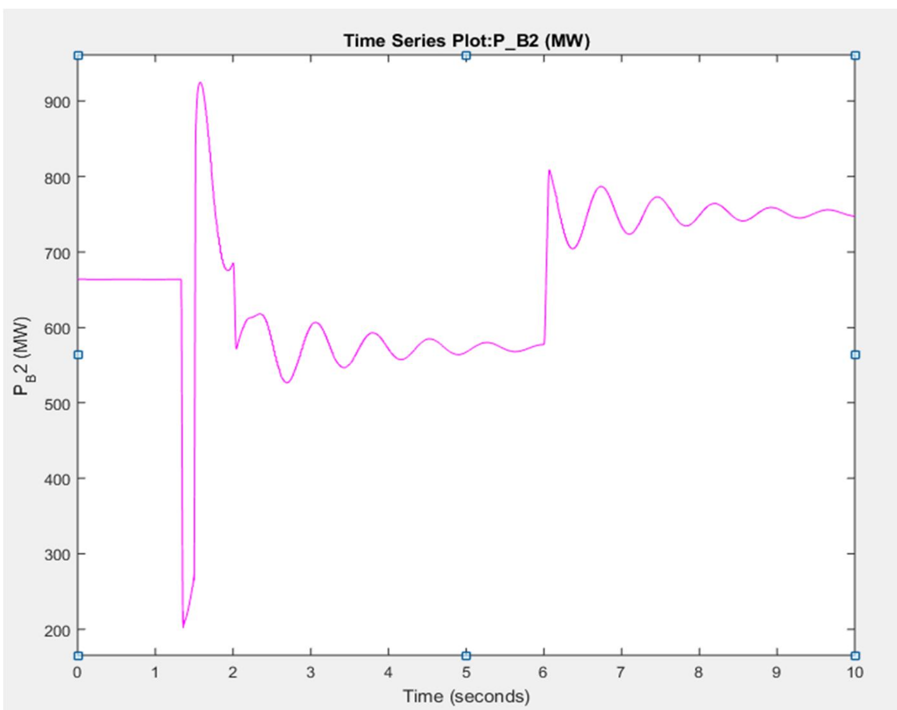

Fig 9(a) POD is not working

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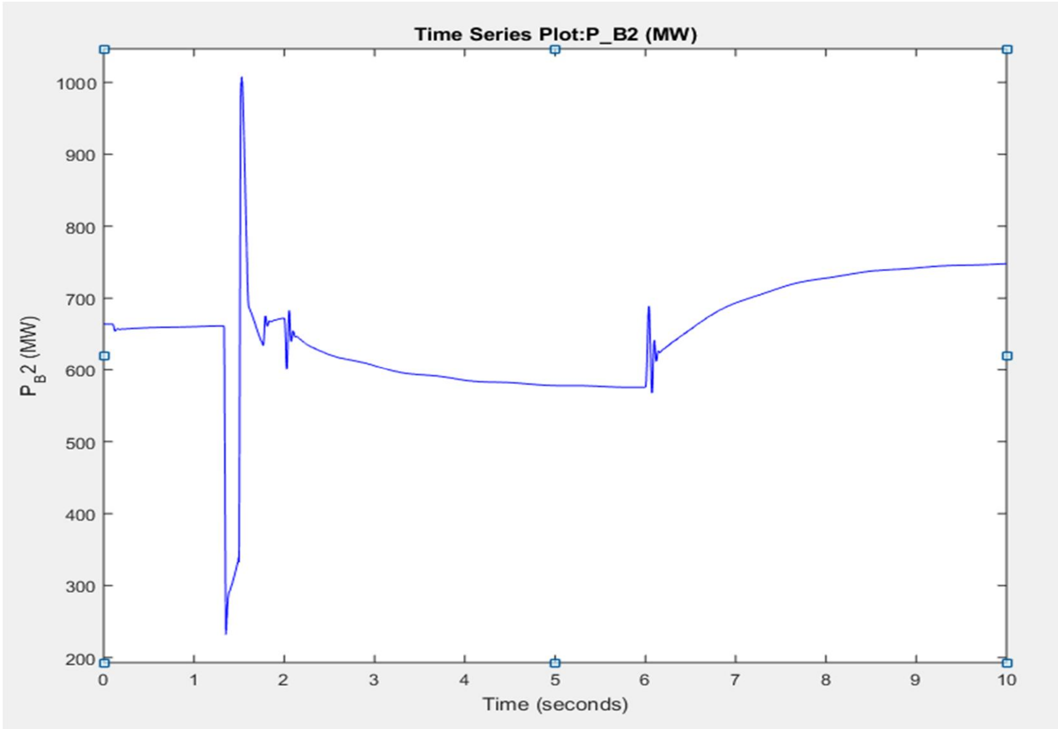

Fig 9(b) POD is working

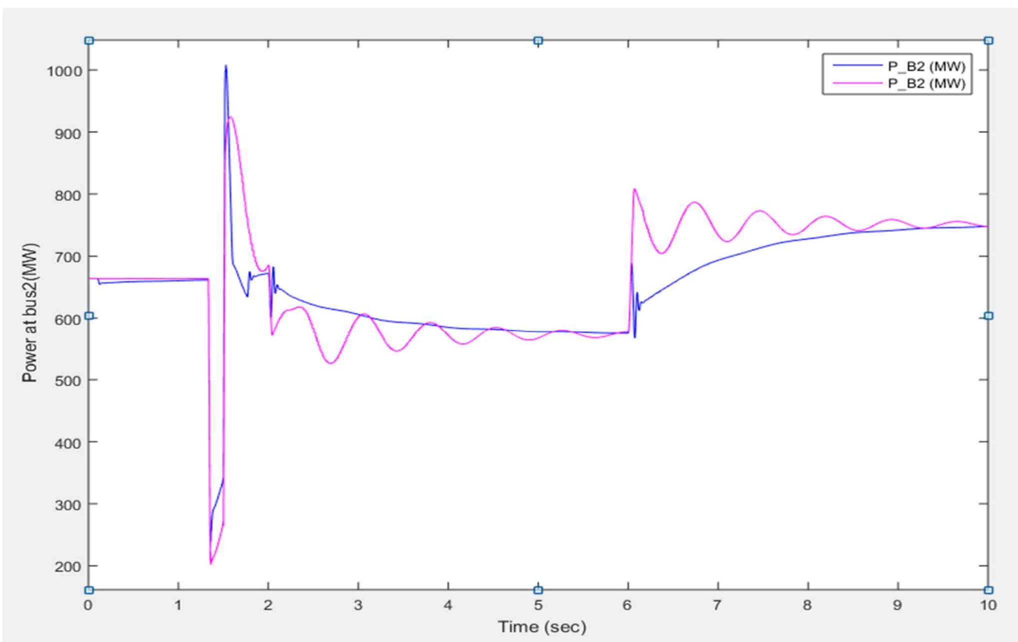

Fig 9(c)

VII. CONCLUSION

In this proposed paper simulation are performed on a two machine four bus power system with and without SSSC based (POD) controller under various unsymmetrical faults conditions. It is clear from the results that the settling time for power system oscillations are reduced by considerable amount. Hysteresis band control provide excellent dynamic performance. SSSC can provide both lead and lag compensation, it injects voltage which is in quadrature with line current. It is also concluded that SSSC is proficient in maintaining desired power flow on all the buses of transmission line. SSSC not only reduce the oscillation but also significantly improved the stability of the power system and increased the power transmission capability.

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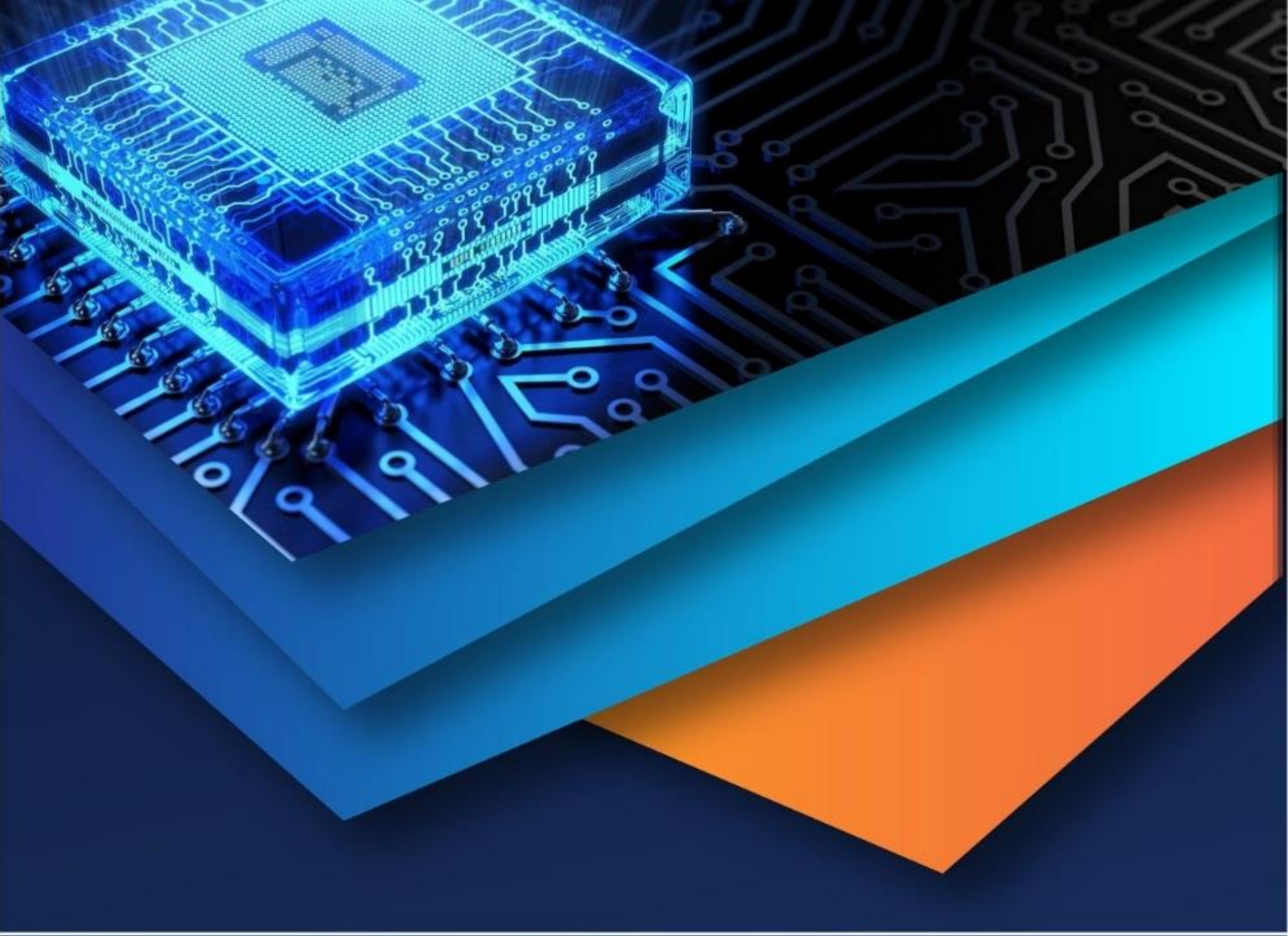

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