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Research Article

PRESENTING AN INNOVATIVE METHOD TO DETERMINE THE OPTIMAL SIZE OF STATCOM TO IMPROVE THE STATIC VOLTAGE STABILITY IN THE POWER SYSTEMS

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ABSTRACT
Given the importance of voltage stability and maximum sustainable loading in the power systems the control and reactive power injection are very important as the parameters affecting these parameters. One of the ways of providing and controlling the reactive power in power systems is using the parallel FACTS devices like STATCOM. In this article an innovative and simple method to determine the optimal STATCOM size in specific location is provided that can maximize the network load and its stability. The method is based on the formation of STATCOM capacity curve and the network loading at the desired bus. Accordingly, with the help of PSAT and MATLAB, the location and the optimal size of STATCOM in a sample 14-bus network has been determined for which the maximum system load is determined as well.

Keywords: *Voltage Stability, Maximum Load, STATCOM, Reactive Power*

INTRODUCTION
The study of various blackouts in the world indicate that the most important involved in these blackouts is voltage collapse and the repeated overloads created by the relay and circuit breaker functions. Accordingly, the use of control devices and power system stabilizers can greatly improve network stability and by optimizing the balance between production and demand for power, the overloading of lines voltage collapse are prevented (Condor, 1997; Hamadani, 2007).
Generally the stability of the power system is defined as the ability of a power system to remain at balance under conditions of normal operation as well as the ability to obtain a new balance after the occurrence of turbulence. So to avoid blackouts the study of the system based on the stability is essential which is conducted using the stability improvement methods. Also according to the various indicators of network power system stability is divided into three main categories, namely: frequency stability, angle stability and voltage stability (Condor, 1997).
Despite the importance of the stability of frequency and angle, their analysis is dynamic and will not be addressed in this paper because of the related objectives.
Static voltage stability in this paper refers to the power system's ability to maintain the bus voltage within the acceptable range which must be in the normal operation of the power system and the ability to prevent the blackout through the reactive power control. It should be noted that a power system voltage experiences voltage instability when there is a sudden increase in load demand or in the condition that the bus voltage begin to steadily decline uncontrollably. One of the important factors that are involved in voltage instability is the inability of the system for providing reactive power required by the network. The lack of reactive power in power networks has led the system to instability and creates voltage drop and fluctuation. Also the reasons such as high power in transmission lines, the remoteness of the voltage resources from consumption centers, low voltage sources, lack of compensation for reactive power and excessive use of compensation capacitator has led to voltage instability and consequently the voltage collapse so that the voltage drop is so high that the system is not capable of retrieving it.
Usually in order to enhance voltage stability and to prevent its collapse methods such as reactive power transformation using the transformers with under load tab changers, load shedding, or generating reactive

power by compensators such as the capacitator banks and FACTS devices are used (Miller, 1992; Condor, 1997).

It should be noted that the use of tab changers has limited efficiency due to limited range of the tap transformers. Also the load shedding method is less popular due to the limitations for the consumers rather than reactive power injection method due to economic and social issues. However, the produced of reactive power by the generators and capacitator banks is too slow for sudden changes and instant applications such as wind turbines and as a result, the best solution is to use compensator FACTS devices.

Given the extensiveness of the equipments many studies have been carried out in this area and the effects of different types of them have been evaluated. In (Iman *et al.*, 2012) the stability improvement of power system voltage is evaluated by Iman *et al.*, using UPFC and continuous power flow (CPF) algorithm. The results show that the use of this compensator has an important role in improving the voltage stability. In (Shahmorady *et al.*, 2012) the improvement of power network was analyzed using TCSC in the transmission line. In (Larakīs *et al.*, 2009) the static stability of the voltage is addressed in a 400kV Khuzestan network by SVC and STATCOM and the results were compared. In (Ahmadi and Lesani, 2011) the static stability of voltage is addressed using a variety of devices, including STATCOM, T CSC, SSSC and the UPFC.

The results of the study indicated that UPFC has created higher marginal voltage stability than other devices and has a more appropriate performance for the intended network. Also it is indicated in this study that the network needs higher reactive power in its weakest bus and the placement of UPFC in that bus leads to increased marginalization of the loading. In (Gupta and Trapathi, 2010) the effect of two FACTS controllers called UPFC and STATCOM on the voltage stability is studied. The continuous power flow (CPF) is used by the accurate modeling of these devices. The obtained results in this paper show that these devices can control the variables such as voltage amplitude and phase angle of the bus using line impedance. In (Messina and Perez, 2003) while presenting a review of the development of a variety of FACTS devices the performance of each one of them and their effect of the static voltage stability is studied. Also these analyses include the installation features and the control system of any of them in operating conditions considering the power network of India.

It should be noted that in most papers only the effects of devices are studied and in case of optimization only their location is addressed. Accordingly, in this paper, while providing a brief introduction of FACTS devices, first the STATCOM structure is addressed as the providing the parallel compensator and the effect of its application of the network load limit and static voltage stability is addressed. Finally by proposing a method based on drawing the curve the changes in the size of STATCOM In terms of voltage stability, size and location optimization is presented in a 14 bus network in order to improve static stability of the voltage. So by the proposed method the optimal size and location of STATCOM can be determined in a way that the maximum voltage stability is achieved.

Facts Devices (Miller, 1992; Jourabian et al., 2007)

In a general statement, FACTS includes the application of power electronic devices in the high power network the indicators of which can be controlled using some methods. Since a power system's properties including consumption and production change through the time, if the transmission conditions are not updated the power system is damaged due to stability issues of the steady and transient mode and the limits of stability are reduced. It should also be noted that the ability of the transmission system is reduced in the amount of power transmission by the dynamic limitations and stable mode such as angle stability, Voltage range and thermal limits. In practice, these limitations determine the maximum electric power being transferred without causing damage to the transfer lines and the electric equipments. However, the limitations in the transmission can be greatly modified by increased production and transmission facilities and the FACTS controllers are among these facilities. Among the advantages of FACTS controllers to the network include: the reduced implementation cost and investment in the field of power transmission, the increased reliability of the system, the increased capacity of power transmission and the improved quality of electric energy handed to the customer. Also it should be also noted that these devices in the form of series and parallel equipments have various forms the most common of which include: SVC, STATCOM,

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TCSC, SSSC, and UPFC. Considering the desired properties of STATCOM and their widespread application in this article we address the performance of this equipment and its optimization.

STATCOM and its Properties (Miller, 1992; Jourabian et al., 2007)

The performance of STATCOM is similar to synchronous condenser. Since in the construction of this devise the power electronic devices are used it is considered as the static compensator. Transformer used in the compensator provides the necessary reactive power locally (at the STATCOM network junction) and its output is adjustable continuously therefore, in cases that the power network voltage has wide variations (in case of turbulence or after the occurrence of an error) this compensator is used.

Figure 1 presents an image of STATCOM and the V-I characteristic. The production or absorption of reactive power is performed by voltage source converter (VSC) by adjusting the voltage V_{ref}. Generally the most important STATCOM applications include: the dynamic voltage control, transient stability improvement, eliminating fluctuations in the transmission and real and reactive power control.

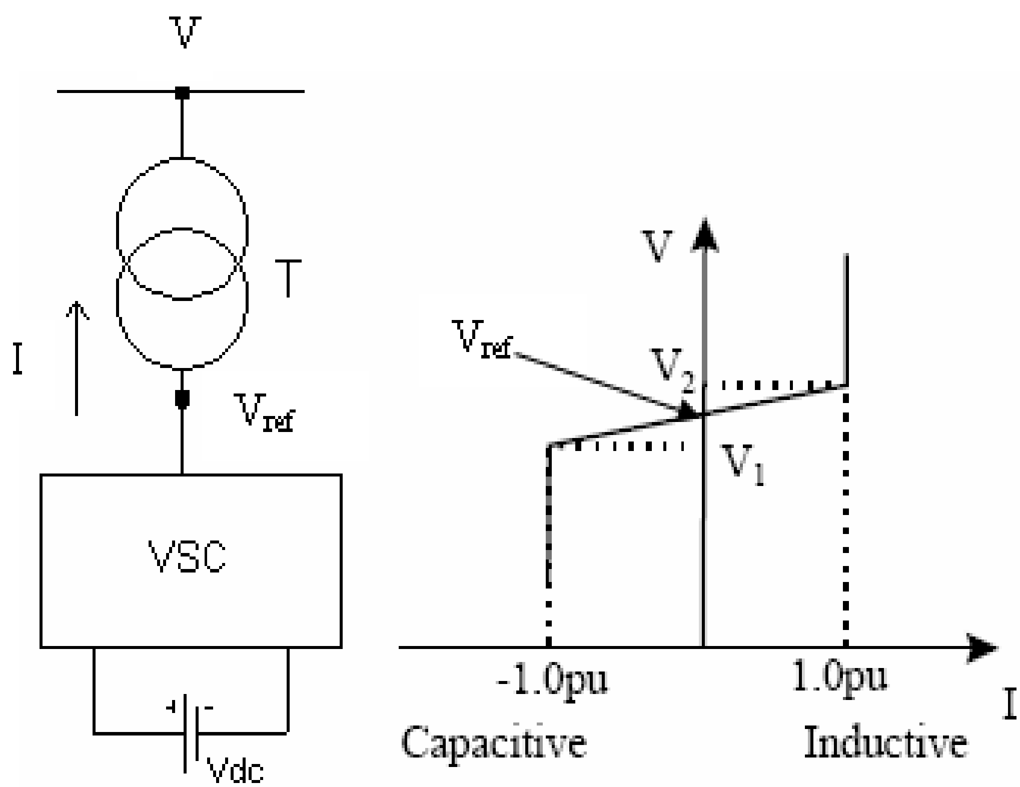

Figure 1: STATCOM and its V-I characteristic

Procedure

The static stability analysis can be performed through various methods such as VQ sensitivity analysis, VQ curve, and the P-V curve one of which is described in (Condor, 1997) by detail. Accordingly, in this paper, the static stability analysis is performed using P-V curve and PSAT software. Due to the variables such as the optimal location and size of STATCOM, the optimization problem was obtained in two stages including choosing the location and then the appropriate capacity in the obtained location and the method of calculation of each one is described below.

Determining the Optimum STATCOM Location

Since there are different methods to determine the direction of locating the optimal compensator and one of these methods is to choose the low bus, it should be noted that the variations in the voltage of each bus caused by the load variation in the system must be accessible which can be calculated by CPF easily. Using the flow-power, the active power system derivation can be written by the relation (1).

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$$P_{total} = Cd\,\lambda \quad (1)$$

So the weakest bus is the one in which the relation (2) prevails.

$$BUS=\max\{|\frac{dV1}{Cd\lambda}|, |\frac{dV2}{Cd\lambda}|,\ldots,|\frac{dVn}{Cd\lambda}|\} \quad (2)$$

Since the value of C dλ for each one of the elements in dV is the same based on relation (1), the weakest bus is easily selected so that the dV component of the low bus has the highest value. Obviously, the optimum location for installation STATCOM is the weakest obtained bus.
Normally by injecting enough reactive power to the weakest bus the stability of the static voltage margin increases. In order to apply STATCOM in the power system, equations and the state variables are entered from the systems in the Load flow equations and the stage of modifying the CPF process (Gupta and Trapathi, 2010).
The flowchart of drawing the voltage stability curve along with STATCOM using CPF is presented in figure (2). It can be observed from figure (2) that how the STATCOM devices equations are added to the power flow equations. The power flow equations are used in the modifying the CPF process. In this paper in order to determine the low bus using CPF the PSAT software is used.

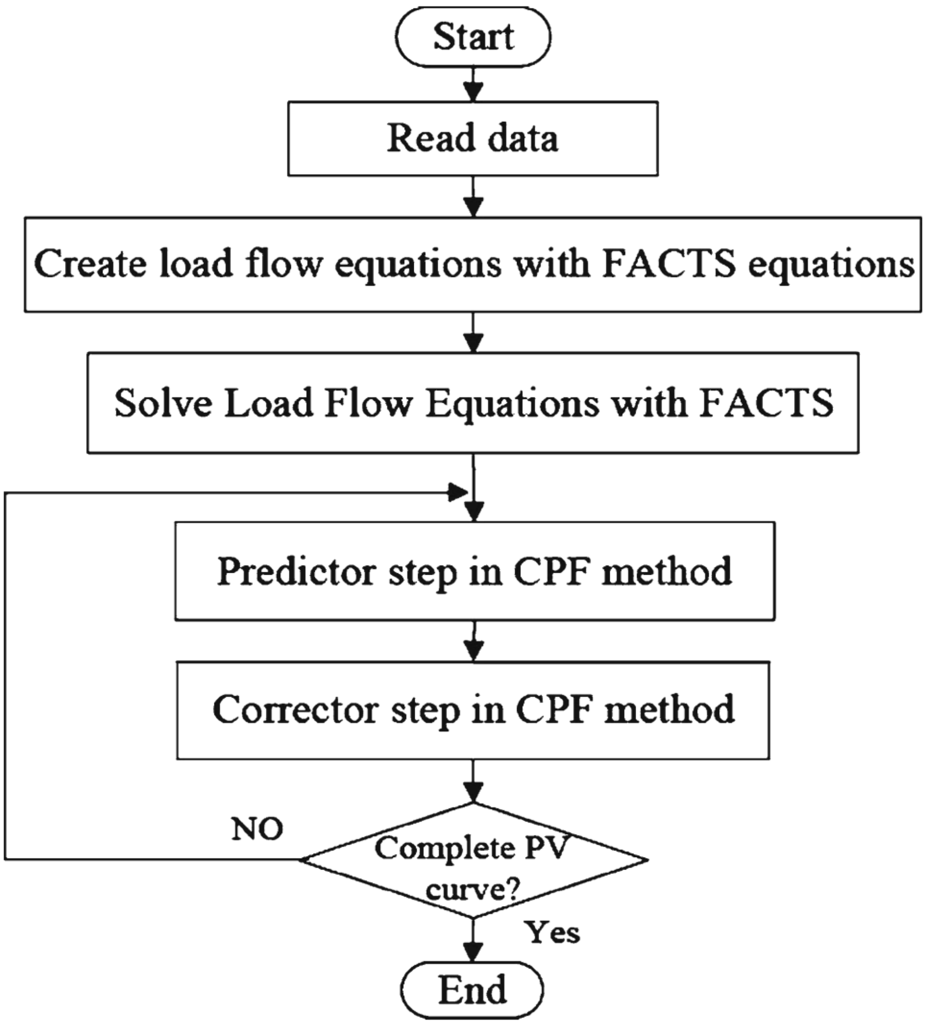

Figure 2: Flowchart of CPF process

Determining the Optimal STATCOM Size

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In order to determine the optimal STATCOM size in the determined location first some various capacities of it in the low bus within the 20-200% of the nominal power of the power system are considered. Then for each of these capacities the maximum system load is considered. Then for each one of these capacities the maximum system load is calculated. Obviously, the behavior of the load capacity of the system based on the STATCOM capacity variations is in the form of a non-linear function (λ (C) = f (C)) that can be obtained by the MATLAB software and the obtained points. Then according to equation (3) it is possible to find the capacities of STATCOM based on which the system load is maximized.

$$\frac{\partial f(C)}{\partial C} = 0 \quad (3)$$

Obviously, if there are more than one answers the optimal capacity as the problem solution is the one that maximizes the load ability of the system.

Simulation Results

The power system being studied in this article is a 14 bus IEEE system. According to figure (3) this system has 8 production units in which the bus 1 is considered as the main (base) bus. The system has 16 transmission lines, 4 transformers and 11 load buses. In this system the production units are modeled as the PV standard buses wit P and Q limits and the loads as PQ loads are considered to be constant.

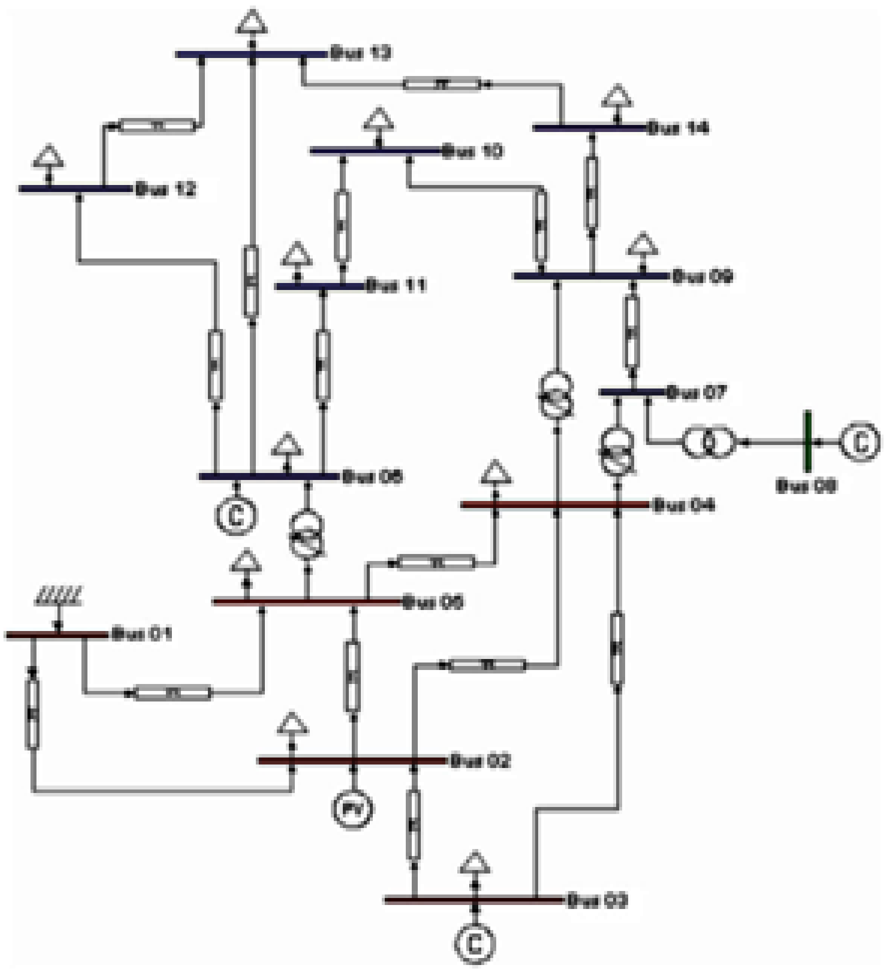

Figure 3: 14-bus standard system

First it is assumed that the system has no compensators and the purpose of power flow implementation is to locate the optimum place for the compensator. After the analysis of power flow in PSAT the results including the voltage profile and P-V figure are presented in figures 4 and 5.

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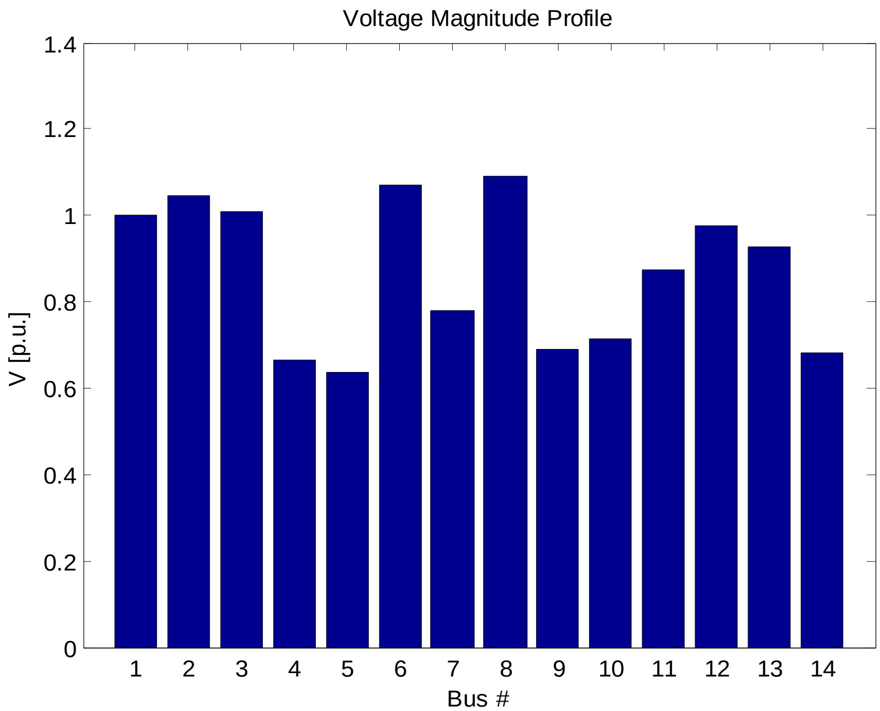

Figure 4: The voltage profile without STATCOM

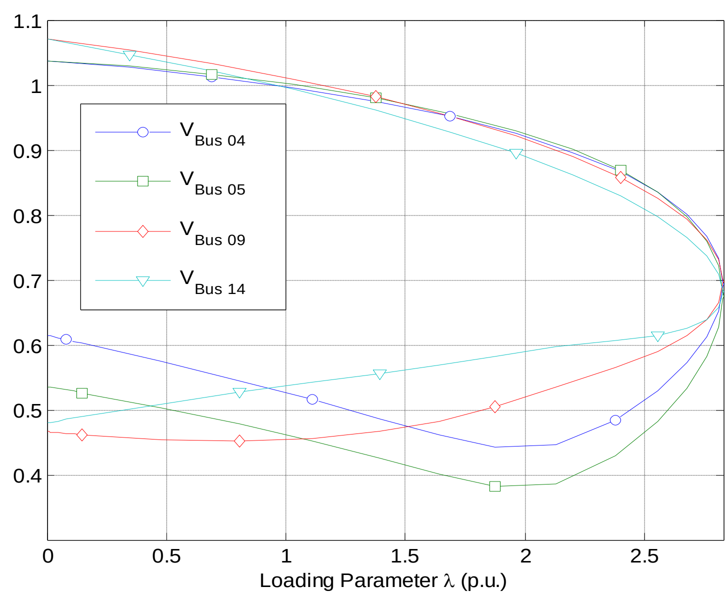

Figure 5: Voltage curve - The maximum load without STATCOM

With the analysis of the obtained results from figure 4 it can be observed that the bus 5 with the voltage range 0.63542 PU has the lowest voltage and it is known as the weakest bus. Also according to the obtained results from figure 5 the maximum system loading is in case that there is no compensation in the system equals 2.7616 PU. It is noted that this value is obtained based on the P-V diagram in figure 5.
Now that the weakest network bus STATCOM as the compensator places reactive power in this bus the results of which are presented in figures 6 and 7.

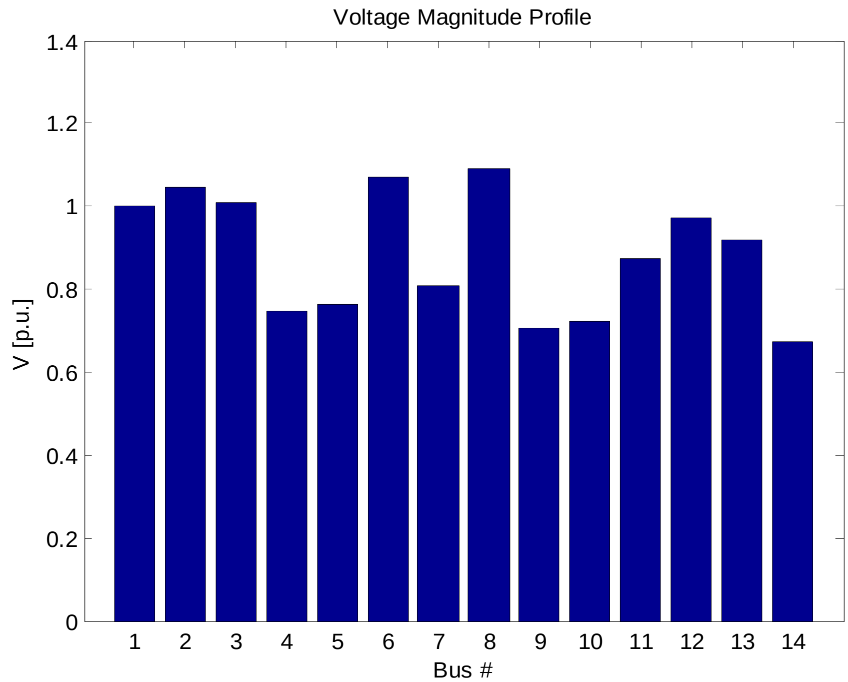

Figure 6: Voltage profile in the presence of STATCOM

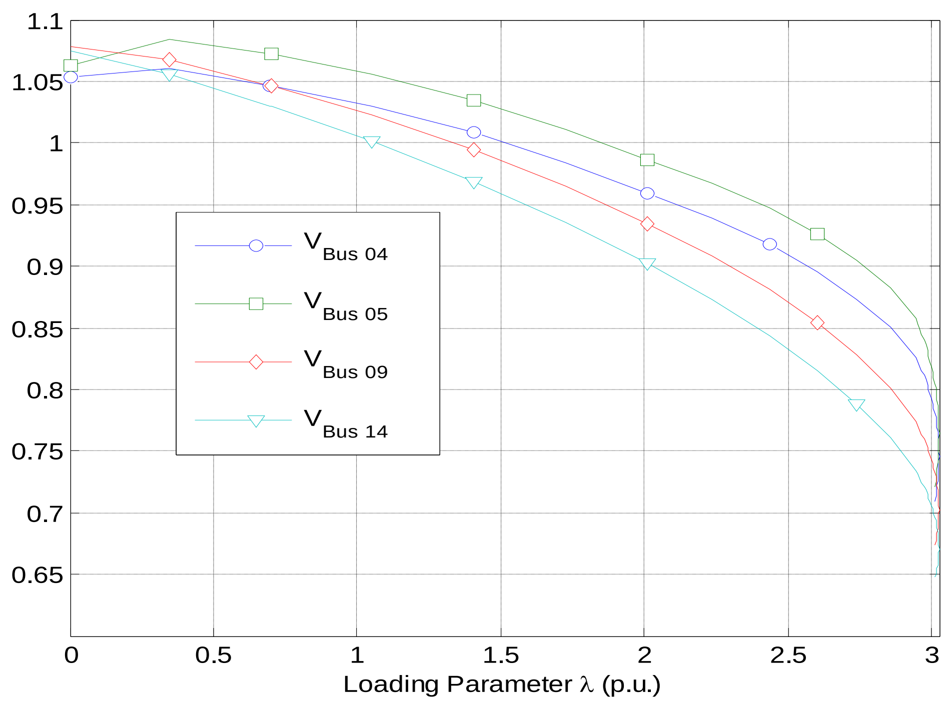

Figure 7: Voltage curve - The maximum loading with STATCOM

According to the obtained results from figures 6 and 7 as predicted before the low bus voltage is improved to 0.76466 PU which is the result of reactive power injecting by STATCOM. However, by adding the compensator to the network the maximum load was upgraded up to 3.0172 PU which is presented in the P-V diagram in figure 7.

Now by determining the STATCOM optimum location based on the technique presented in Section 4.2 first various capacities of STATCOM are considered. Then by placing each of them in the network the maximum load in the system is calculated beside the low bus voltage range which is presented on table 1. Thus, using these points it is possible to observe the behavior of the load of the system compared to the variations of STATCOM capacity.

Table 1: The maximum load and low bus voltage based on STATCOM capacity

STATCOM	0	20	50	80
Maximum loading	2.7619	2.8238	2.9123	2.9968
Bus voltage 5	0.63542	0.63996	0.69593	0.72714
STATCOM	130	160	180	200
Maximum loading	3.1285	0.72775	0.6875	0.56665
Bus voltage 5	0.76946	1.1232	1.1356	1.1591

According to the results of Table 1 the variation in STATCOM capacity is very effective on low bus voltage and system loading. The results also show that against the common belief the increased STATCOM capacity will not always increase the loading. In fact, if the compensator capacity is higher than a certain range, it will causes a dramatic reduction in system loading and in other words it will lead to the load discharge and partial or general blackout. Accordingly, to determine the optimal STATCOM size it is possible to use the relation (3) by specifying the variation in network loading limit curve versus the system variations. Figure 8 presents the maximum system loading curve based on the STATCOM capacity which is drown by the MATLAB software.

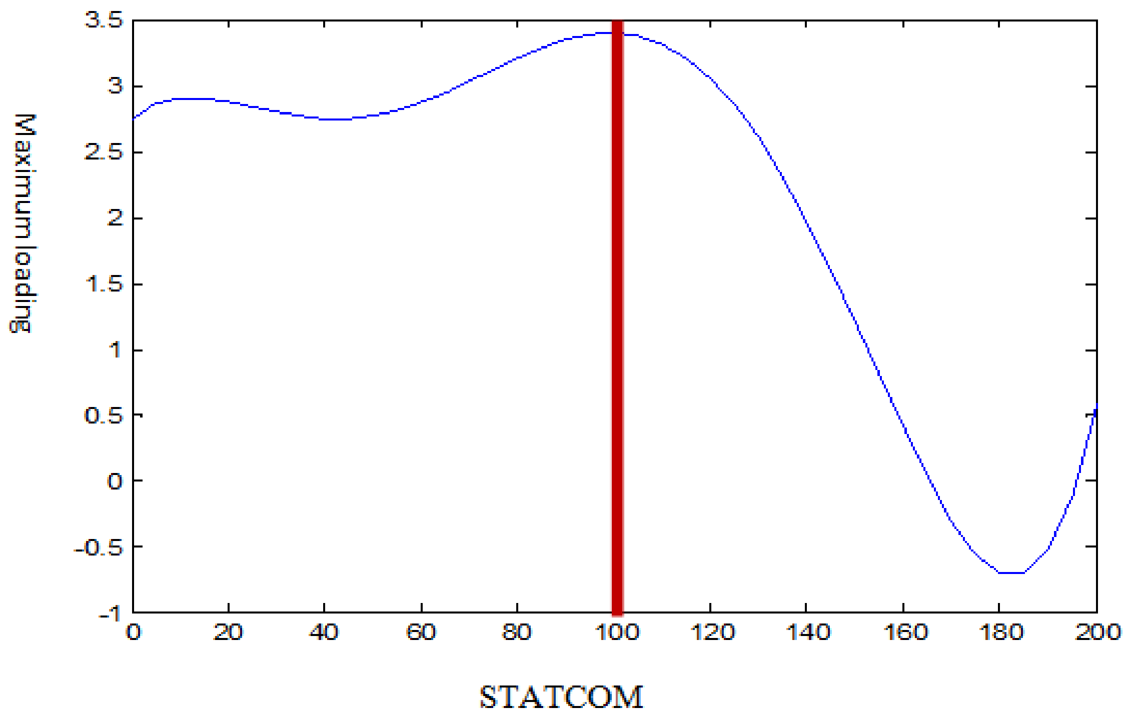

Figure 8: Maximum system loading curve - STATCOM Capacity

According to the diagram in Figure 8, the curve includes a maximum point that occurs in 100 MVA capacity using equation 3. It should be noted that for this capacity the maximum system load equals 3.3968 PU which will be the best installed capacity for STATCOM. So it can be stated that the installation of STATCOM with 100 MVA capacity at the bus 5 is the best status based on the stability of the network.

Conclusion

Given the growing importance of the stability in the power systems and the necessity to use the compensators to improve it, in this article an innovative method is presented to determine the optimal STATCOM capacity in the right location. The optimization is performed in two stages that include determining the location and size each one is done independently using the PSAT and MATLAB programs. Considering the obtained results it can be stated that the optimal location of the compensator is always the lowest bus which has the lowest voltage for the network load. However, the optimal size of the compensator depends on the optimal size of the compensator depends on the stability of the network which has a nonlinear relationship according to the equations. Also the obtained results indicate that increasing the compensator capacity doe not always lead to the improved stability limit which is very important from an economic standpoint in addition to the technical criteria.

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