Design and Simulation of the Flexible AC Transmission System (FACTS) with Power Oscillation Damping (POD)

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ABSTRACT

In electrical power systems there are many problems, from these problems voltage drop, over voltage and instability. These problems are solved by using FACTS technology. Flexible AC transmission system (FACTS) can provides better control than conventional control and achieves fast control time response; therefore FACTS controllers play an important role in power system stability enhancement. STATCOM is a shunt FACTS device which is used for voltage controlling and increasing the performance of the system. In this paper STATCOM is used to improve voltage magnitude and stability of electrical network by using MATLAB/SIMULINK. To show its effectiveness a prototype of electrical network has been chosen which consists of five buses, three generators and four loads. Simulation results show a robust improvement in network with STATCOM. If a three phase to ground fault occurs between buses (3&4) there are oscillations after clearing fault. To reduce these oscillations power oscillations damping (POD) has been proposed with STATCOM. Simulation results show that an enhancement of the network prototype with proposed controller (STATCOM− POD).

Keywords: MATLAB/simulation; FACTS; STATCOM; three phase to ground fault; Power oscillation damping (POD); proposed controller (STATCOM−POD)

تصميم ومحاكاة لنظام نقل التيار المتناوب المرن مع مخمد التذبذب بالقدرة

الخلاصة

في انظمة القدرة الكهربائية توجد العديد من المشاكل منها مشاكل زيادة او نقصان الفولتية وعدم استقراريتها. لغرض حل هذه المشاكل تستخدم تقنية نظام نقل التيار المتناوب المرن الذي يمكن ان

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يجهز سيطرة افضل من السيطرة التقليدية ويحرز تحكم سريع بزمن الاستجابة. لذلك هذه التقنية تلعب دور مهم في زيادة استقرارية نظام القدرة. احدى هذه التقنيات المعوض التزامنـــي الســـتاتيكي الـــذي يستخدم للسيطرة على الفولطية وزيادة جودة اداء النظام. في هذا البحث المعوض التزامني الســـتاتيكي يستخدم لتحسين قيمة الفولطية واسقرارية الشبكة الكهربائية بأســـتخدام برنـــامج المـــاتلاب. لغـــرض ملاحظة تأثير هذا المسيطر يتم ربطه لنموذج شبكة كهربائية. هذه الشبكة تتكون من خمـــس قضـــبان توصيل و ثلاث مولدات و اربعة احمال. نتائج برنامج الماتلاب توضح تحسن كبير لاداء الشبكة مـــع ربط المسيطر. في حالة ظهور عطل من نوع (ثلاثي الطور ارضي وهو اقوى انواع الاعطال) بين قضيب التوصيل الثالث والرابع من الشبكة الكهربائية تنتج ذبذبات بعد زوال العطل. هـــذه الذبـــذبات تقل عن طريق استخدام مخمد ذبذبات القدرة مع المعوض التزامني الستاتيكي كمسيطر مقترح. نتـــائج برنامج الماتلاب توضح تحسين عمل الشبكة بعد زوال العطل باستخدام المسيطر المقترح.

INTRODUCTION

The rapid development of the high-power electronics industry has made Flexible AC Transmission System (FACTS) devices viable and attractive for utility applications. FACTS devices have been shown to be effective in controlling power flow and damping power system oscillations. In recent years, new types of FACTS devices have been investigated that may be used to increase power system flexibility and controllability, to enhance system stability and to achieve better utilization of existing power systems. The static synchronous compensator (STATCOM) is one of the most important FACTS devices and it is based on the principle that a voltage-source inverter generates a controllable AC voltage source behind a transformer-leakage reactance so that the voltage difference across the reactance produces active and reactive power exchange between the STATCOM and the transmission network[1,2]. STATCOM is defined by IEEE as a self commutated switching power converter supplied from an appropriate electrical energy source o to produce a set of adjustable multiphase voltage, which may be coupled to an AC power system for the purpose of exchanging independently controllable real and reactive power. The controlled reactive compensation in electric power system is usually achieved with the variant STATCOM configurations. The STATCOM has been defined as CIGRE/IEEE with following three operating structural components. First component is Static: based on solid state switching devices with no rotating components; second component is Synchronous: analogous to an ideal synchronous machine with three sinusoidal phase voltages at fundamental frequency; third component is compensator: provided with reactive compensation [3]. Voltage Stability improvement was presented in [4, 5, 6 and 7]. In [8] damping oscillations by power oscillation damping (POD) and power system stabilizer (PSS), in [9] fuzzy controller was used with thyristor control switch capacitor (TCSC) to damp oscillations and in [10] power system stabilizer is used with many types of FACTS to damp oscillations. In this paper POD method is used to damp oscillations.

STATCOM MODEL

Typical STATCOM functionalityTypical STATCOM is shown in Figure (1), herein a static compensator functional capability to handle dynamic system conditions, such as transient stability and power oscillation damping in addition to providing voltage regulation [3].

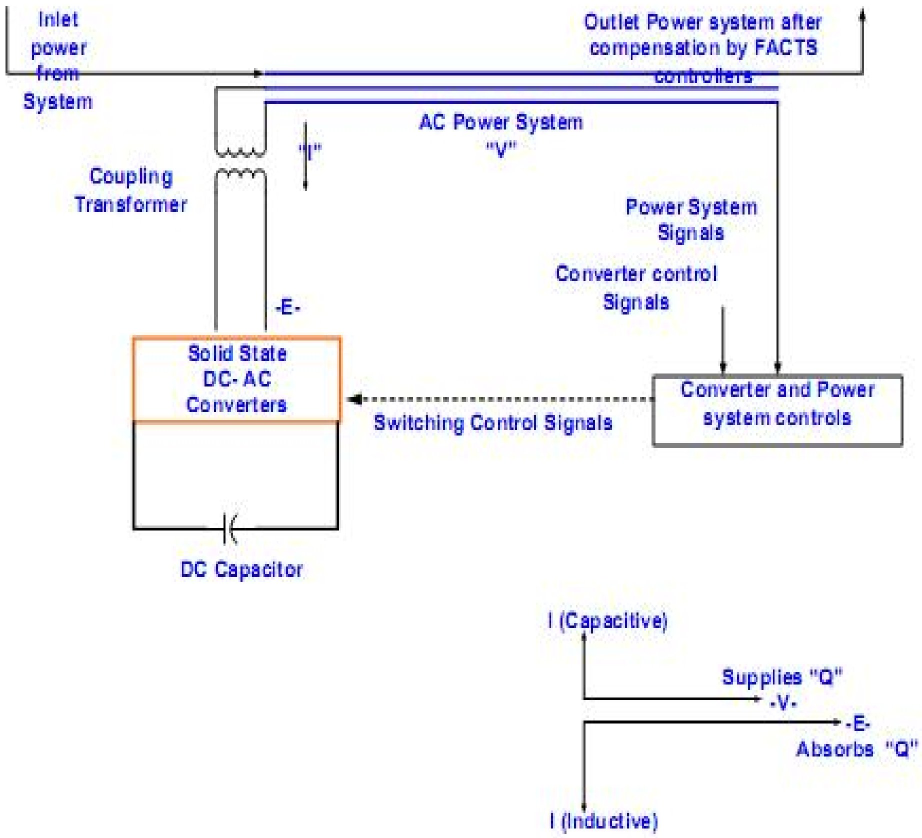

Figure (1) Typical STATCOM compensator

STATCOM CONFIGURATION

The STATCOM is based on the principle that a voltage source inverter generate a controllable ac voltage source behind a transformer leakage reactance so that the voltage difference across the reactance produce active and reactive power exchange between the STATCOM and transmission network. Fig (2) shows a configuration of a STATCOM, which consist of a step down transformer (SDT) with leakage reactance (XSDT), a three phase (GTO) based voltage source converter (VSC) and a DC capacitor [10].

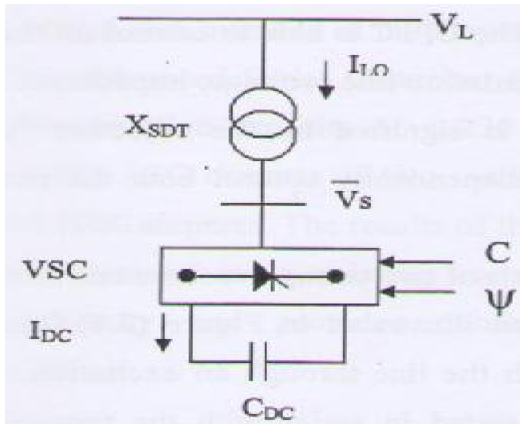

Figure (2) STATCOM configuration

MATHMATICAL OPERATION

The voltage source inverter generates a controllable ac voltage source Vs (t) = Vs sin (wt-ψ), Behind the leakage reactance. The voltage difference between the STATCOM (Vs (t)) and bus Ac voltage (VL (t)) produce active and reactive power exchange between the STATCOM and the power system, which can be controlled by adjusting the magnitude Vs and phase (ψ).

$$Vs = c\,Vdc\,(\cos\theta + j\sin\theta) = c\,Vdc\angle\theta \qquad \text{...... (1)}$$

$$\frac{dVDC}{dt} = \frac{c}{Cdc}\,(Id\,\cos\Psi + Iq\,\sin\Psi) \qquad \text{...... (2)}$$

Where, c = mk and k is the ratio between ac and dc voltage, m is the modulation ratio defined PWM [10].

STATCOM V-I CHARACTERISTIC

The voltage-current characteristic STATCOM are shown in Figure (3) as can be seen in the linear operating range.

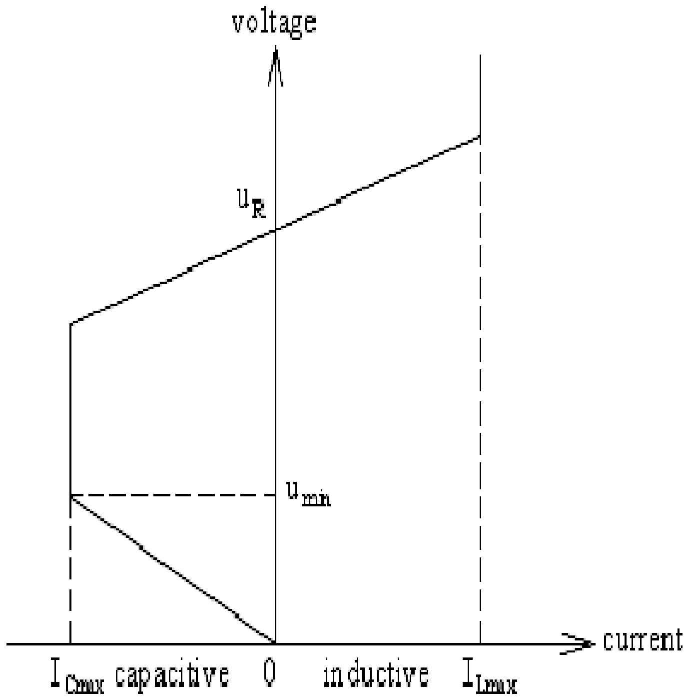

Figure (3) voltage current characteristic of the STATCOM

From V-I characteristic of the STATCOM, STATCOM can serve as a controllable current source without changing the network structure parameters and beyond the limitation of bus voltage, it can supply required reactive current even at low values of bus voltage and its ability to produce required reactive current even at low values of bus voltage make it highly effective in improving the transient stability[11].

POWER OSCILLATION DAMPING (POD)

A damping controller is provided to improve the damping of power system oscillations. The damping controller is considered as comprising two cascade blocks. The speed deviation signal is derived from the difference of measured power at STATCOM location, the set of mechanical input power and the error signal is integrated and multiplied by 1/M, where M is inertia constant of the machine. Figure (4) shows the block diagram of power oscillation damping controller (POD). We can achieve the desired damping ratio of the electromechanical mode and compensate for the phase shift between the control signal and the resulting electrical power deviation [8].

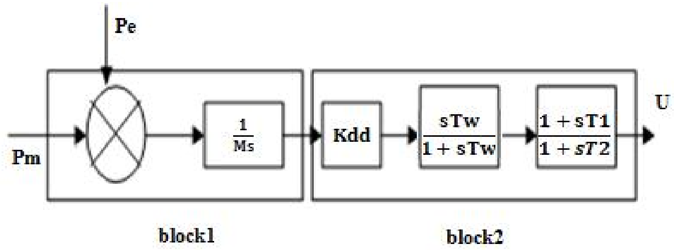

Figure (4) Transfer function block diagram of the POD

ELECTRICAL NETWORK PROTOTYPE

The network is shown in Figure (5) will be consider as the case study in this paper. This network contains five buses, the first bus represents slack bus bar, the second and third buses have generators and loads, the fourth and fifth buses just have loads. The network data includes generators data, transmission lines data and loads data. Generators and transmission lines data values are given in pu therefore generators voltages are multiplied by rated voltage (base value (400kV)) and have been entered in the generators blocks diagram of the electrical network simulink, also transmission lines data are multiplied by base impedance value ($Z_{base} = \frac{V_{base}^2}{MVA}$) and have been entered in the transmission lines blocks diagram of the electrical network simulink. The active and reactive power data of the load buses are entered in the load blocks diagram of the network simulink, electrical network data are shown in appendix.

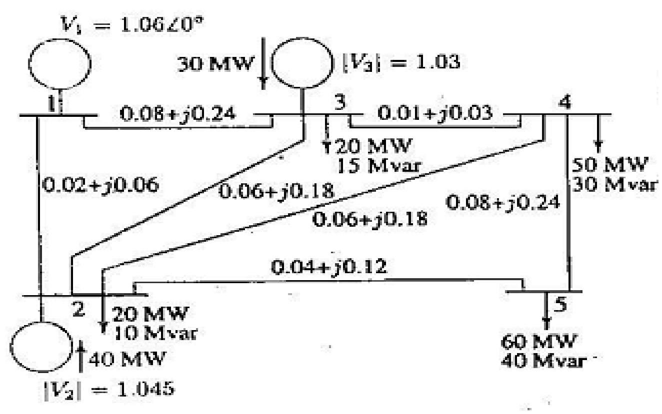

Figure (5) electrical network prototype

NETWORK IMPLEMENTATION IN MATLAB/SIMULINK AND RESULTS

A. without STATCOM

Figure (6) shows the representation of the electrical network by MATLAB simulation, the rated voltage, power and frequency is 400kV, 100MVA, 50Hz respectively. The loads on buses (4&5) are dynamic loads with small parallel resistances because three phase dynamic load cannot connected in series with bus bar. The drop voltage on the buses is shown in the simulation.

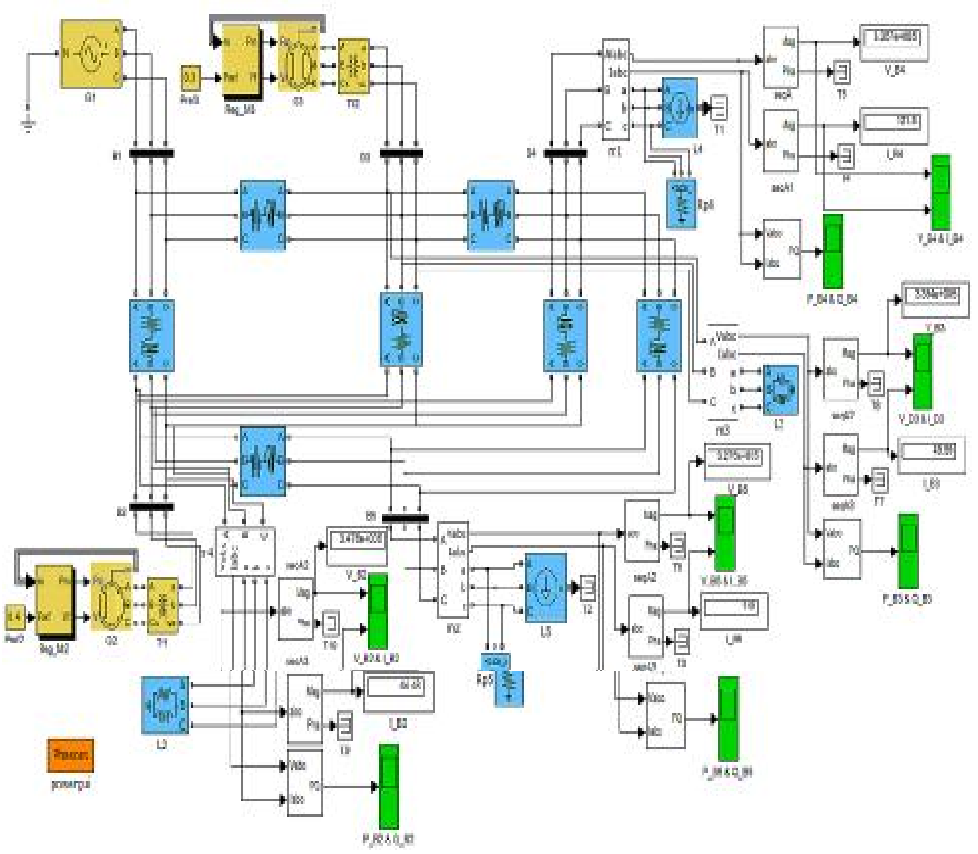

Figure (6) MATLAB simulation of five buses electrical network

Figure (7) shows simulation of the electrical network with STATCOM which is connected to buses (2, 3, 4 & 5) and in voltage regulation mode.

Figure (8) shows three phase to ground fault occur between buses (3&4). Figure (9) shows POD has been implemented with STATCOM to reduce oscillations produced after clearing fault.

B. with STATCOM

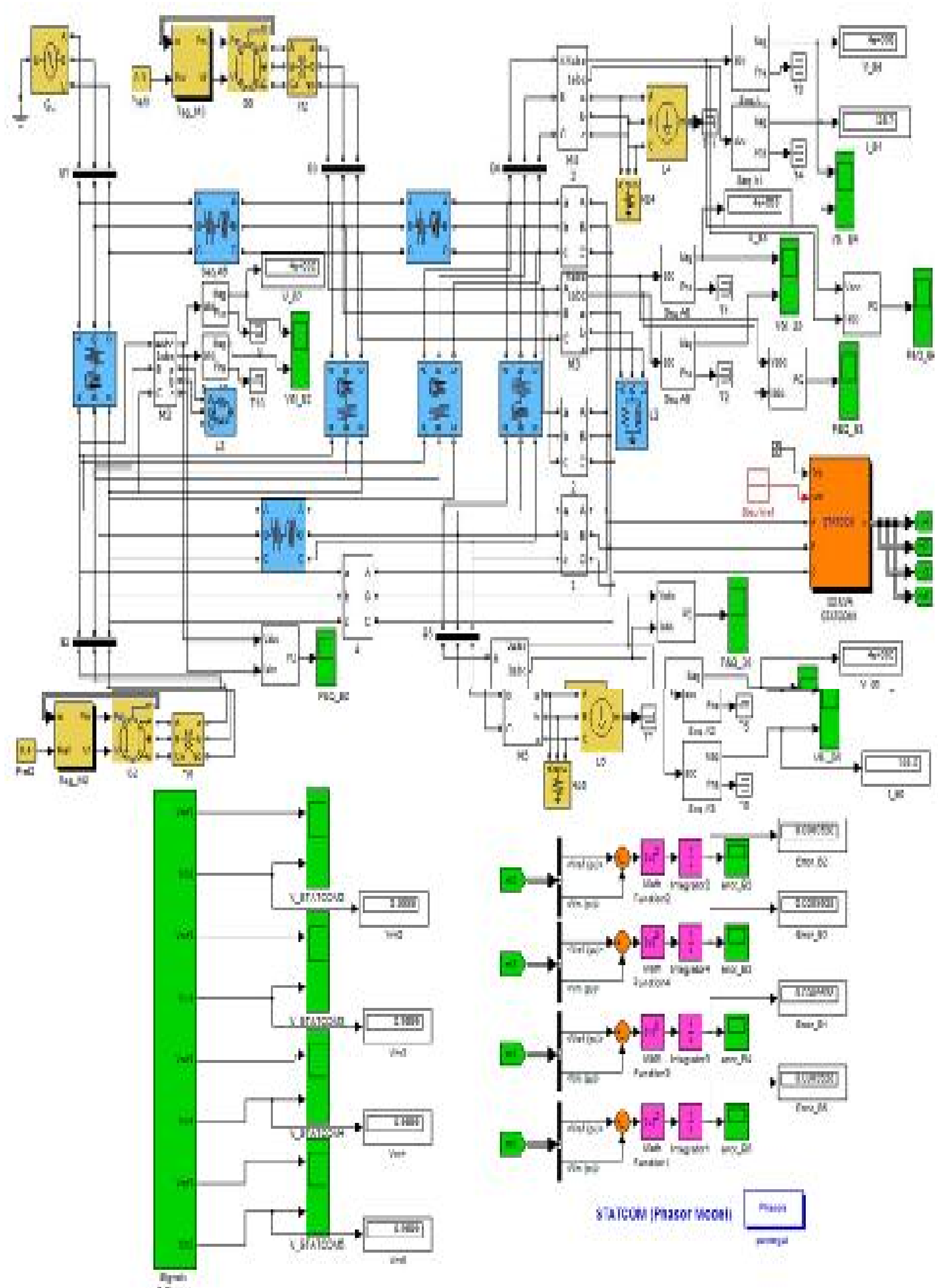

Figure (7) simulation of the electrical network with STATCOM

C. Without STATCOM with three phase to ground fault

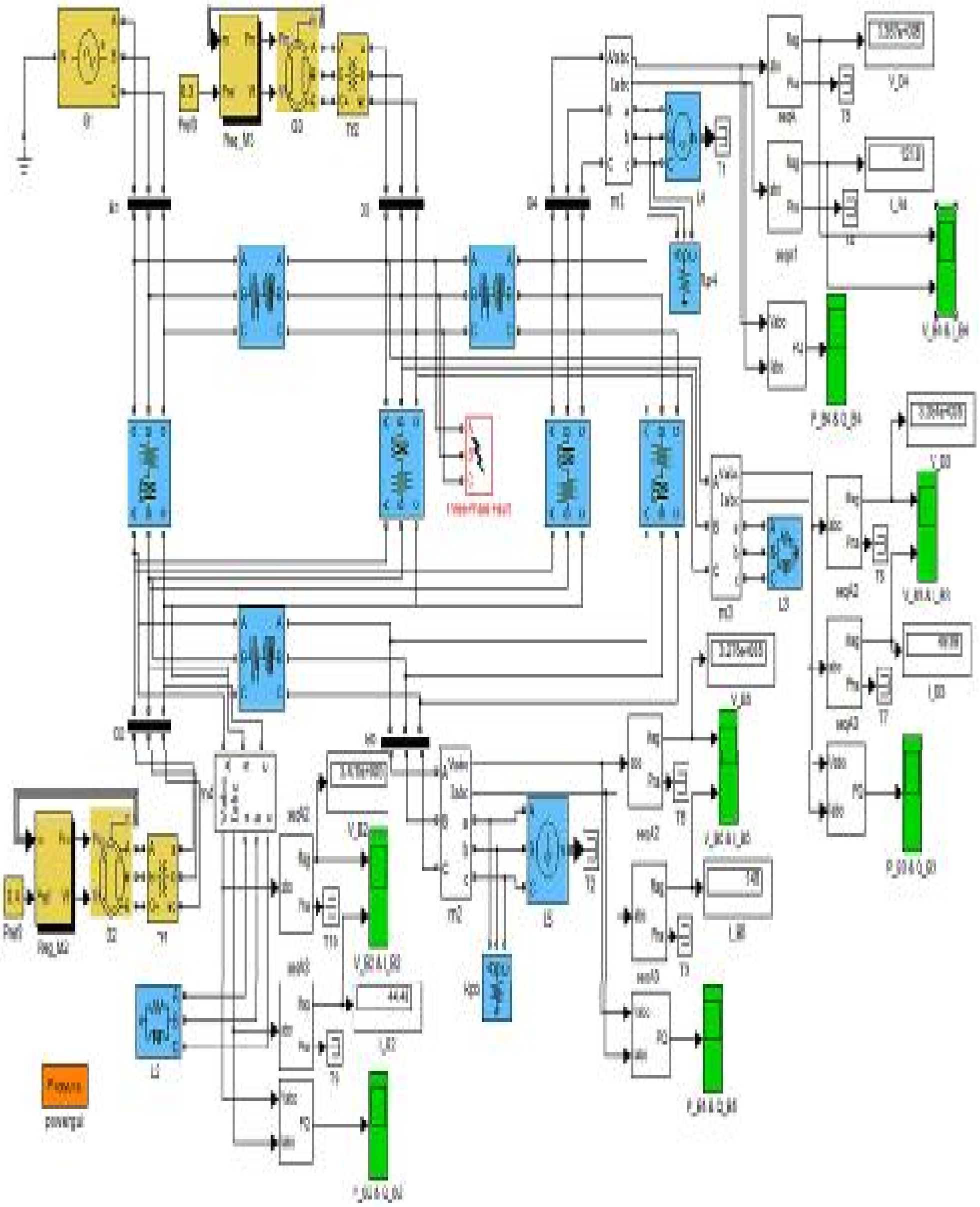

Figure (8) three phase to ground fault occur between buses (3&4)

D. Proposed structure

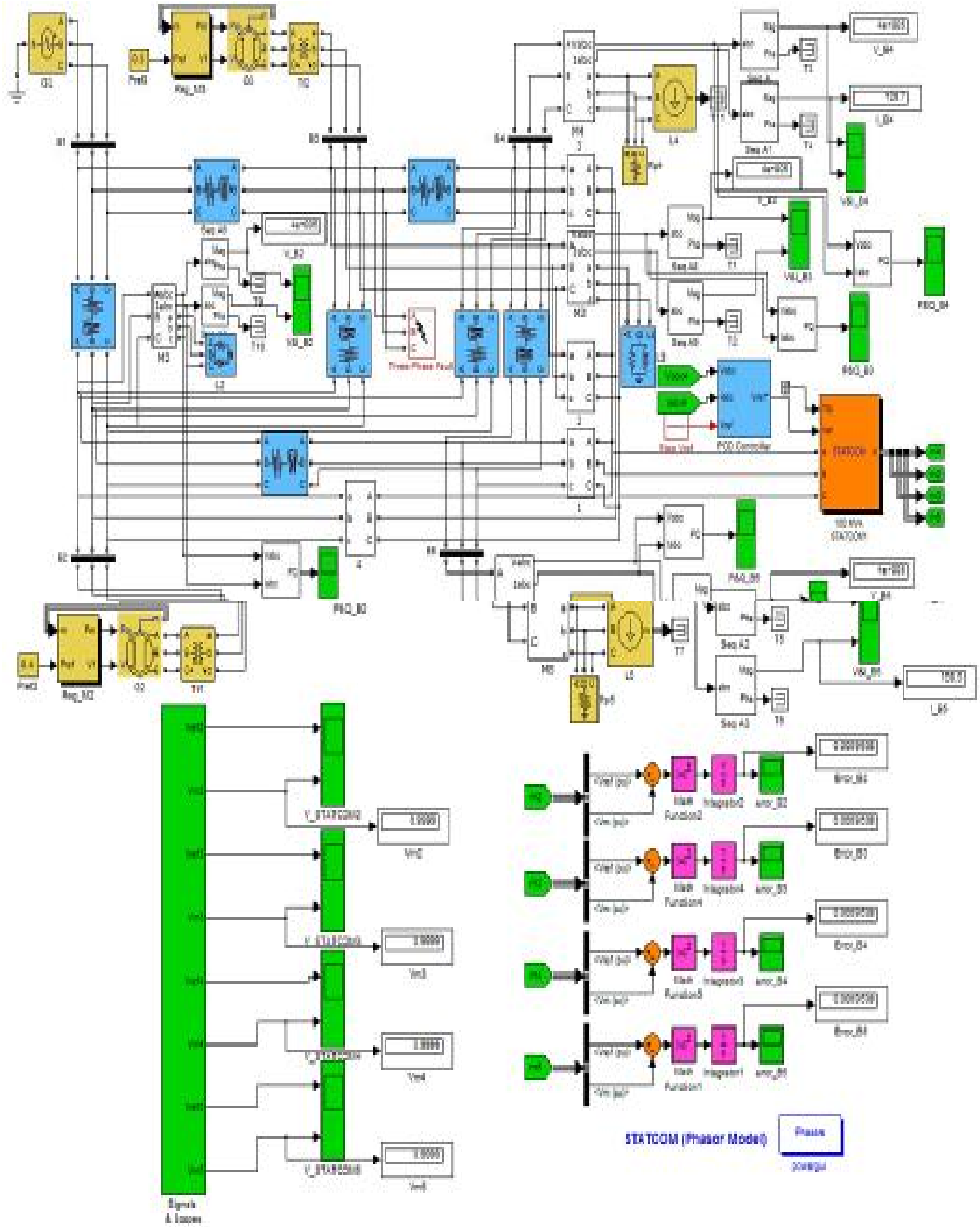

Figure (9) Three phase to ground fault occurs between buses (3&4) with STATCOM and POD

SIMULATION RESULTS

Simulation results show the effect of the STATCOM and POD in improving voltage magnitude and stability are taken on bus bar (4). Figure (10) shows voltage and current on bus (4) before STATCOM connection, the voltage magnitude is (335.7kV). Figure (11) shows active and reactive power on bus (4) without STATCOM controller.

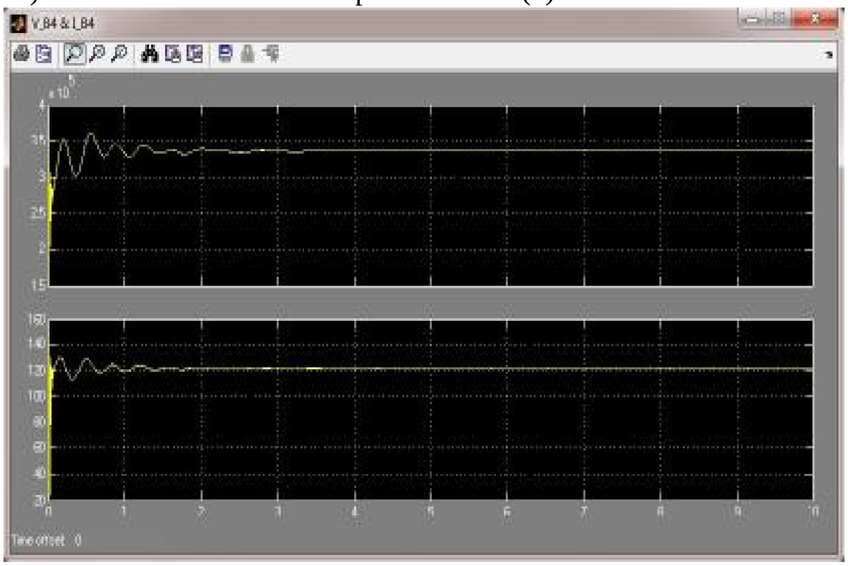

Figure (10) voltage and current on bus (4) without STATCOM

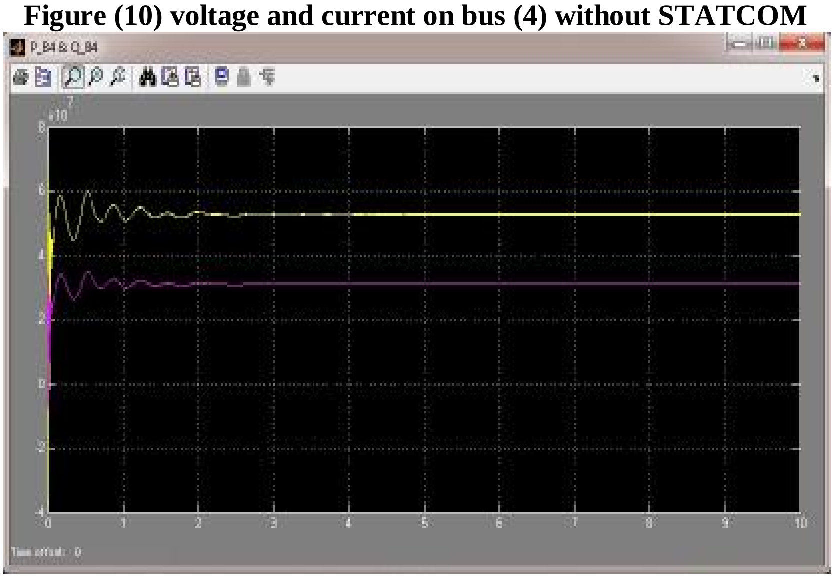

Figure (11) power and reactive power on bus (4) without STATCOM

Figure (12) shows voltage improvement in pu on bus (4) when STATCOM has been connected to the network, the voltage magnitude is (0.9999 pu) with respect to reference value (1.0 pu). The voltage is returned to the rated value (400kV) because the reactive power compensation by STATCOM and the voltage stability is increased as shown in Figure (13). Figure (14) shows active and reactive power on bus (4) after STATCOM connection, the magnitude of reactive power is increased for voltage improving. The error ratio of the voltage on bus (4) is (0.09545%) as shown in Figure (15).

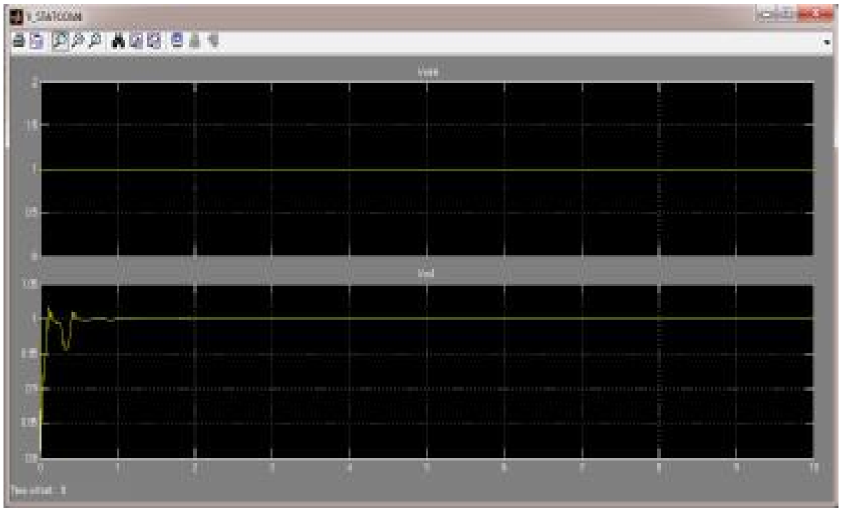

Figure (12) voltage improvement in Pu on bus (4)

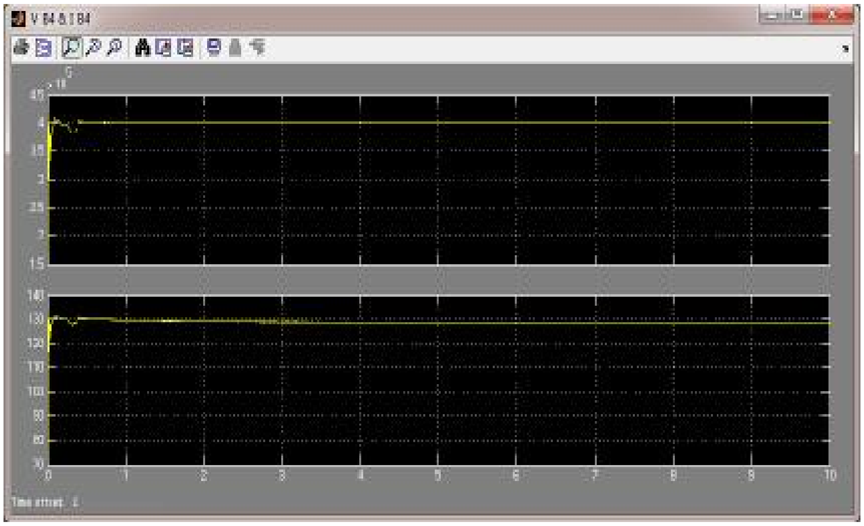

Figure (13) voltage and current on bus (4) with STATCOM

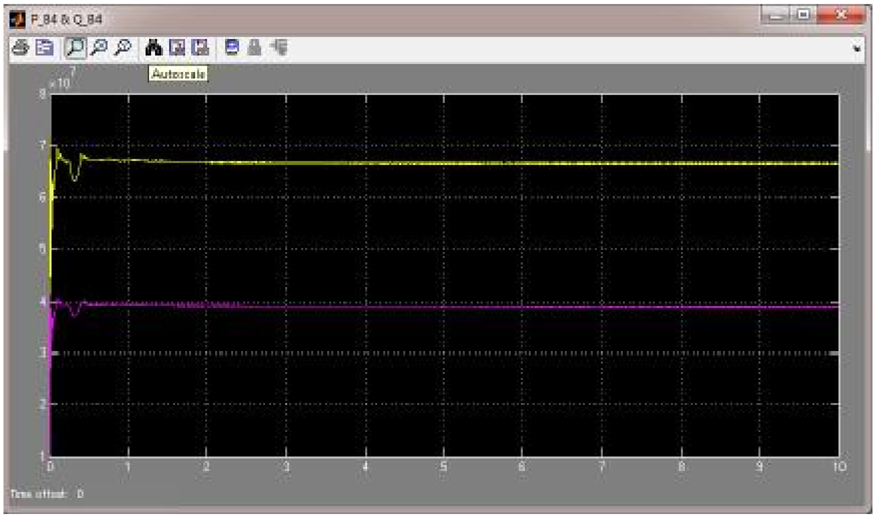

Figure (14) power and reactive power on bus (4) with STATCOM

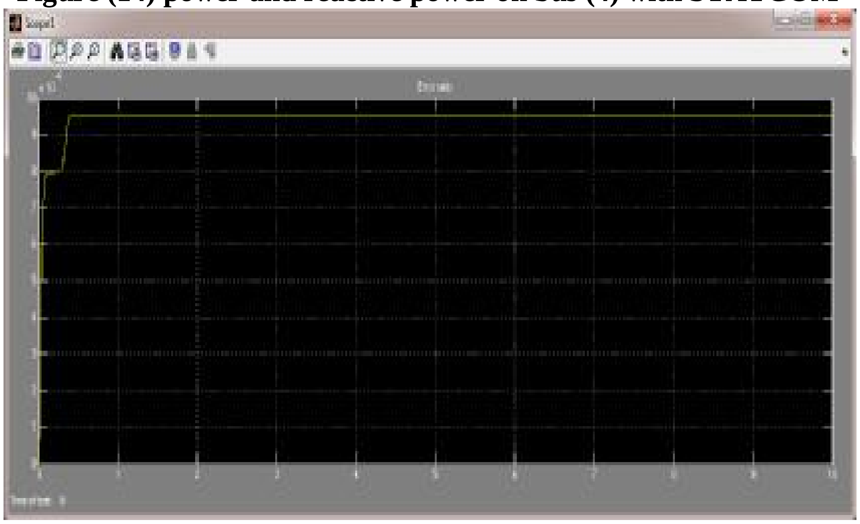

Figure (15) Error ratio of the bus voltage (4) without fault

If three phase to ground fault occurs for period (0.2sec) and ends on the transmission line between buses (3&4), there are oscillations after clearing fault. Figure (16) shows the voltage and current on bus (4) when the fault occurs without STATCOM. The stability of the voltage after clearing fault is increased when the STATCOM is connected to the electrical network as shown in Figure (17). The error ratio of the voltage on bus (4) is increased to (19.42%) as shown in Figure (18).

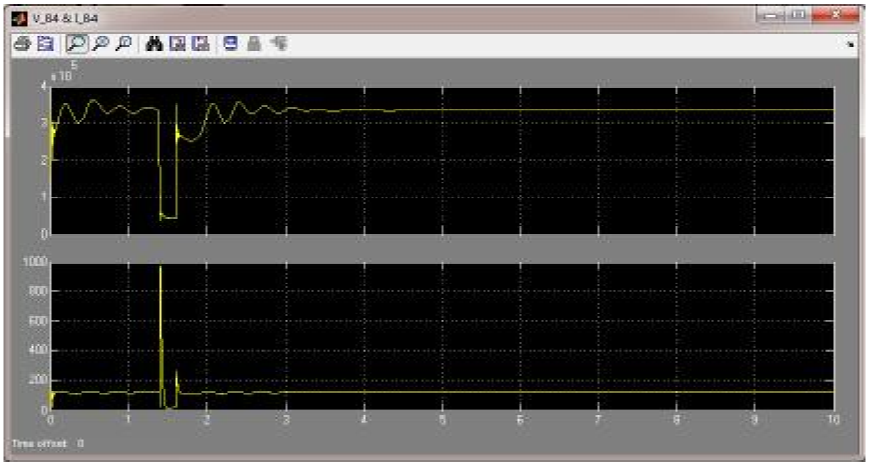

Figure (16) Voltage and current on bus (4) when fault appearing and clearing without STATCOM

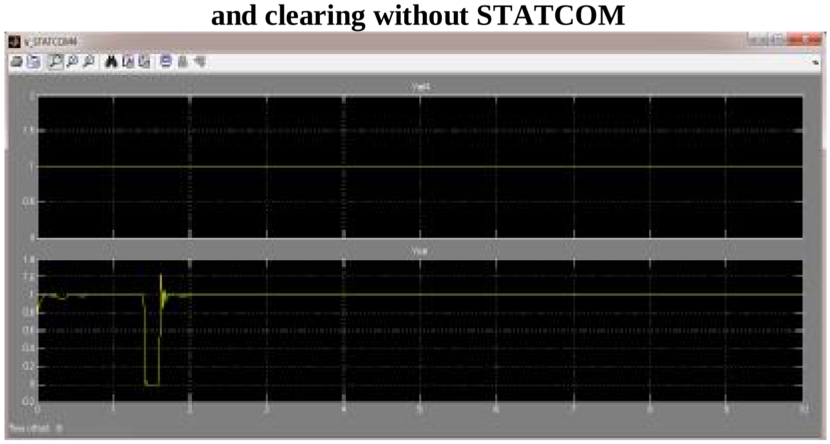

Figure (17) reference and measured voltage in Pu on bus (4) with STATCOM when fault appears and clears

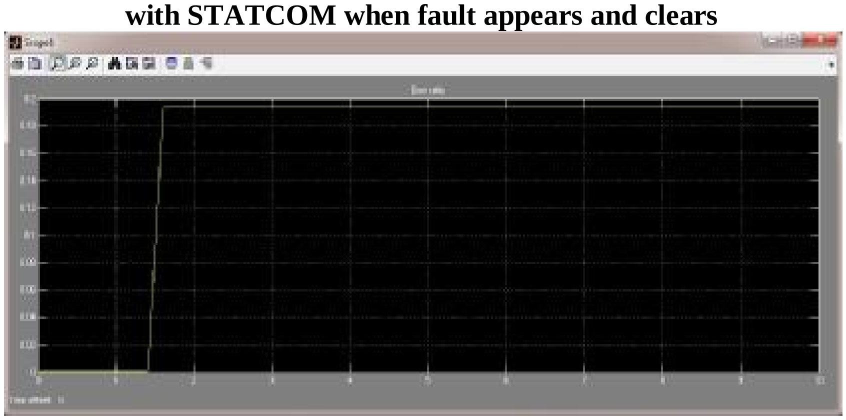

Figure (18) Error ratio of the bus voltage (4) with fault without POD

To increase oscillations reducing power oscillation damping (POD) has been implemented with STATCOM as a proposed controller (STATCOM- POD). Figure (19) shows oscillations are reduced with the proposed controller more than in Figure (17). The error ratio of the voltage on bus (4) is reduced to (15.97%) as shown in Figure (20). Table (1) shows network results without STATCOM connection, the buses voltage is under rated value (400Kv) because the drop voltage. When STATCOM is connected to the electrical network the voltage is returned to rated value by reactive power compensation as shown in Table (2). To improve the voltage on bus (2) STATCOM compensates (4.6MVAR), in bus (3) it compensates (7.2MVAR), in bus (4) it compensates (8.1MVAR) and in bus (5) it compensates (11.9MVAR).

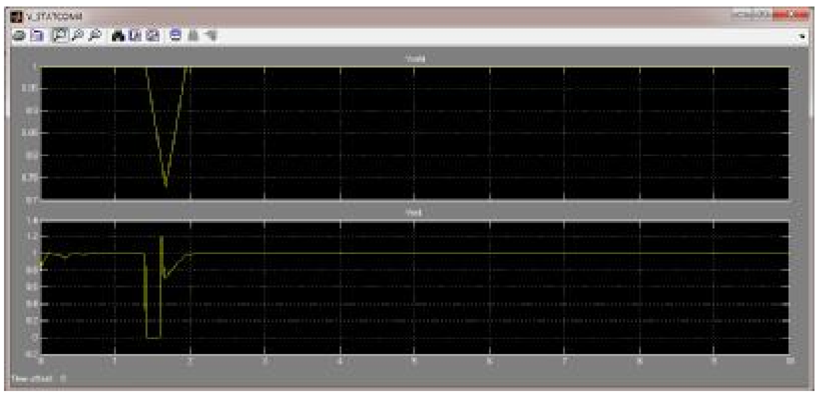

Figure (19) reference and measured voltage in Pu on bus (4) with (STATCOM POD) when fault occurs and clears

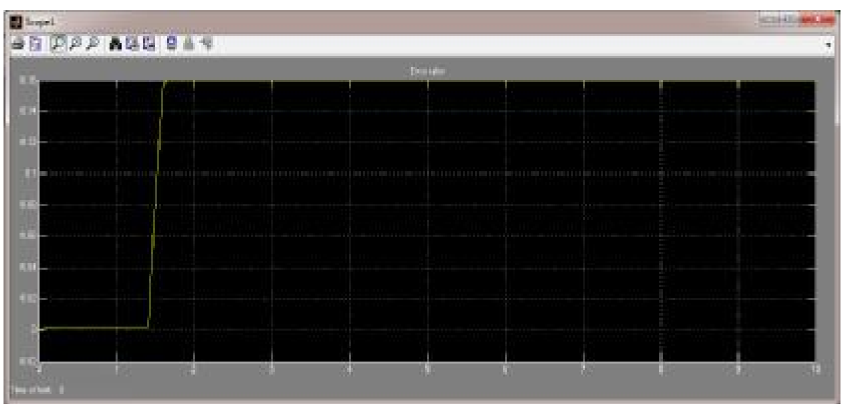

Figure (20) Error ratio of the bus voltage (4) with fault and POD

Table (1) Network results without STATCOM

Buses	Voltage	Current	power	Reactive power
2	347.6kv	44.48Amp	20.7MW	10.4MVAR
3	339.4Kv	49.44Amp	20.3MW	15.3MVAR
4	335.7Kv	121.8Amp	52.28MW	31MVAR
5	327.6Kv	149.1Amp	61MW	40.3MVAR

Table (2) Network results with STATCOM

Buses	Voltage	Current	power	Reactive power
2	400kv	55.8Amp	30MW	15MVAR
3	400Kv	62.5Amp	30MW	22.5MVAR
4	400Kv	128.6Amp	66.5MW	39.1MVAR
5	400Kv	158Amp	79.5MW	52.2MVAR

CONCLUSIONS

In electrical power systems, nodal voltages are significantly affected by load variations and by network topology changes. Voltages can drop considerably and even collapse when the network is operating under heavy loading. Flexible AC transmission system (FACTS) can handle load variation problems and provide better control than conventional control and achieve fast control response time; therefore FACTS controllers play an important role in power system stability enhancement. The important role of the FACTS is shown though the practical implementation on prototype of the electrical network buses by using MATLAB/Simulink.

In this paper Simulation results of the electrical network Simulink without STATCOM controller connection show buses voltage drop. The voltage drop problem has been solved with STATCOM connection to the network and voltage stability has been increased. If a three phase to ground fault occurs between buses (3&4) there are oscillations after clearing fault. To reduce these oscillations power oscillations damping (POD) has been proposed with STATCOM. Simulation results show that an enhancement of the network prototype with proposed controller (STATCOM- POD).

APPENDIX

Ψ: Phase angle of the mid- bus voltage
c: Magnitude voltage of the STATCOM control
Cdc, Vdc: DC link capacitance and voltage
Id, Iq: Direct and quadrature current
Kdd: Gain
TW: Wash out time

T1 & T2: Lead lag time constant

ELECTRICAL NETWORK PROTOTYPE DATA
Rated power = 100MVA
Rated frequency = 50Hz
Rated voltage = 400kV and rated voltage in per unit = 1
Slack generator (G1) voltage =424kVand in per unit=1.06
Second generator (G2) voltage =418kV and in per unit=1.045
Third generator (G3) voltage =412kV and in per unit=1.03

Transmission line data:
R13 =128 , L13 = 1.222H
R34 = 16 , L34 = 0.1528H
R12 = 32 , L12 = 0.3057H
R23 = 96 , L23 = 0.9171H
R24 = 96 , L24 = 0.9171H
R25 = 64 , L25 = 0.6114H
R45 = 128 , L45 = 1.2229H
Transmission lines suscptance is neglected because it is very small

STATCOM data:
Rated voltage of the STATCOM =400kV
Rated power of the STATCOM =500MVA

Power oscillation damping (POD) data:
Gain (Kdd) =10
Wash out time (TW) =2sec
Lead lag time constant [num (T1) den (T2)] = [1 0.1]

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