Impact of HVDC System on Power System Stability

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Abstract: Recently, the application of High Voltage Direct Current (HVDC) technology in the electrical network become more popular due to their advantages comparing with High Voltage Alternating Current (HVAC) system. This paper focuses on studying the impact of HVDC system on the power system stability and this accomplished based on applying Location Marginal Price (LMP) which used to select and manage the congestion lines, besides increasing loading stability limit for the electrical network. After that we studying the effect of replacing the selected congested transmission lines in the proposed network with HVDC system and observe its effect on the performance of the network and on the system stability at normal and up normal cases. The proposed Power System network is IEEE 14-BUS in PSAT toolbox which operated under Matlab program. We observe from simulated results at certain replacement for the congestion lines with HVDC model the proposed system still stable.

Keywords: HVDC, HVAC, Power System Stability, Location Marginal Price (LMP).

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1. INTRODUCTION

With the development of high voltage rating Valves, it was possible to transmit DC power at very high voltages, known as the HVDC transmission systems as shown in the figure (1) ,therefore HVDC system is becoming an efficient technology used as transmission line to deliver large amounts of electricity over long distance [1-2].
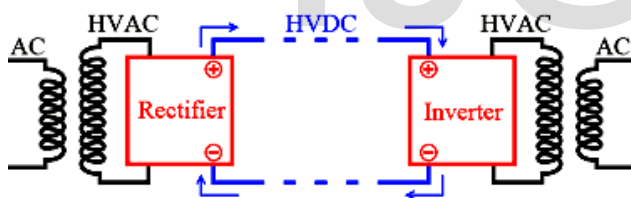

Fig. 1: configuration of HVDC system[2].

HVDC offer important technical ,economical and environmental advantages which making it very attractive comparing with HVAC line, wherefigure (2) shows the variation of costs of transmission with distance for AC and DC transmission and it showing that, AC tends to be more economical than DC for distances less than the "breakeven distance" but is more expensive for longer distances[3].
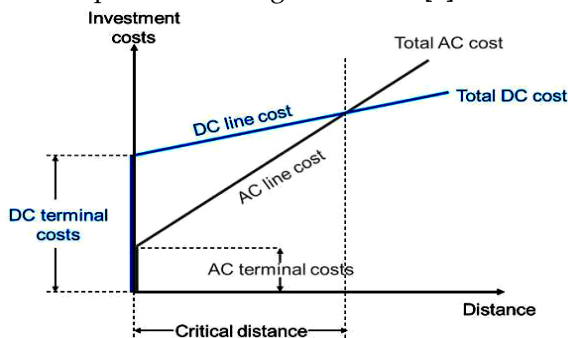

Fig. 2: Variation of costs of transmission with distance for AC and DC transmissions [3]

Also, HVDC acts as innovative solution for interconnections between separated power systems and used to avoid congestion and to improve stability and it also provides the necessary features to avoid technical problems in the power systems and increase the transmission capacity and system stability very efficiently and it assists in prevent of cascaded disturbances[2-4]. HVDC system is applied as a Back-to-Back for grid power flow control to elimination of congestion and loop flows or used as a long-distance point-to-point transmission[3-4].

2. Types of HVDC Transmission system

There are several configurations to browse when planning and arranging of HVDC systemand the most normally and commonly used HVDCconfigurations are:

i.   Back-to-back system configuration
ii. Monopolar system configuration
iii. Bipolarsystemconfiguration

THEbrief description of each configuration is given belowin figure (3) [3-5]

2.1: back-to-back Configuration

Back to back configuration is consists of two converters at the same site, they are connected directly to each other, without any transmission line in between, Where both rectifier and inverter located at one station. This configuration is basically used to tie asynchronous systems consists of two neighboring AC systems with different frequencies or with different control philosophies [5-6].

system reliability and security[7]. The disturbances

mentioned in the definition could be faults, load changes, generator outages, line outages, voltage collapse or some combination of these[7-8].

3.1 Definition of power system stability

Can be defined as the ability of electrical system to has initial operating condition and regain system equilibrium operation after the system has subjected to physical disturbance and achieves the power
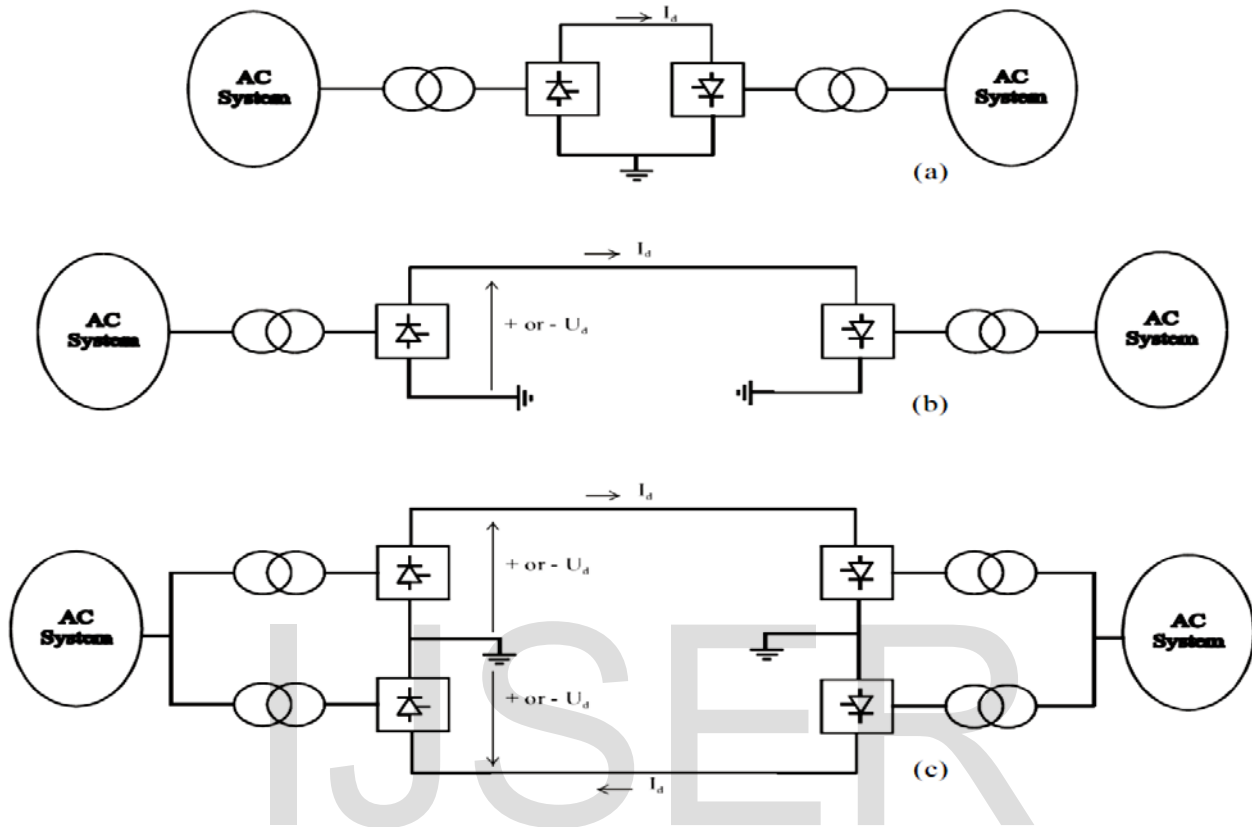

Fig. 3: Configurations of HVDC system[5-6](a) Back-to-back (b) Monopolar (c) Bipolar

2.2: Monopolar Configuration

The monopolar configuration uses one conductor between both converters while the return path is through ground or sea. It is used with generally and relatively low power ratings and in possibility conditions with bipolar systems[5-6].

2.3: Bipolar Configuration

The bipolar configuration is the most broadly used one in HVDC transmission. Two converters are used at each end of the link and the midpoint between the converters is grounded. Consequently, the upper converter operates with a positive DC voltage with respect to ground, while the lower converter operates with a negative DC voltage with respect to ground.The Ground way is used by both converters and the DC currents flows stream in opposite directions in the ground. In this way the net ground DC current is very small and it has little effect on the neighboring metallic structures[5-6].

3. Power System Stability

The importance of power system stability is increasingly becoming one of the mostlimiting factors for power system performance.

3.2 Classification of Power System Stability:

Power system stability can be broadly classified into:
  i.   rotor angle stability
  ii.   voltage stability
  iii. Frequency stability.

Each of these three stabilities can be further classified into large disturbance or small disturbance, short term or long term. The classification is showing in figure. (4) [7-8].
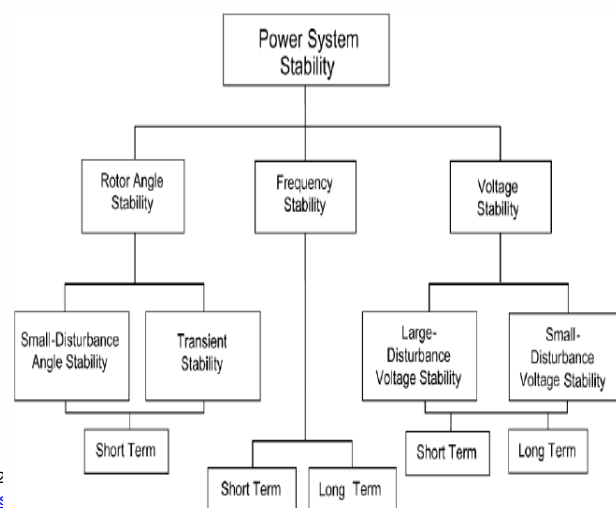
Fig. 4: Classification of power system stability[7-8]

3.2.1 Rotor Angle Stability:

Rotor angle stability refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to a disturbance. The rotor angle of a generator is depends on the ability to maintain/restore balance or equilibrium between electromagnetic torque due to the generator electrical power output and mechanical torque of each synchronous machine in the system due to the input mechanical power through a prime mover [7-8].

3.2.2 Voltage Stability:

Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operatingcondition.If the disturbance is large then it is called as large-disturbance voltage stability and if the disturbance is small it is called as small-disturbance voltage stability.Voltage stability depends on the ability to maintain/restore equilibrium between load demand and load supply from the power systemtherefore,the main difference between voltage stability and angle stability is that voltage stability depends on the balance of reactive power demand and generation in the system where as the angle stability mainly depends on the balance between real power generation and demand[7-8].

3.2.3 Frequency Stability:

Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. It depends on the ability to maintain/restore equilibrium between system generation and load, with minimum unintentional loss of load. Frequency instability may lead to sustained frequency swings leading to tripping of generating units or loads. During frequency excursions, the characteristic times of the processes and devices that are activated will range from fraction of seconds like under frequency control to several minutes, corresponding to the response of devices such as prime mover and hence frequency stability may be a short-term phenomenon or a long-term phenomenon[7-8].

4. Location marginal price [LMP]

In recent years, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. As a consequence, some transmission lines are heavily loaded and the power system stability becomes a power transfer-limiting factor.

Recent studies reveal that HVDC controllers could be employed to enhance power system stability in addition to their main function of power flow control,also HVDC improves both the static and dynamic stability and it reducing the losses and the cost of generation, also enhances the system loading capability with rerouting the power flow in the network. In order to reach the above goals, these devices must be located optimally ,therefore placement of HVDC in the more heavily loaded lines to limit the power flow in that lines causes more power to be sent through the remaining portions of the system while protecting the line with the device for being overloaded. The method that sites the devices in the heavily loaded line is the most effective and it known as Location marginal price(LMP) and it defined as the marginal cost of supplying the next increment of electric energy at a specific bus while considering the generation marginal cost and the physical aspects of the transmission system[9].

The main concept behind the (LMP) difference method is to make use of the economic signal given as (LMP) to select the congested lines to manage congestion and hence increasing loading stability limit. It is motivated from the fact that (LMP) contains significant information regarding level of congestion in the system [10]. (LMP) is composed of three components, an energy component, a loss component and a congestion component. For a meshed system, loss component is generally small. Hence, the difference in (LMP) between two buses gives direct hint regarding the level of congestion in that line [11].

5. Proposed Simulated Network

Power system analysis toolbox software (PSAT) simulated under matlab is used which has many features including power flow and continuation power flow and it used to observe the voltage stability of the test system [12].

THE single line diagram of Back To Back HVDC obtained from (psat) program is showing in figure (5) and based on applying of (LMP) mentioned above theand on the IEEE14-bus test system the congestion lines are selected and detailed in table(1).Thesimulated test system is also detailed as shown in figure(6) which depicts the single line diagram of the IEEE 14- bus network andit consists

of 14 buses, 20 branches, three transformers, and five synchronous machines. The generators are molded as standard PV buses with both P and Q limits, loads are represented as constant PQ loads[12].

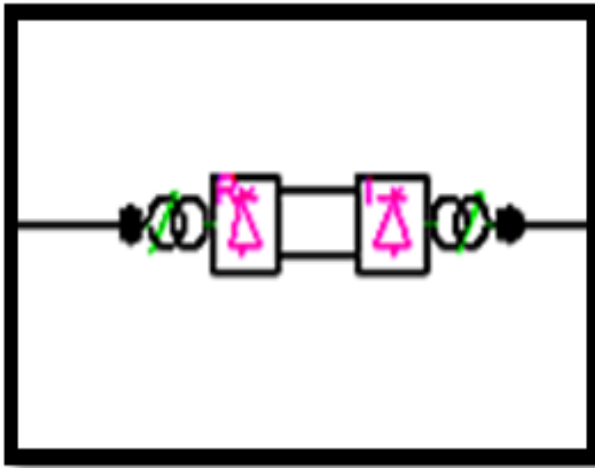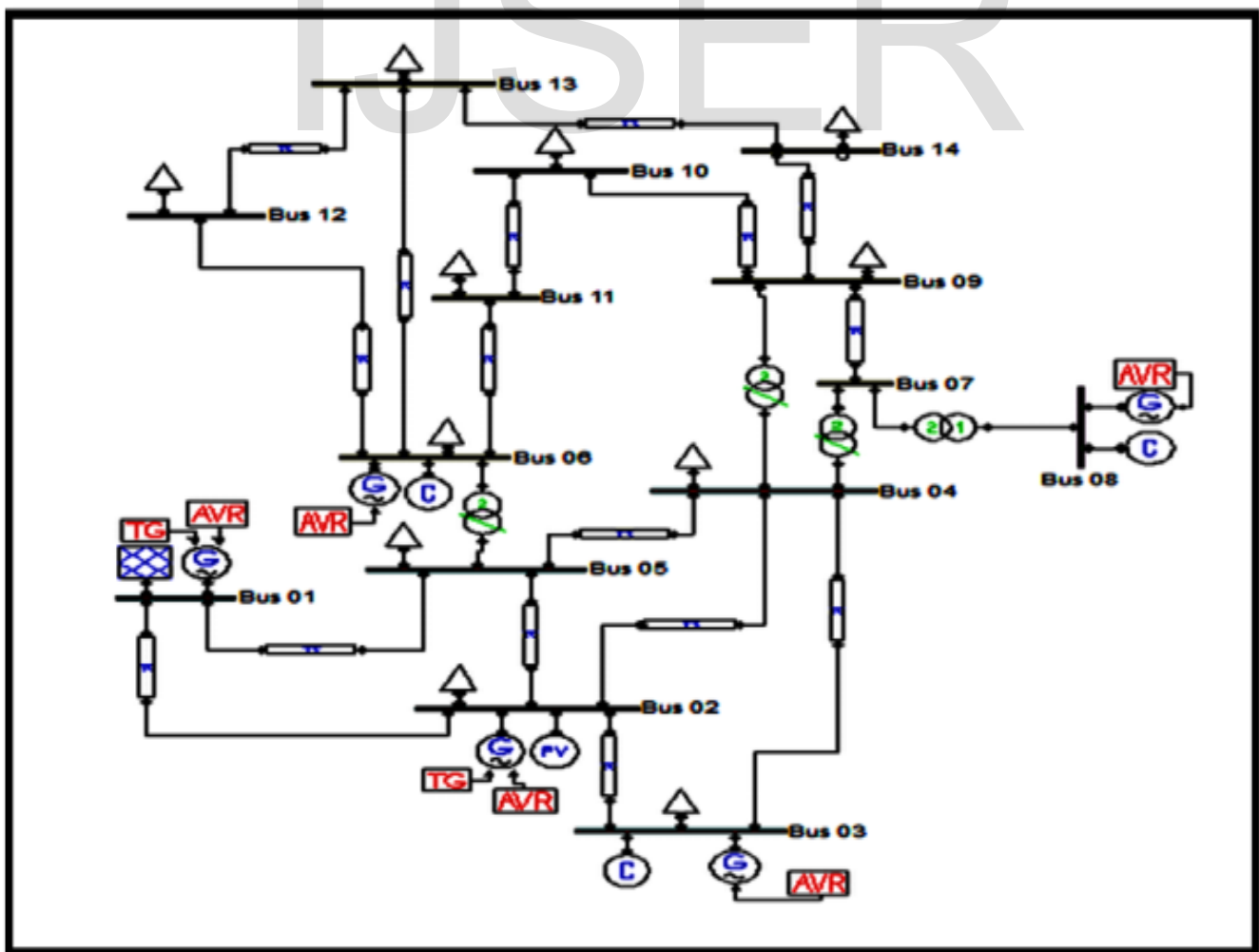Fig. 6: Single line diagram of IEEE 14 bus obt

Fig. 5: Single line diagram of Back To Back HVDC obtained from PSAT program [12].

Table (1): Selection of congestion linesbased on Location marginal price (LMP).

Priority no.	(LMP) difference	Priority lines location
1	0.848742	Line 1-5
2	0.806644	Line 3-2
3	0.509299	Line 2-4
4	0.483512	Line 1-2
5	0.365231	Line 2-5

6. Simulation Results

The simulation output results have curves as a function of time (T) with the following parameters:

    i. Voltages at all buses, (V)
    ii. Generator speed deviation, (ω)
    iii. Active power at all buses, (P)
    iv. Reactive power at all buses, (Q)

6.1 Simulation of Inserting HVDC

between Buses 1-5 and fault in the network at bus-12.

Based on (LMP), HVDC is located at the optimal location in network instead of line (1-5) and makes fault at the network. Then to study the system stability, a power flow and time domain simulation using (PSAT features) were performed and the output curves at figures (7), (8), (9) and (10) shows that the system has large perturbations (unstable).
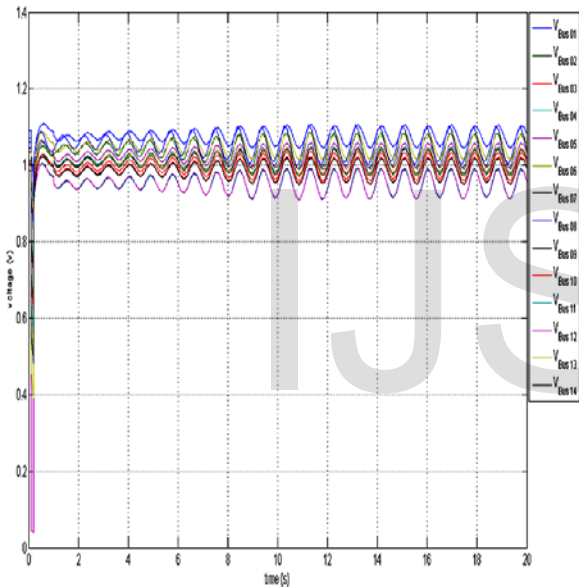
Fig. 7: Voltages at all buses, (V) and HVDC at line 1-5.
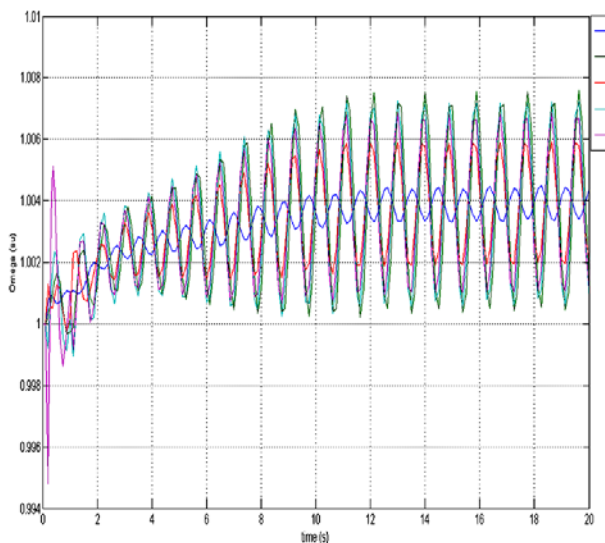
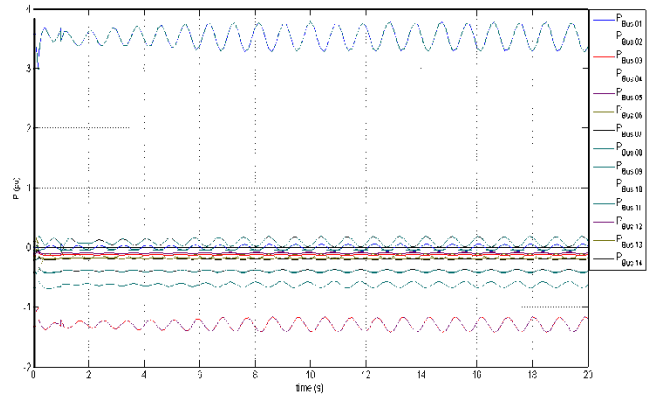Fig. 8: Generator speed deviation, (ω) at all buses and HVDC at line 1-5

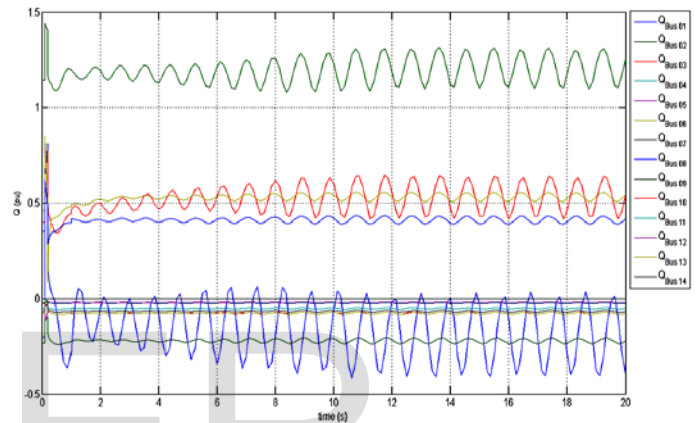Fig. 9: Active power at all buses, (P) and HVDC at line 1-5.

Fig. 10: Reactive power at all buses, (Q) and HVDC at line 1-5.

6.2 Simulation of Inserting HVDC between Buses 3-2 and make fault in the network at bus-12.

Based on (LMP), HVDC is located at the second optimal location in network instead of line (3-2) and makes fault at the network. The performed output curves in figures (11), (12),(13) and (14) shows that the system has large perturbations and still unstable.
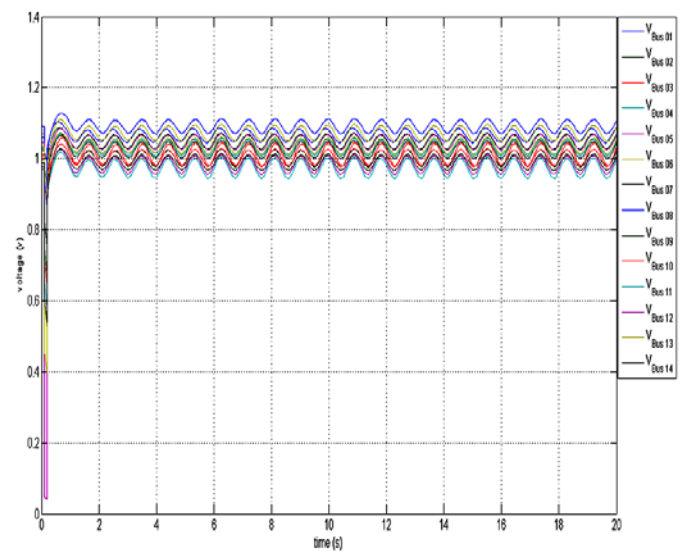

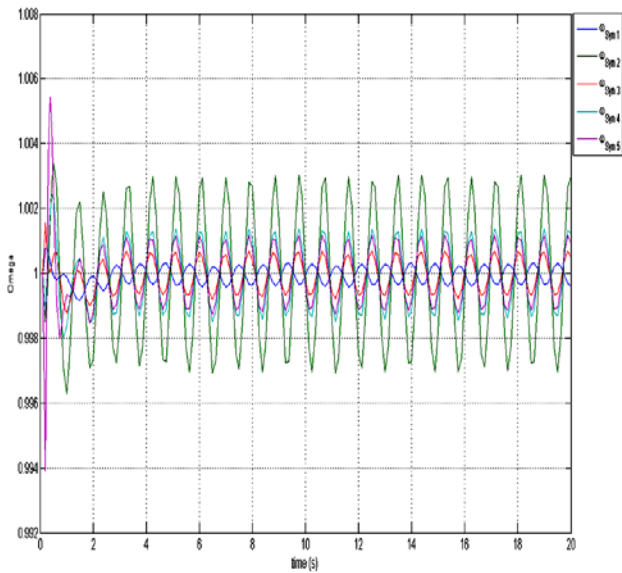Fig. 11: Voltages at all buses, (V)   and HVDC at line 3-2.

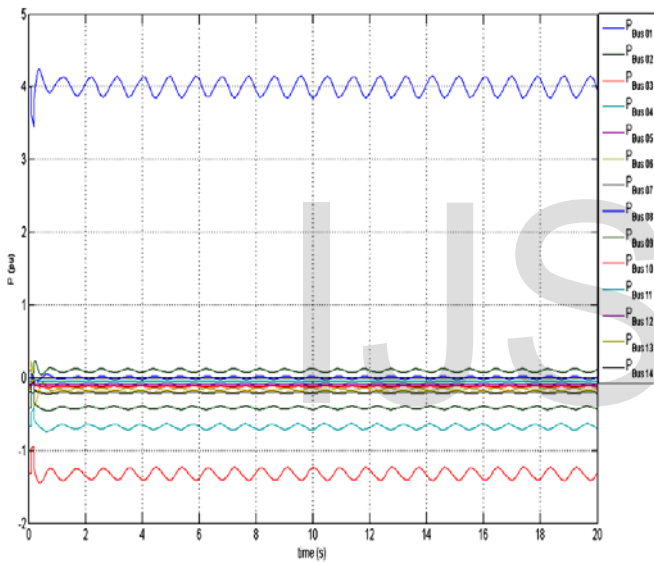Fig. 12: Generator speed deviation, (ω) at all buses
and HVDC at line 3-2.

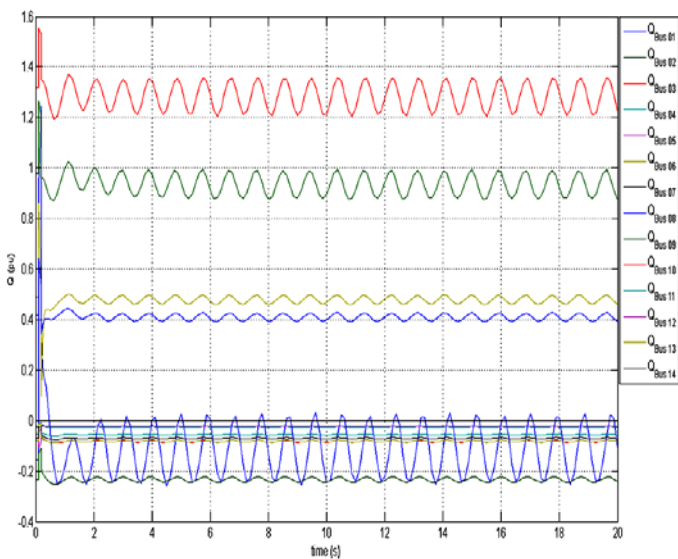Fig. 13: Active power at all buses, (P) and
HVDC at line 3-2.

Fig. 14: Reactive power at all buses, (Q) and
HVDC at line 3-2.

6.3 Simulation of Inserting HVDC between Buses 2- 4 and make fault in the network at bus-12.

Based on (LMP), HVDC is located at the third optimal location in network instead of line (2-4) and makes fault at the network. The performed output curves in figures (15), (16), (17) and (18) shows that the system has small perturbations and after about 10 seconds the system became stable.
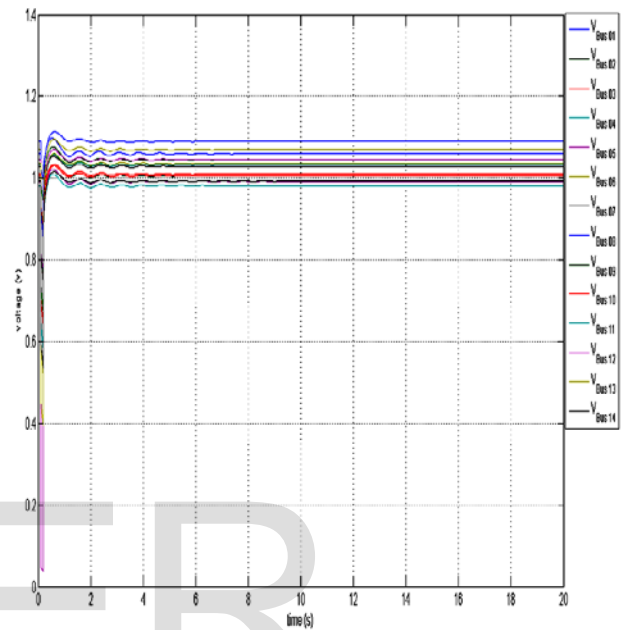

Fig. 15: Voltages at all buses, (V)   and
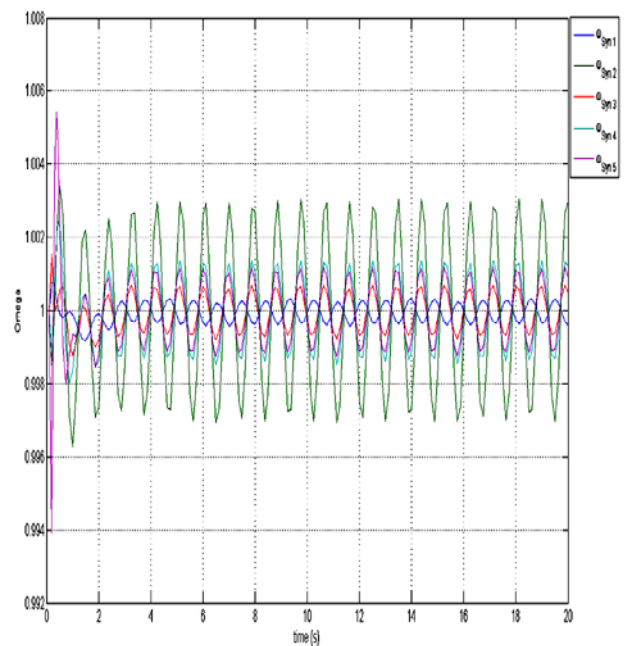HVDC at line 2-4.

Fig. 16: Generator speed deviation, (ω) at all buses
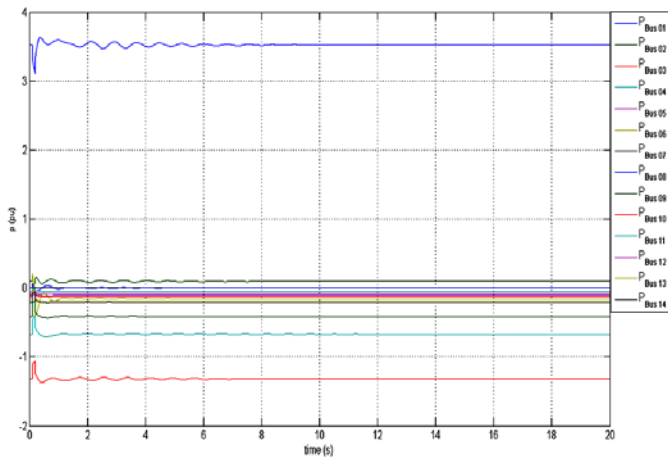and HVDC at line 2-4.

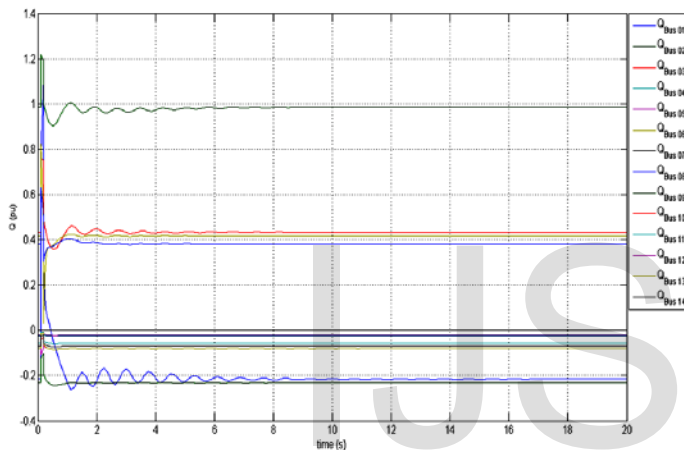Fig. 17: Active power at all buses, (P) and
HVDC at line 2-4.

Fig. 18: Reactive power at all buses, (Q) and
HVDC at line 2-4.

7. Conclusion

By inserting of HVDC in several optimal locations at "14-Bus" network, those locations were selected according to Location Marginal Price [LMP] then use [PSAT] features (power flow and time domain simulation) to study the impact of connecting HVDC at congested lines and applying fault at Bus-12, then observing the power system stability by studying the [PSAT] simulation output curves for Voltages, generator speed deviation, active and reactive power with the time. It observing from the simulated results, when HVDC is connected at the first location the system has large perturbations and was unstable. Also, when HVDC is connected to the second location the system is still has large perturbations and unstable. After that, when connecting of HVDC to the third location, in this case the system has small perturbations and after about 10 seconds the system became stable.

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