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STATCOM Application on the Iraqi (400kv) Super Grid Network with Power Oscillation Damping(POD) & Proportional Integral (PI) Controller

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ABSTRACT

Flexible ac transmission system (FACTS) can provide control more than conventional control and achieve fast control response time, STATCOM is a shunt FACTS device it is used to voltage control and increase the performance of the system. In this paper STATCOM is used to improve the voltage magnitude and stability for the Iraqi (400KV) super grid network byusing MATLAB/SIMULINK. STATCOM is connected to Iraqi (400kv) super gridnetworkwhich is consisting of twenty four buses, eleven generators, eleven step up transformers fromeach generator side, twenty step down transformers from each load side and twenty loads.The loads variation through the seasons of the year causesdrop voltage on the buses of the network**.**To return the voltage to the rated value (400kv) STATCOM is used for this purpose. STATCOM provides suitable reactive power to the network to compensate the drop voltage on the buses, in the same time when the STATCOM improves the voltage there are large oscillations. These oscillations are handled by using power oscillation damping (POD) and proportional integral (PI) controller with the STATCOM.Each of thepower oscillation damping (POD) and Proportional integral (PI) controller is connected inside current regulator of the STATCOM device.The performance of the (POD) and (PI) in cancelation the oscillations is compared.

Keywords- MATLAB/simulation; facts; STATCOM; generators; transformers; loads; power oscillation damping (POD); proportional integral (PI) controller.

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تطبيق المعوض المتزامن الستاتيكي على الشبكة العراقية الوطنية مع مخمد ذبذبات القدرة و المسيطر التناسبي التكاملي

الخلاصة

نظام نقل التيار المتناوب المرن يمكن ان يجهز سيطلرة افضل من السيطرة التقليدية ويحرز سرعة تحكم بزمن الاستجابة. المعوض المتزامن الستاتيكي جهاز تحويل نظام نقل التيار المتناوب المرن انه يستخدم للسيطرة على الفولطية وزيادة اداء النظام. في هذا البحث المعوض المتزامن الستاتيكي يستخدم لتحسين قيمة واستقرارية الشبكة الوطنية العراقية (جانب الاربعمائة كيلو فولت) بأستخدام سمنلك برنامج الماتلاب. المعوض الستايكي المتزامن يربط الى الشبكة الوطنية العراقية جانب (الاربعمائة كيلو فولت) التي تتكون من اربعة وعشرون قضيب توصيل, احد عشر مولد, احد عشر محولة رافعة للفولطية من جهة كل مولد, عشرون محولة خافضة للفولطية من جهة كل حمل و عشرون حمل.تغير الاحمال خلال فصول السنة تسبب سحب الفولطية على قضبان توصيل الشبكة. لارجاع الفولطية الى القيمة التقديرية اربعمائة كيلو فولط المعوض الستاتيكي المتزامن يستخدم لهذا الغرض. المعوض الستاتيكي المتزامن يجهز قدرة متفاعلة مناسبة الى الشبكة لتعويض سحب الفولطية على القضبان, في نفس الوقت عندما المعوض الستاتيكي المتزامن يحسن الفولطية توجد ذبذبات كبيرة. هذه الذبذبات تعالج بأستخدام مخمد ذبذبات القدرة و مسيطر نوع تناسب تكامل الربح مع المعوض الستاتيكي المتزامن. كل من مخمد ذبذبات القدرة و مسيطر نوع تناسب تكامل الربح يربط داخل منظم التيار من جهاز المعوض الستاتيكي المتزامن. اداء مخمد ذبذبات القدرة و مسيطر نوع تناسب تكامل الربح في ازالة او تقليل الذبذبات يقارن.

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 electric energy source and operated 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 per 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 3 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, in [10] power system stabilizer is used with many types of facts to damp oscillations and in [11] A Unified Power Flow Controller (UPFC) based damping controller was proposed to improve the dynamic stability of theIraqi National Super Grid System (INSGS).PI controller was applied to the design of the damping controller. In this paper POD method is used to damp oscillations. The paper is organized as follows:
In section (2) STATCOM model, in section (3) power oscillation damping (POD), in section (4) proportional integral (PI) controller, in section (5) Iraqi (400kv) super grid network implementation in MATLAB/SIMULINK and results, in section (6) conclusion, in section (7) appendix and in section (8) references.

STATCOM MODEL

A. Typical STATCOM functionality

Typical 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].

B. 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 (X_{SDT}), a three phase (GTO) based voltage source converter (VSC) and a DC capacitor.

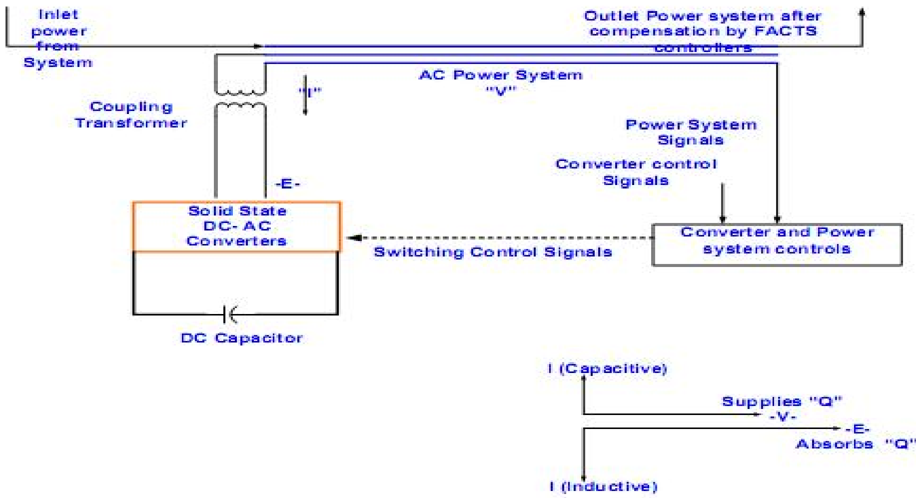

Figure (1) Typical STATCOM compensator

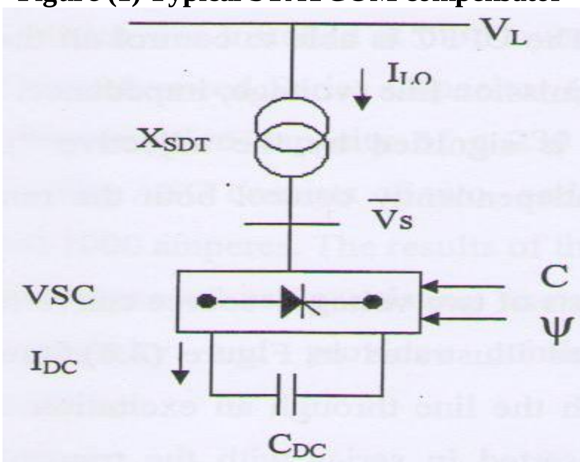

Figure (2) STATCOM configuration

C. Mathmatical operation

The voltage source inverter generates a controllable ac voltage source:

$$V_S(t) = V_S \sin(wt-\psi) \text{ .... } (1)$$

Behind the leakage reactance. The voltage difference between the STATCOM (V_S(t)) and bus ac voltage (V_L(t)) produce active and reactive power exchange between the STATCOM and the power system, which can be controlled by adjusting the magnitudeV_S and phase (ψ).

$$V_S = C\,V_{DC}\,(\cos\,\theta + j\,\sin\,\theta) = C\,V_{DC}\llcorner\theta \ldots\ldots (2)$$

$$\frac{dV_{DC}}{dt} = \frac{c}{CDC}\,(I_d\cos\Psi + I_q\sin\Psi) \quad \ldots\ldots (3)$$

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

D. STATCOM V-I characteristic

The voltage current characteristic STATCOM are shown in Fig (3) As can be seen in the linear operating range.From V-I characteristic of the STATCOM, STATCOM can serve as a controllable current sourcewithout changing the network structure parameters and beyond the limitation of bus voltage, it cansupply 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[12].

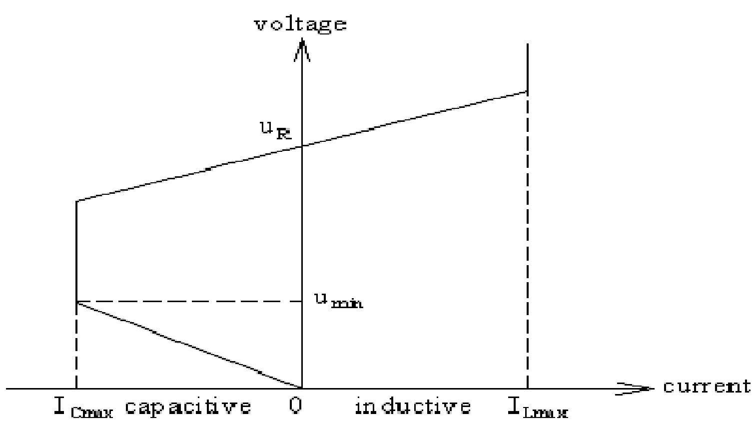

Figure (3) voltage current characteristic of the STATCOM

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 connected blocks. The speed deviation signal is derived from the difference of measured power at STATCOM location and the set 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].

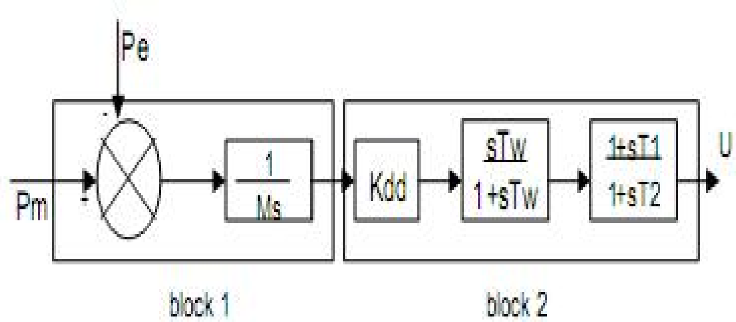

Figure (4) Transfer function block diagram of the POD

PROPORTIONAL INTEGRAL (PI) CONTROLLER

PI controller generates a gated command to operate the converters to compensate the error, which has been calculated by comparing defined values against measured values for both reactive and real powers [13].A proportional controller (K_P) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error. An integral control (K_i) will have the effect of eliminating the steady-state error, but it may make the transient response worse.

1. Iraqi (400kv) super grid network implementation in MATLAB/SIMULINK and results

A. without STATCOM

Figure (5) shows the representation of the Iraqi (400kv) super grid network by MATLAB simulation without STATCOM during maximum load and figure (6) during minimum load. The rated voltage,power and frequency are 400kv, 100MVA, 50HZ respectively. From Iraqi (400kv) super grid network dataduring maximum load there is a shunt positive MVAR (shunt inductive reactance) and during minimum load there is a negative MVAR (shunt capacitive reactance).

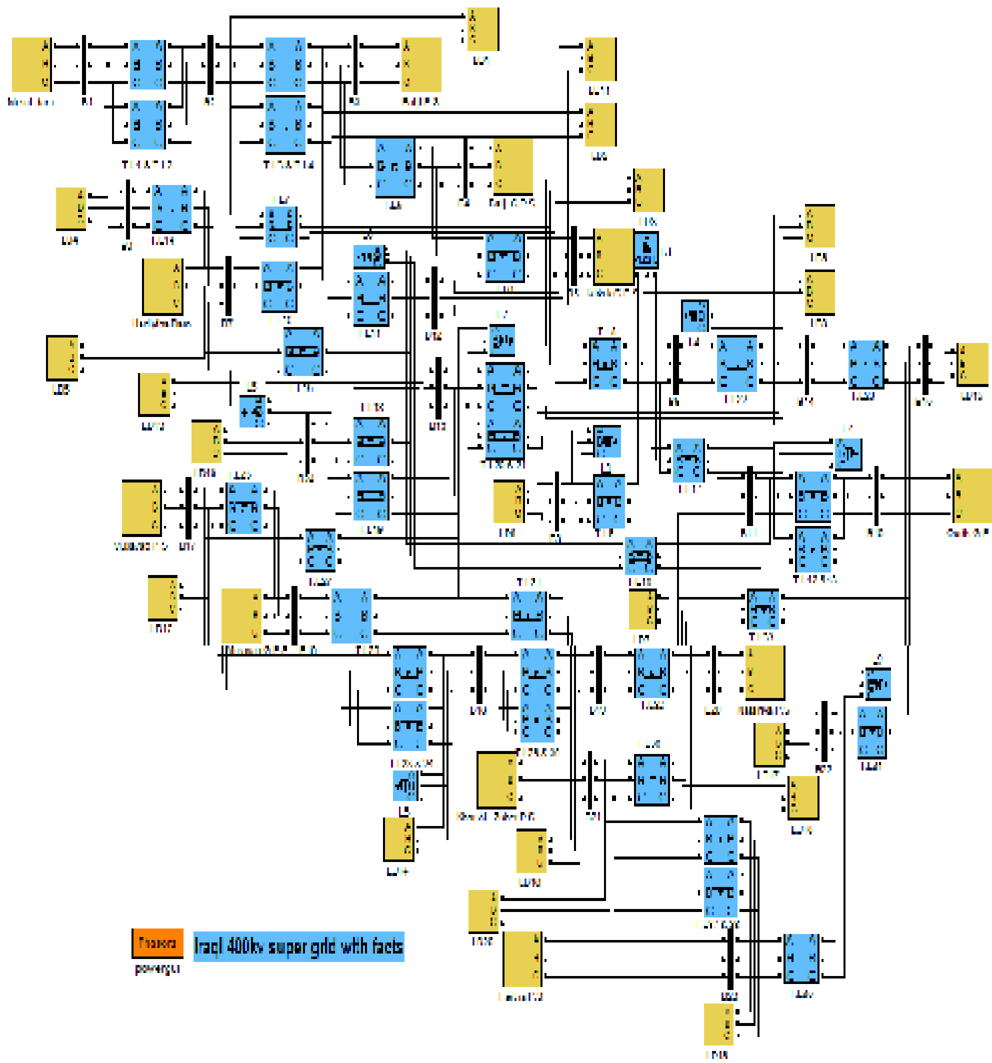

Figure (5) MATLAB simulation of the Iraqi (400kv) super grid network during maximum load without STATCOM

B. With STATCOM

Figure (7) the representation of the Iraqi (400kv) super grid network with STATCOM during maximum load and figure (8) during minimum load. Through the simulation results the best location of the STATCOM is on Mosul bus bar to improve the voltage on the other buses.

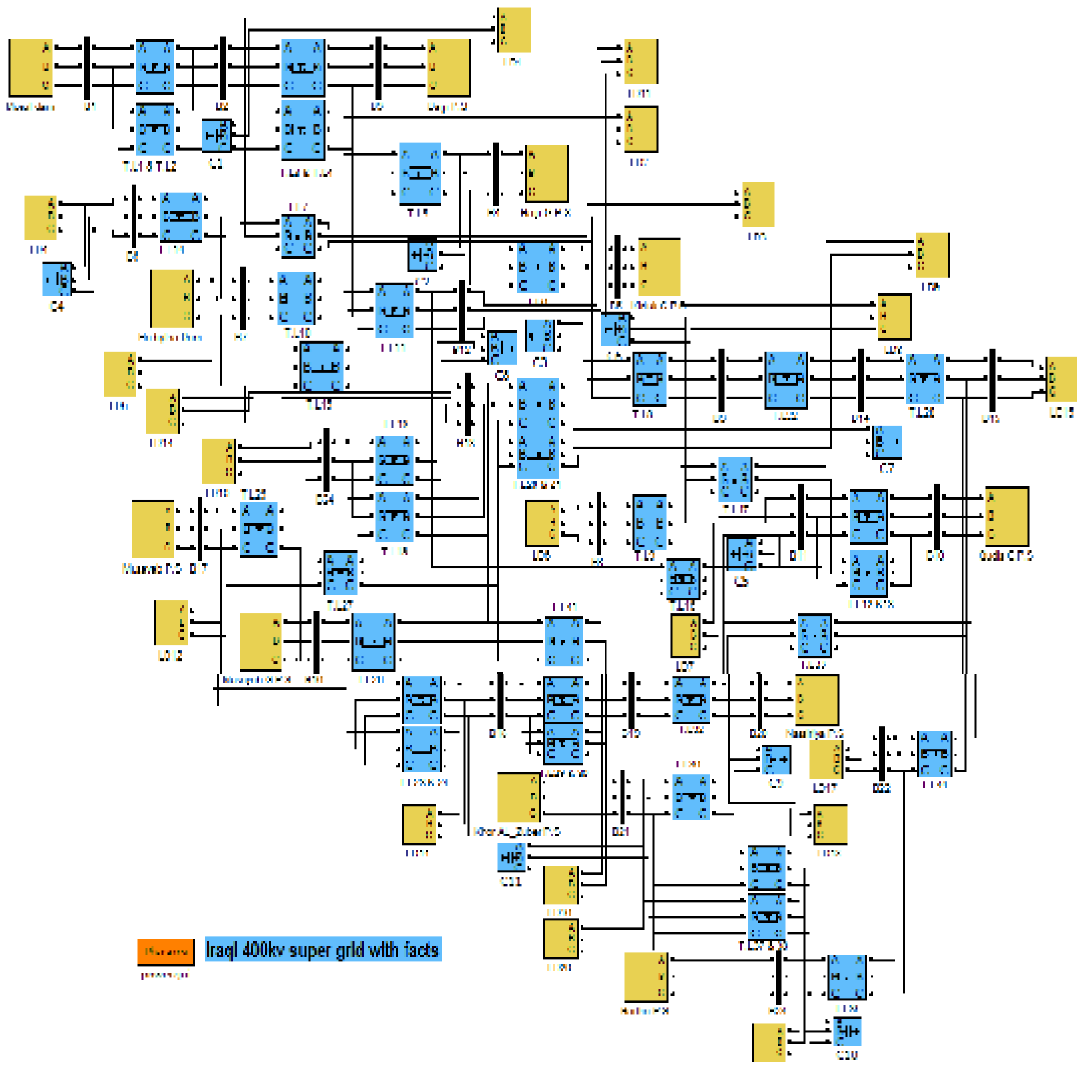

Figure (6) MATLAB simulation of the Iraqi (400kv) super grid network during minimum load without STATCOM

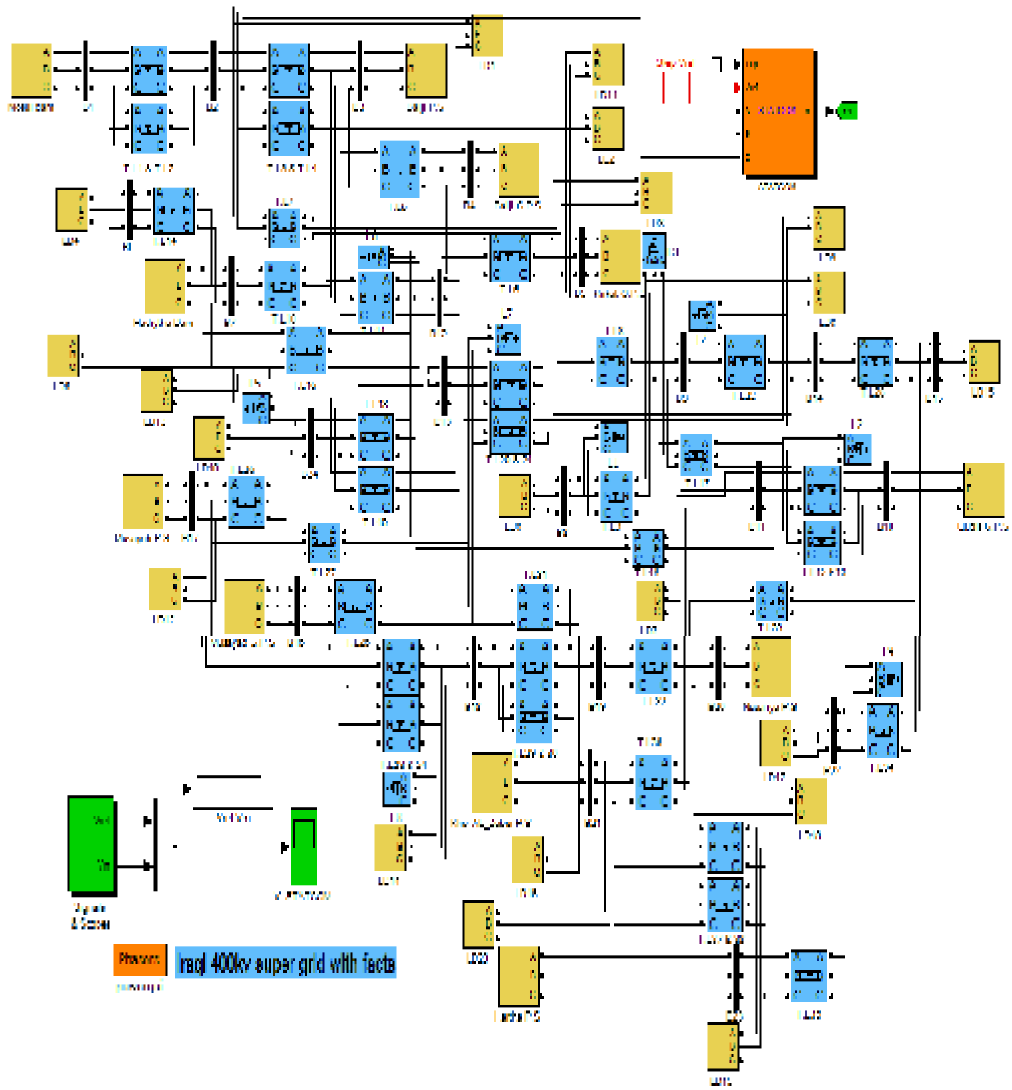

Figure (7) MATLAB simulation of the Iraqi (400kv) super grid network with STATCOM during maximum load

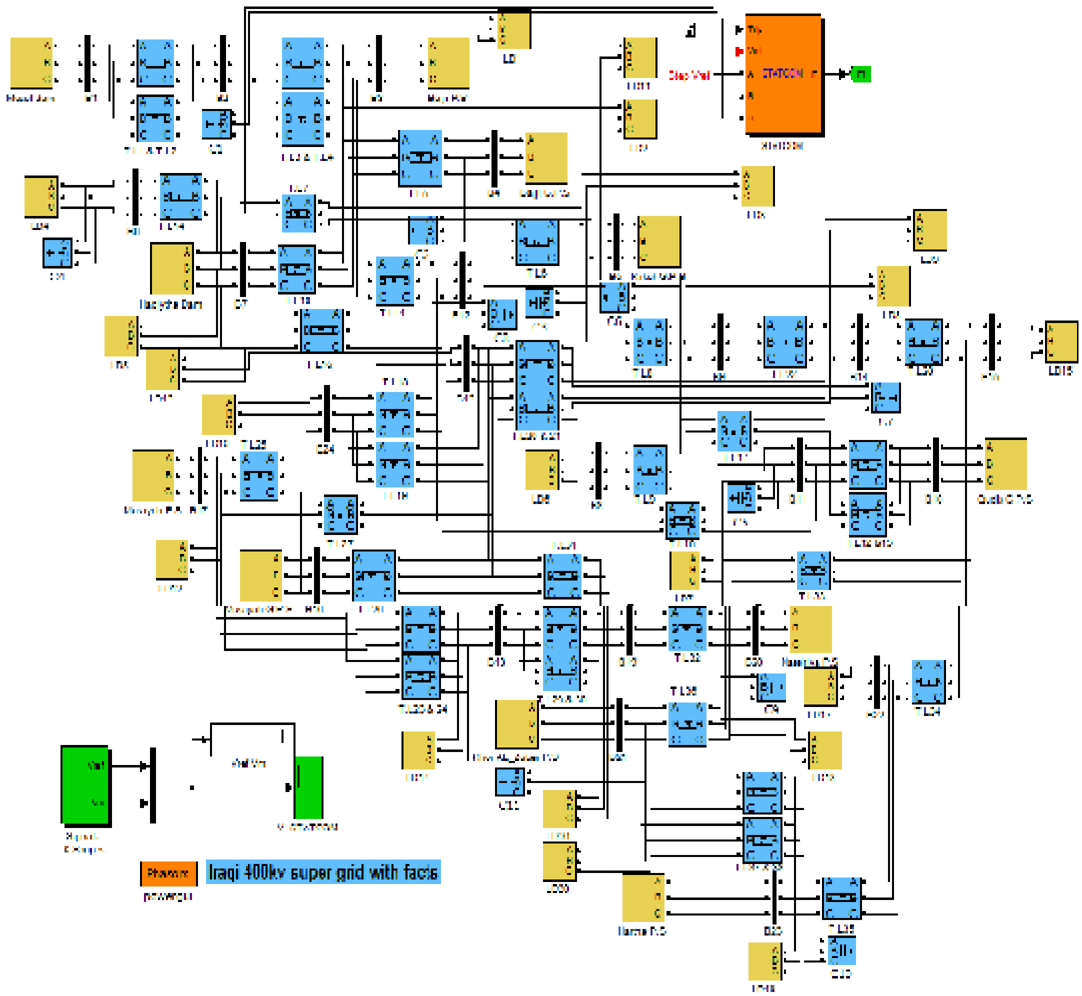

Figure (8) MATLAB simulation of the Iraqi (400kv) super grid network with STATCOM during minimum load

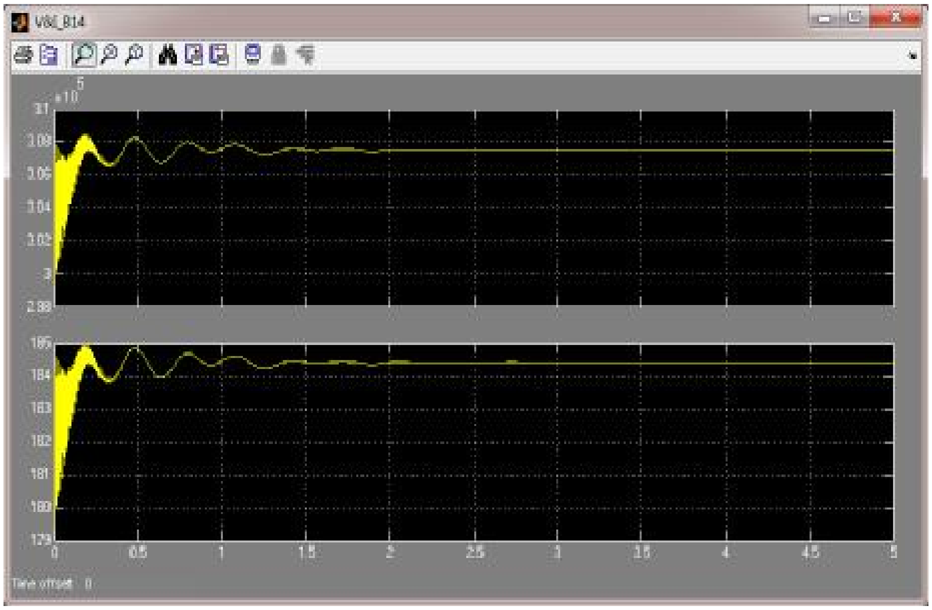

Figure (9) voltage and current without STATCOM during maximum load

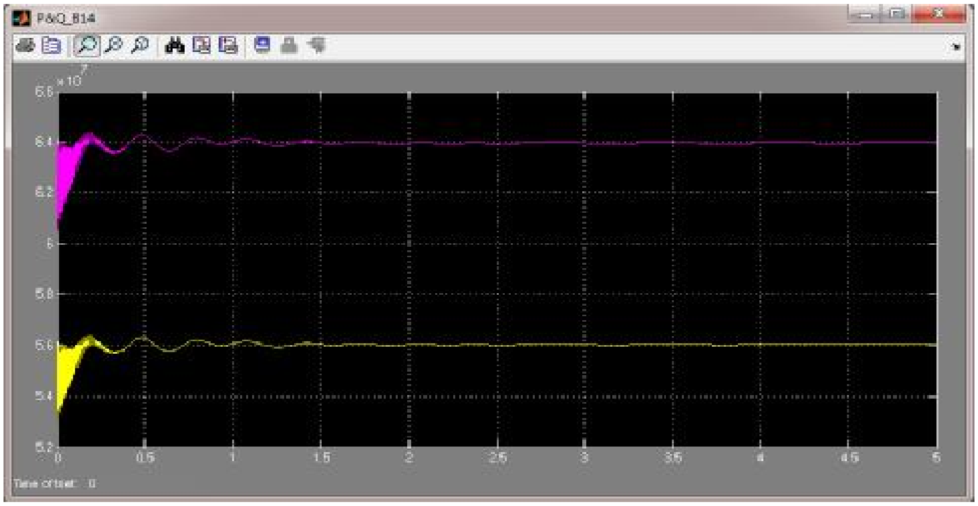

Figure (10) active and reactive power without STATCOM during maximum load

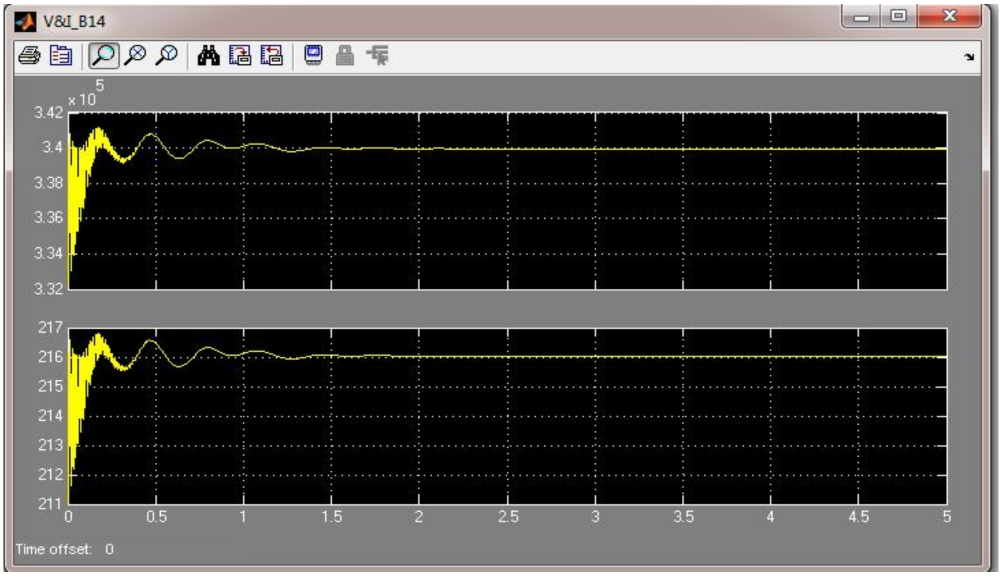

Figure (11) voltage and current without STATCOM during minimum load

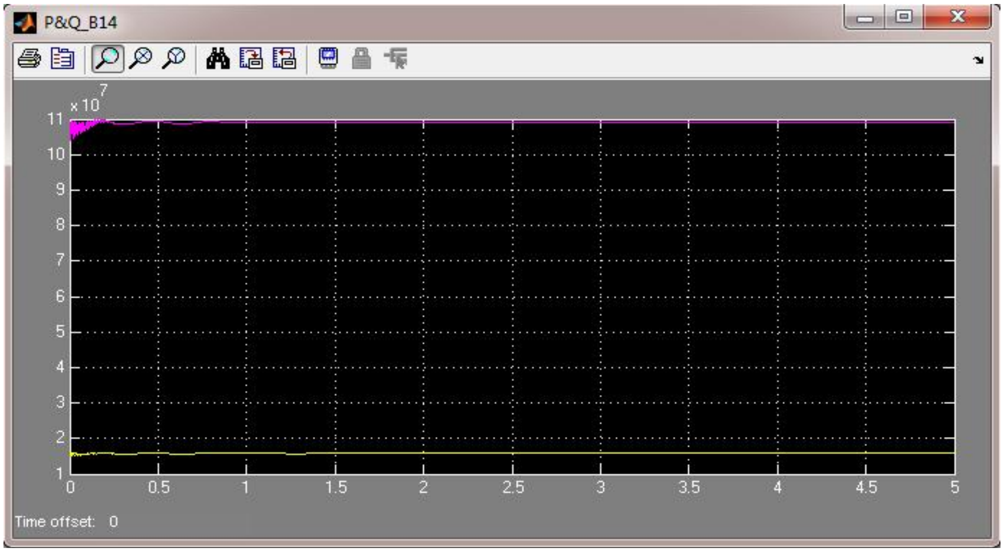

Figure (12) active and reactive power without STATCOM during minimum load

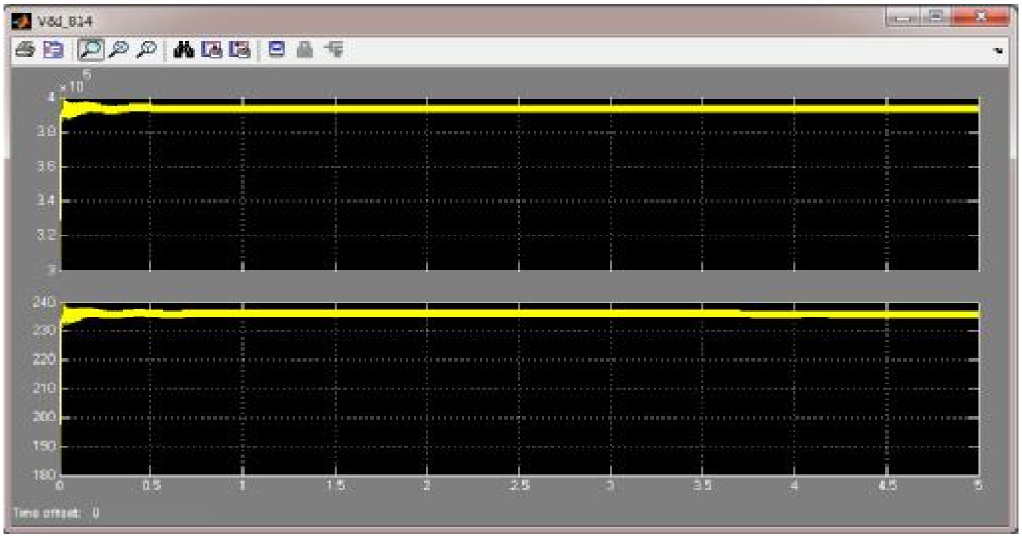

Figure (13) voltage and current with STATCOM during maximum load

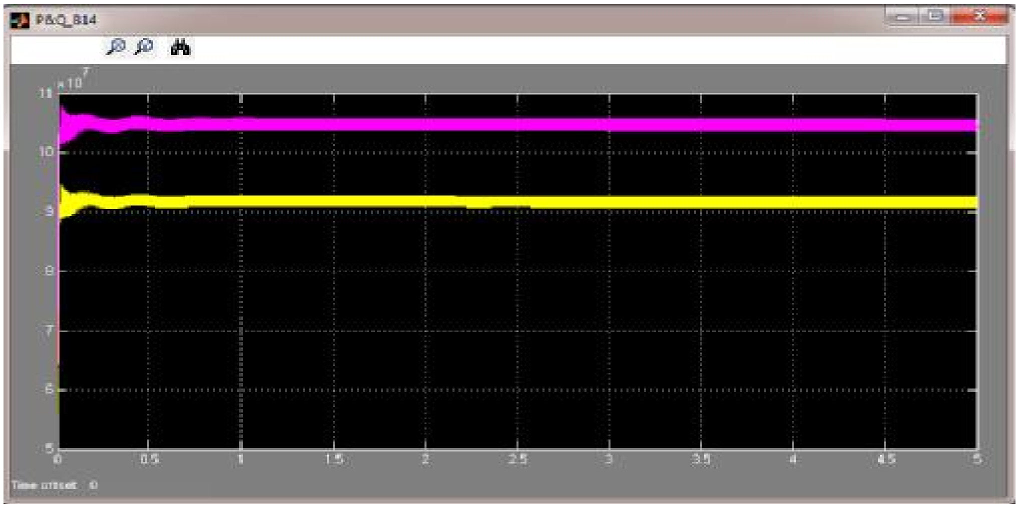

Figure (14) active and reactive power with STATCOM during maximum load

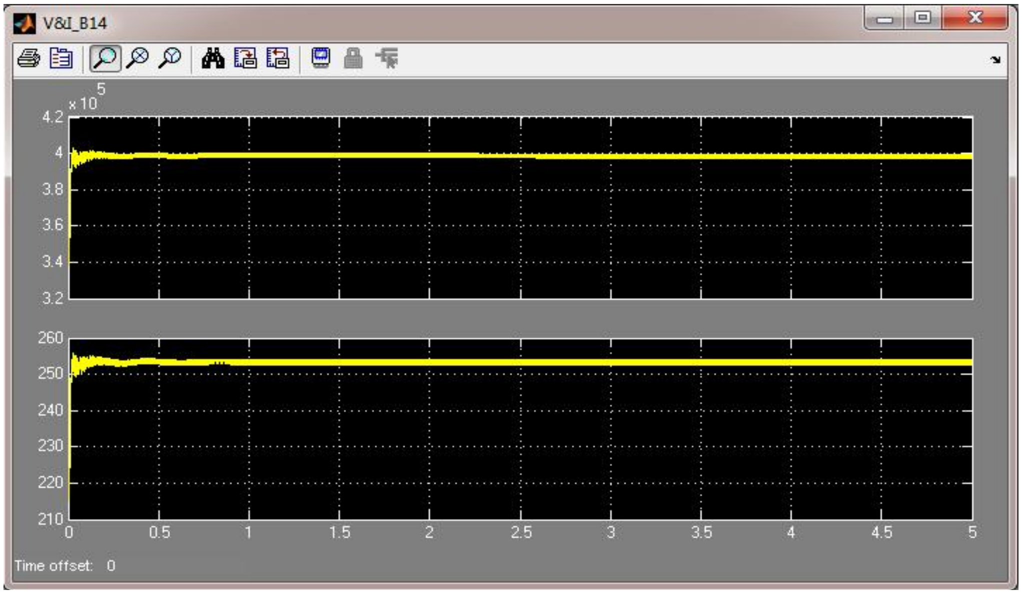

Figure (15) voltage and current with STATCOM during minimum load

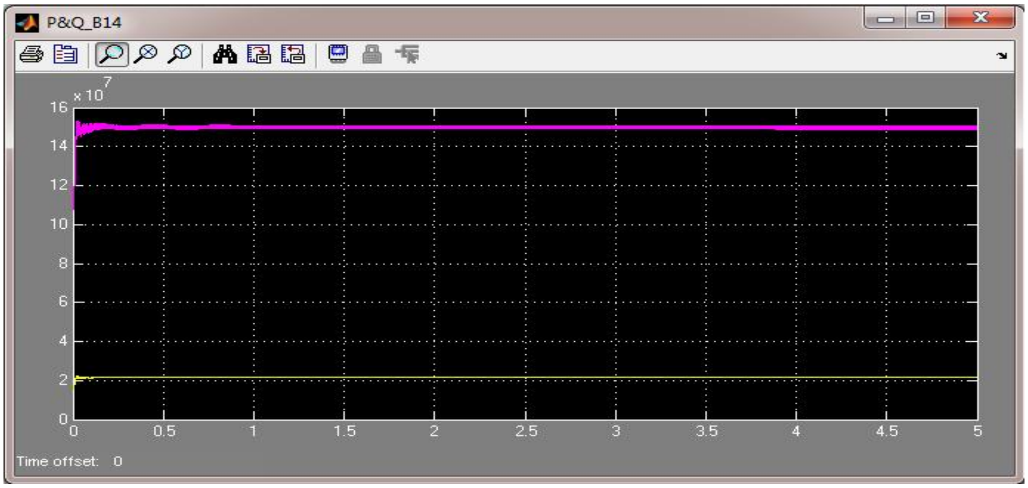

Figure (16) active and reactive power with STATCOM during minimum load

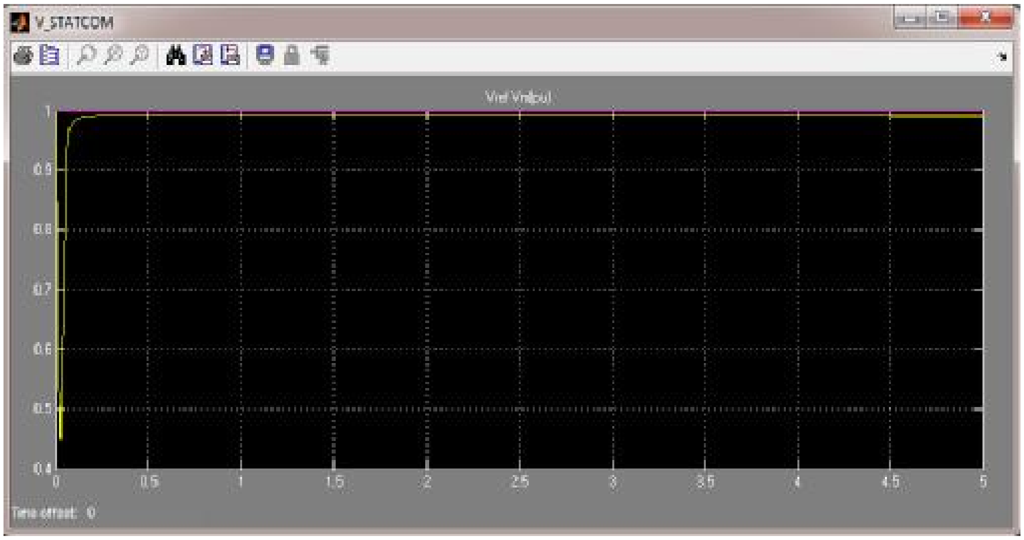

Figure (17) reference and measurement voltage of the STATCOM in (PU) during maximum load

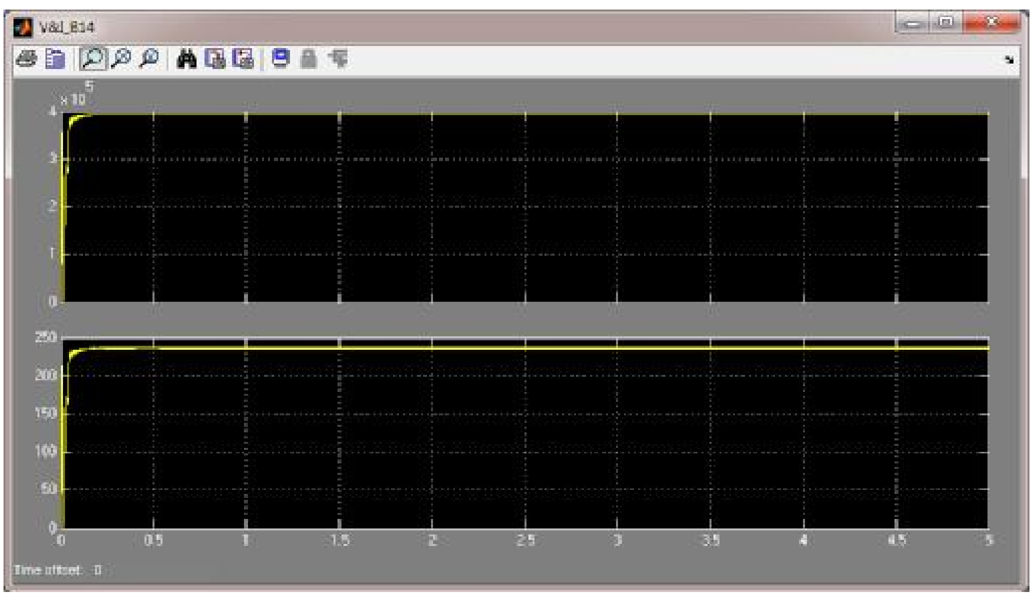

Figure (18) voltage and current with STATCOM during maximumload with POD

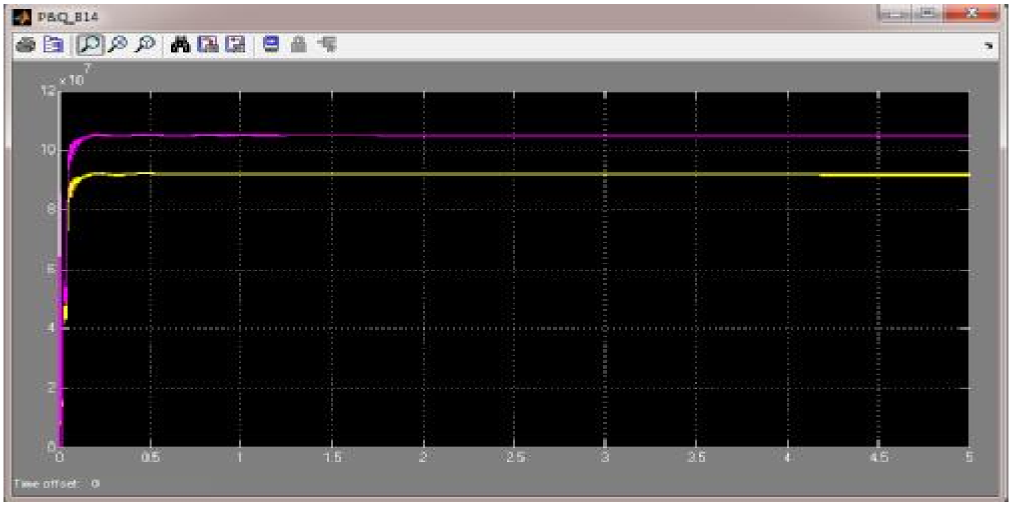

Figure (19) active and reactive power with STATCOM during maximum load with POD

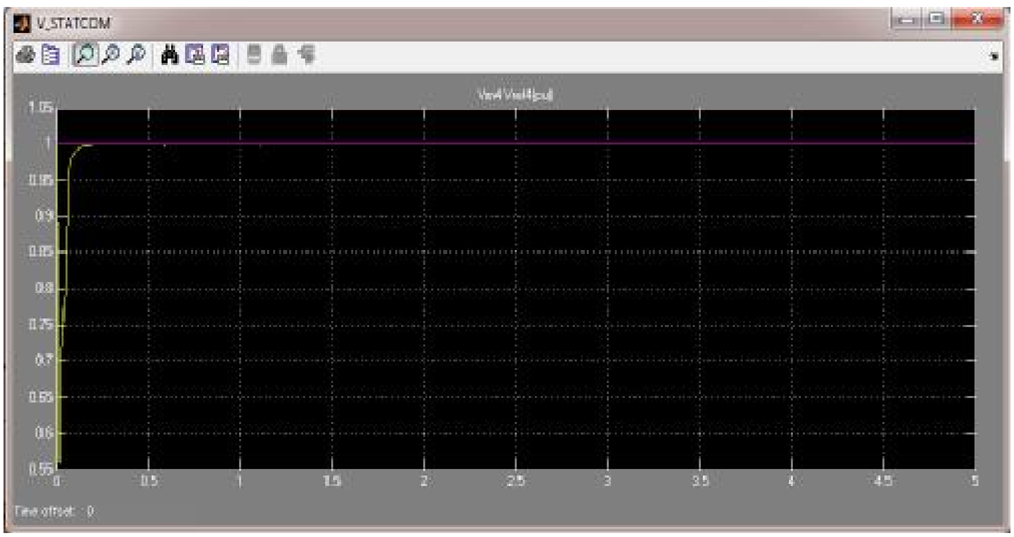

Figure (20) reference and measurement voltage of the STATCOM in (PU) during minimum load

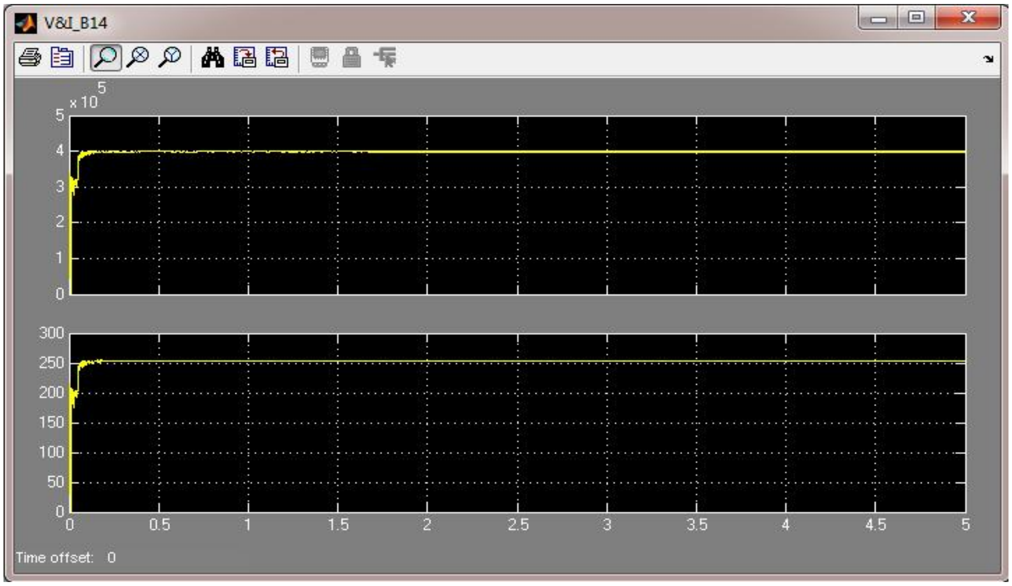

Figure (21) voltage and current with STATCOM during minimum load with POD

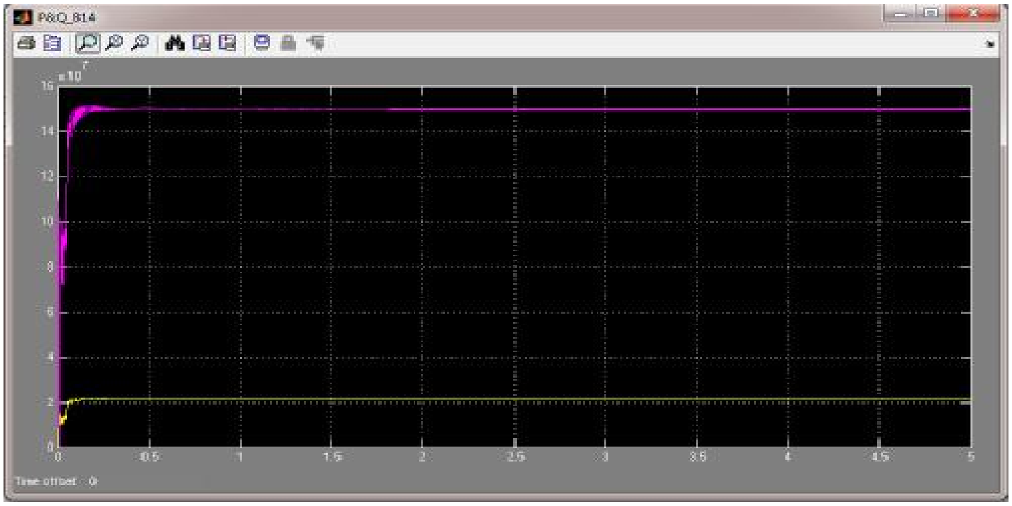

Figure (22) active and reactive power with STATCOM during minimum load with POD

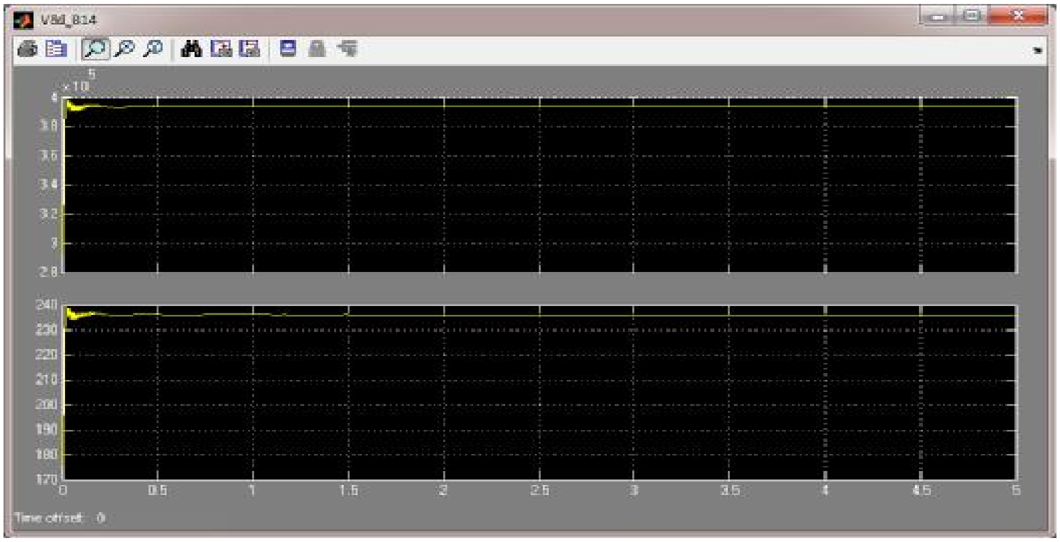

Figure (23) voltage and current with STATCOM during maximum load with PI controller

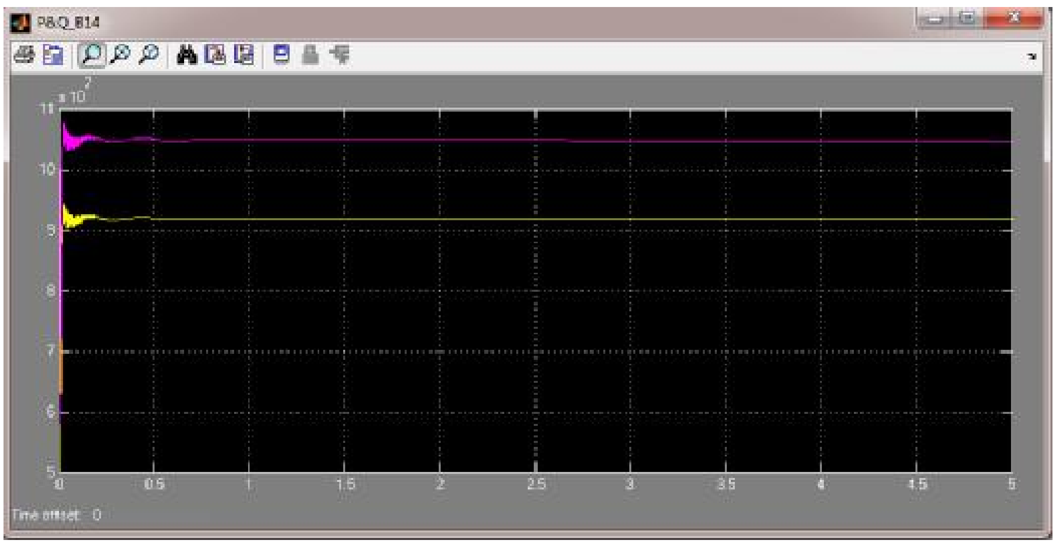

Figure (24) active and reactive power with STATCOM during maximum load with PI controller

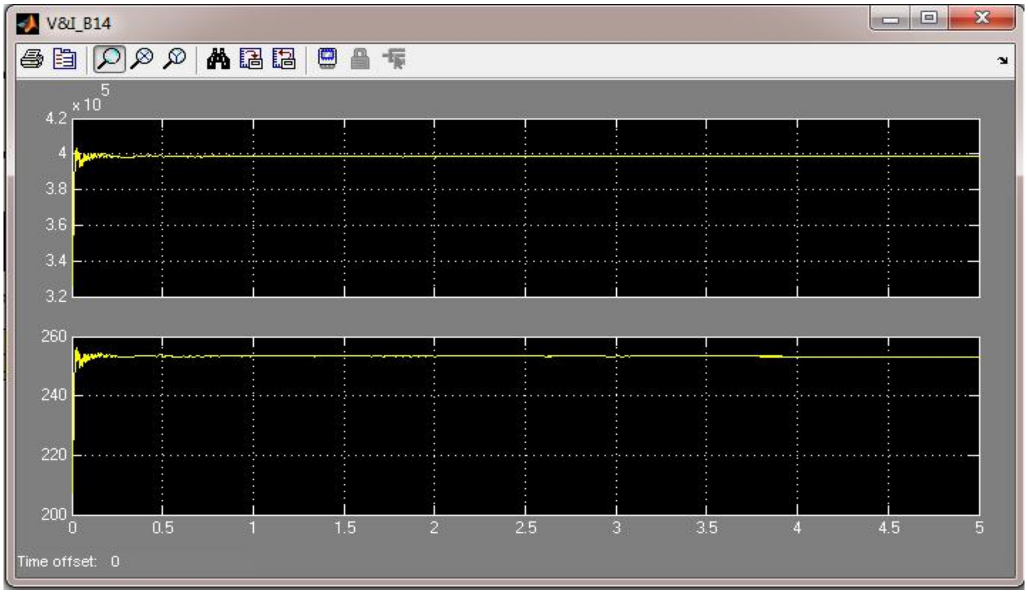

Figure (25) voltage and current with STATCOM during minimum load with PI controller

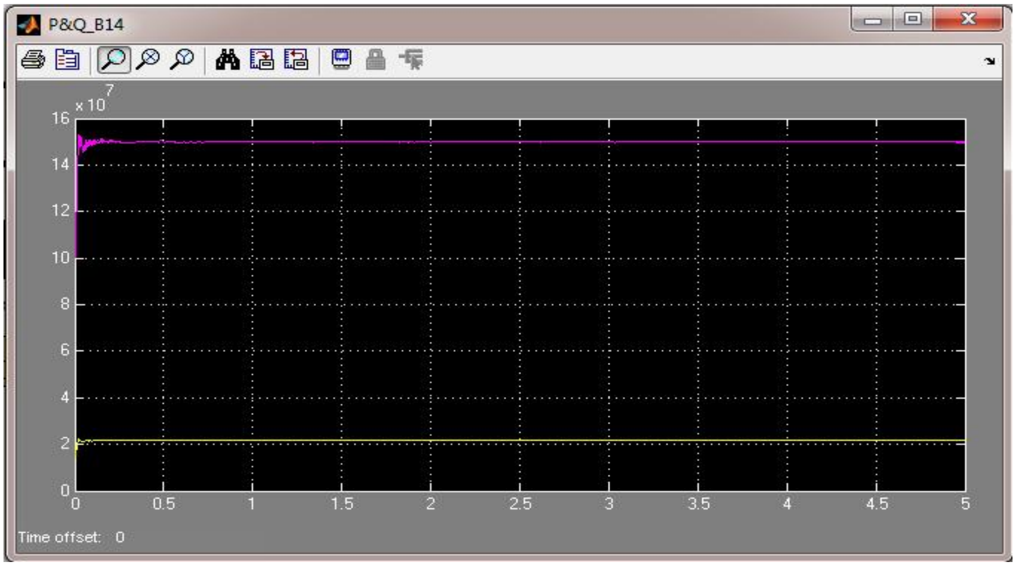

Figure (26) active and reactive power with STATCOM during minimum load with PI controller

The results on AL-AMEEN bus bar during maximum and minimum load is taken as example to show the effect of the STATCOM, POD and PI controller. Figure (9) shows the voltage and current on AL-AMEEN bus bar without STATCOM connection to the network during maximum load, because the drop the bus voltage is (307.5KV) and figure (10) shows the active and reactive power on AL-AMEEN bus bar without STATCOM. Figure (11) shows the voltage and current on AL-AMEEN bus bar without STATCOM connection to the network during minimum load, the bus voltage is (340KV) and figure (12) shows the active and reactive power on AL-AMEEN bus bar without STATCOM. The improvement of the voltage during maximum load represent in figure (13) when the STATCOM is connected to the network, voltage is improved to (393.6KV) and figure (14) shows active and reactive power when the voltage is improved during maximum load. Figure (15) shows voltage improvement during minimum load and figure (16) shows active and reactive power when the voltage is improved during minimum load. When the voltage is improved there are oscillations. These oscillations are handled by using power oscillation damping (POD) and proportional integral (PI) controller. Figure (17) shows STATCOM voltage improvement in (P.U) during maximum load and figure (20) during minimum load. During maximum load the voltage oscillations are reduced from (3KV) as shown in figure (13) to (500V) as shown in figure (18) by using (POD) and figure (19) shows active and reactive power under POD operation. During minimum load the voltage oscillations are reduced from (2.170KV) as shown in figure (15) to (350V) as shown in figure (21) by using (POD) and figure (22) shows active and reactive power under POD operation. By using (PI) controller during maximum load the voltage oscillations are reduced from (3KV) to (0V) as shown in figure (23) and figure (24) shows active and reactive power under PI controller operation. During minimum load the voltage oscillations also are reduced from (2.170KV) to (0V) as shown in figure (25) and figure (26) shows active and reactive power under PI controller operation, therefore PI controller is better than POD in oscillations reducing. The amplitudes of the voltage, current, power and reactive power on the buses before and after STATCOM connection to the Iraqi (400KV) super grid during maximum and minimum load are shown in table (1), (2), (3) and (4). Tables (1&3) represent the results during maximum and minimum load without STATCOM respectively; the drop voltage during maximum load on the network buses is larger than during minimum load, therefore STATCOM provides reactive power compensation during maximum load larger than during minimum load as shown in tables (2&4), for example reactive power magnitude on Baghdad south bus bar during maximum load is (90.15MVAR) without STATCOM but with STATCOM contribution the reactive power magnitude is (147.44MVAR), this means STATCOM reactive power compensation during maximum load is (57.29MVAR)for improving voltage to (393.1KV) on the bus bar, also during minimum load reactive power magnitude is (91MVAR) without STATCOM and with STATCOM is (125MVAR), this mean STATCOM reactive power compensation (34MVAR) for improving voltage is (398.2KV).

Table (1) Before STATCOM connection to the network during maximum load

Bus name	Bus number	Voltage	Current	Power	Reactive power
MOSUL	2	309.3KV	821.8A	200.2MW	324.5MVAR
BAIJI P.S	3	308.8KV	398A	119.08MW	140.78MVAR
KIRKUK	5	308.7KV	510.5A	155.6MW	177.9MVAR
QAIM	6	308.5KV	134.4A	60.58MW	13.94MVAR
Hadiytha dam	7	308.5KV	245.6A	88.11MW	71.8MVAR
DYLA	8	308.1KV	215.6A	86.5MW	49.4MVAR
BAGHDAD EAST	9	308.1KV	359.5A	132.9MW	99.6MVAR
BAGHDAD NORTH	11	308.1KV	628.7A	233.33MW	173.07MVAR
BAGHDAD WEST	12	308.2KV	752.3A	197.3MW	286.4MVAR
BAGHDAD SOUTH	13	307.4KV	271.6A	86.9MW	90.15MVAR
AL-AMEEN	14	307.5KV	184.4A	56.05MW	64MVAR
KUT (WASIT)	15	306.7KV	347.5A	123.2MW	101.8MVAR
MUSAYAB P.S	17	307.2KV	414.8A	125.3MW	144.2MVAR
BABIL	18	307.1KV	370.3A	119.19MW	122MVAR
KADISIYAH	19	307KV	405.4A	113.5MW	148.2MVAR
NASSIRIYAH	20	306.8KV	495.4A	130.7MW	186.7MVAR
KHOR ALZUBER	21	306.7KV	311.4A	84.4MW	115.7MVAR
AMARA	22	306.6KV	327.4A	125MW	84MVAR
HARTHA	23	306.6KV	269.1A	88.9MW	86.09MVAR
AL-RASHID	24	307.7KV	254.4A	59.06MW	101.5MVAR

Table (2) After STATCOM connection to the network during maximum load

Bus name	Bus number	Voltage	Current	Power	Reactive power
MOSUL	2	396.8KV	1054A	329.4MW	532MVAR
BAIJI P.S	3	395.8KV	510.1A	195.5MW	231.19MVAR
KIRKUK	5	395.5KV	654.1A	255.4MW	292.1MVAR
QAIM	6	395.2KV	172.1A	99.4MW	22.88MVAR
HAYITHA dam	7	395.2KV	314.6A	144.5MW	117.8MVAR
DYLA	8	394.5KV	276A	141.8MW	81.036MVAR
BAGHDAD EAST	9	394.5KV	460.3A	218MW	163.3MVAR
BAGHDAD NORTH	11	394.4KV	804.9A	382.5MW	283.6MVAR
BAGHDAD WEST	12	394.7KV	963.4A	323.6MW	469.6MVAR
BAGHDAD SOUTH	13	393.1KV	347.4A	142.13MW	147.44MVAR
AL-AMEEN	14	393.4KV	235.9A	91.7MW	104.6MVAR
KUT (WASIT)	15	391.9KV	444A	201.2MW	166.2MVAR
MUSAYAB P.S	17	392.7KV	530.3A	204.8MW	235.6MVAR
BABIL	18	392.6KV	473.4A	194.76MW	199.3MVAR
KADISIYAH	19	392.5KV	518.2A	185.5MW	242MVAR
NASSIRIYAH	20	391.9KV	632.9A	213.4MW	305MVAR
KHOR ALZUBER	21	391.7KV	397.7A	137.6MW	188.7MVAR
AMARA	22	391.7KV	418.2A	204MW	137.04MVAR
HARTHA	23	391.6KV	343.6A	145MW	140.43MVAR
AL-RASHID	24	393.8KV	325.6A	96.74MW	166.27MVAR

Table (3) Before STATCOM connection to the network during minimum load

Bus name	Bus number	Voltage	Current	Power	Reactive power
MOSUL	2	340.7KV	782.7A	252.5MW	310.3MVAR
BAIJI P.S	3	340.5KV	323.4A	136.3MW	93.3MVAR
KIRKUK	5	340.5KV	388.8A	140MW	140.8MVAR
QAIM	6	340.4KV	119.6A	59.23MW	14.8MVAR
Hadiytha dam	7	340.4KV	198.6A	93.412MW	39.46MVAR
DYLA	8	340.5KV	203.2A	94.98MW	41.84MVAR
BAGHDAD EAST	9	340.3KV	346.5A	166.75MW	59MVAR
BAGHDAD NORTH	11	340.2KV	631.9A	279.2MW	161.4MVAR
BAGHDAD WEST	12	340.3KV	751.9A	294.4MW	246.1MVAR
BAGHDAD SOUTH	13	339.8KV	205A	51.37MW	91MVAR
AL-AMEEN	14	340KV	216A	15.733MW	109.03MVAR
KUT (WASIT)	15	339.5KV	344.4A	133.9MW	113.16MVAR
MUSAYAB P.S	17	339.7KV	350.7A	159.8MW	79.6MVAR
BABIL	18	339.7KV	284.9A	140.18MW	37.62MVAR
KADISIYAH	19	339.6KV	433.4A	119.6MW	185.6MVAR
NASSIRIYAH	20	339.5KV	412.3A	164.5MW	130.37MVAR
KHOR ALZUBER	21	339.4KV	288.5A	58MW	135MVAR
AMARA	22	339.4KV	229.1A	92.9MW	70.56MVAR
HARTHA	23	339.4KV	217.4A	96.6MW	54.05MVAR
AL-RASHID	24	340KV	233.3AA	31.26MW	114.8MVAR

Table (4) After STATCOM connection to the network during minimum load

Bus name	Bus number	Voltage	Current	Power	Reactive power
MOSUL	2	400KV	918.8A	348MW	327.5MVAR
BAIJI P.S	3	399.5KV	379.4A	187.6MW	128.4MVAR
KIRKUK	5	399.4KV	456.1A	192.6MW	193.8MVAR
QAIM	6	399.2KV	140.2A	81.5MW	20.37MVAR
Hadiythadam	7	399.2KV	232.9A	128.4MW	54.2MVAR
DYLA	8	399.2KV	238.3A	130.5MW	57.5MVAR
BAGHDAD EAST	9	399KV	406.2A	229.2MW	81.1MVAR
BAGHDAD NORTH	11	398.9KV	740.8A	383.8MW	221.8MVAR
BAGHDAD WEST	12	399KV	881.7A	404.8MW	338.4MVAR
BAGHDAD SOUTH	13	398.2KV	240.2A	70.5MW	125MVAR
AL-AMEEN	14	398.4KV	253.2A	21.6MW	149.7MVAR
KUT (WASIT)	15	397.5KV	403.3A	183.7MW	155.17MVAR
MUSAYAB P.S	17	397.9KV	410.4A	219.2MW	109.3MVAR
BABIL	18	397.9KV	333.7A	192.3MW	51.6MVAR
KADISIYAH	19	397.8KV	507.7A	164.13MW	254.68MVAR
NASSIRIYAH	20	397.5KV	482.7A	225.6MW	178.7MVAR
KHOR ALZUBER	21	397.4KV	337.4A	79.5MW	185MVAR
AMARA	22	397.4KV	268.3A	127.3MW	96.7MVAR
HARTHA	23	397.3KV	254.4A	132.4MW	74.08MVAR
AL-RASHID	24	398.5KV	273.5A	42.9MW	157.7MVAR

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 the Iraqi (400kv) super grid network buses by using MATLAB/Simulink. In this paper AL-AMEEN bus bar results during maximum and minimum load four two states: without STATCOM and with STATCOM show the bus voltage reduced under rated value (400KV) because the drop voltage due to load effects during maximum and minimum load. When STATCOM is connected to the network the drop voltage is reduced by STATCOM reactive power compensation. When the voltage magnitude is improved there are oscillations. The voltage stability is achieved by canceling these oscillations by using power oscillation damping (POD) and PI controller. The results show PI controller performance is better than POD in damping oscillations by fifty percent because the oscillation magnitude on PI controller operation is reduced to zero during maximum and minimum load while on POD operation it is reduced to (500V) and (350V) during maximum and minimum load respectively.

APPENDIX

A. List of symbols

V_L	line voltage
Ψ	Phase angle of the mid-bus voltage
C	Magnitude voltage of the STATCOM control
C_{dc}	DC link capacitance voltage
V_{dc}	DC link voltage
I_d, I_q	Direct and quadrature current
I_{LO}	line current
K	ratio between ac and dc voltage
m	modulation ratio
T_w	wash out time
M	inertia constant
V_{ref}	reference voltage
V_m	measurement voltage
P_m	mechanical power
P_e	electrical power

B. STATCOM data:

1. During maximum load

Rated voltage of the STATCOM =490KV
Rated power of the STATCOM =355500MVA
Rated frequency=50HZ

2. During minimum load

Rated voltage of the STATCOM =490KV
Rated power of the STATCOM =240000MVA, Rated frequency =50HZ

C. Power oscillations damping (POD) data:

Gain (KDD) = 60 during maximum load
Gain (KDD) =50 during minimum load
Wash out time (TW)= 1sec during maximum and minimum load.
Lead lag time constant [num (T1) den (T2)] = [2 4]during maximum and minimum load.
Proportional integral (PI) controller:
Proportional gain = 0.3 during maximum and minimum load.
Integral gain = 0.008 during maximum and minimum load.

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