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Optimal Location And Size of The STATCOM to Enhance The Power System Stability

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ABSTRACT

The importance of power system operation is becoming increasingly significant due to the escalating demand observed in many nations. The exponential growth in load demand exerts substantial stress on electrical power systems, since they run in close proximity to their critical thresholds due to limitations imposed by environmental and economic factors. The basic goal of operating electrical power networks is to efficiently supply energy to users at optimal frequency and voltage levels, with a focus on cost minimization.

The main objective of this study is to examine the augmentation of voltage stability margin by deploying Flexible AC Transmission Systems (FACTS) at their ideal positions. In order to determine the most efficient size of a Static Synchronous Compensator (STATCOM), it is necessary to explore the relationship between the loading factor and the capacity of the STATCOM. The case study utilized the Iraqi National Super Grid System (INSGS), which consisted of a 24-bus configuration.

The effectiveness of the CPF technique has been assessed in the framework of the Iraqi Super Grid test System. The appropriate place for attaching STATCOM to enhance voltage stability in the Iraqi network system was identified to be Bus (20).

Introduction

In contemporary times, the electrical power system has undergone significant advancements, This has led to the emergence of intricate networks with several load centers and power units. These entities are related by the utilization of electrical power transmission cables. The power system may be categorized into four main sections, namely generation, transmission, distribution, and load usage[1].

To address the growing need for electrical load, there is a notable transformation occurring in power systems, characterized by enhanced intricacy in control mechanisms, operational procedures, and stability preservation. Voltage instability, which is also referred to as voltage collapse, is the primary concern that is commonly associated with a power system that is under stress. Voltage stability or collapse occurs within a power system when an external disturbance triggers an uncontrolled and progressive decline in voltage. This phenomenon can occur when the electrical grid is unable to satisfy the heightened requirement for reactive power. The examination of voltage stability is a crucial process in determining the load buses that are near their voltage stability thresholds within an electrical power system. Operators are able to implement targeted strategies in order to proactively mitigate the occurrence of voltage collapse [2]. Voltage instability may manifest in the electrical power system subsequent to voltage collapse, wherein the equilibrium voltages in proximity to loads diminish beyond tolerable thresholds in the aftermath of a disturbance. Voltage collapse, also known as voltage breakdown, is a phenomenon that is characterized by the manifestation of voltage instability, partial breakdown and total breakdown, both of which can lead to a complete loss of electrical power, commonly referred to as a blackout. The main factor contributing to this malfunction is ascribed to the power system's incapacity to provide reactive power or its excessive consumption of reactive power [3]. The emergence of FACTS devices can be attributed to the rapid advancements in power electronics technology witnessed in recent years. These devices provide enhanced utilization of the current transmission infrastructure.

The prioritization of the STATCOM controller's placement, particularly under contingency conditions, outweighs the consideration of the power system's stable state. Several studies have presented various approaches for effectively managing FACTS in order to optimize voltage stability and subsequently enhance the overall stability of power systems [4].

This study introduces the application of Continuation Power Flow (CPF) for determining the optimal placement and sizing of a STATCOM device within the Iraqi Super Grid (400 kV) test system. The software programs utilized in this study were developed using the MATLAB (R2020a) package, with a special focus on the power system load flow analysis toolbox (PSAT version 2.1.11) software. This software leverages the Newton-Raphson (N-R) method for its computational processes.

Voltage stability Measurement

The STATCOM is classified as a shunt-type FACTS device, capable of supplying reactive power and augmenting bus voltage. The STATCOM is a control device that is utilized in alternating current transmission grids. It possesses the notable attributes of transient-free switching and the ability to deflect steady reactive power [5].The device described is a solid-state switching converter that has the ability to absorb or generate reactive and real power. The converter is intended to receive power from an energy storage or energy source device that possesses the suitable rating. The Voltage Source Inverter (VSI) utilized in the Static Synchronous Compensator (STATCOM) generates a tri-phase alternating current (AC) output voltage set that is in synchronization with the appropriate AC system voltage. These output voltages are then linked to the AC system through a reactance that is relatively low. The coupling transformer is typically responsible for delivering the per-phase leakage reactance. The VSI is generated through the utilization of the DC storage capacitor [6].

The STATCOM is capable of injecting reactive power into the system during periods of low system voltage, while it absorbs reactive power during periods of high system voltage. As illustrated in Figure 1,Voltage Source Converter, which is linked to the secondary side of a coupling transformer.The definition of reactive power is as follows:

$$Q = \frac{(Va - Vb)Va}{x} \qquad (1)$$

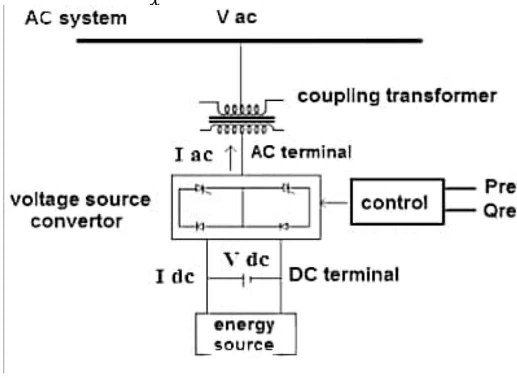

Figure 1. STATCOM Configuration

Newton-Raphson method identified as the most efficient and practical approach for large power systems. The number of iterations necessary to achieve a solution remains unaffected by the size of the system, although a greater number of functional evaluations are necessary during each iteration. The power flow Newton-Raphson formulation can be expressed in polar form, as stated in reference [7].:

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}=\begin{bmatrix}J_1 & J_2\\ J_3 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} \quad (2)$$

This study necessitates the utilization of bus data and line data for the N-R program. These data sets are essential for conducting iterative load flow analysis, enabling the determination of voltage, phase, active power, and reactive power of the load buses within the system.

The flowchart for solving the load flow problem by N-R iteration method which illustrate in flowochrt figure(2).

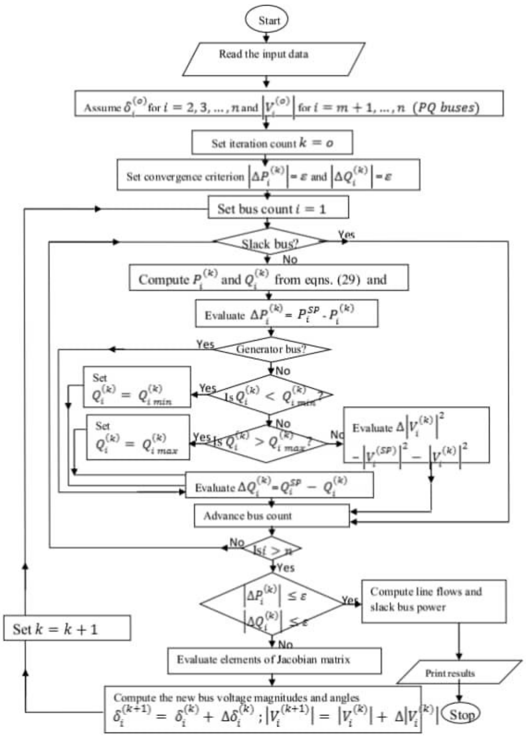

Figure 2. Flow Chart For N-R Method In Load Flow Problem

Optimal Location of STATCOM in Power System

This study aims to investigate the effect of installing FACTS at their optimal locations on voltage stability margin. In order to satisfy the capacity demand, the environment of a power system relies heavily on voltage stability. The ideal location of FACTS devices is determined using three methods: methods such as eigenvectors and eigenvalues, minimum losses, and the CPF through curve (P-V) approach.

- Eigenvalues and Eigenvectors method

Gao et al. [8] provided a technique that calculates the lowest eigenvalue and related eigenvectors of the reduced Jacobian matrix of the power system, based on the steady state system model. One mode of voltage and reactive power change is shown by the eigenvalues. If the system's voltage stability can be calculated, it means that all eigenvalues are positive. The voltage instability of the system is shown if one of the eigenvalues is negative. When the eigenvalue of the reduced Jacobian matrix is 0, the system is about to enter a state of voltage instability. It is feasible to predict the possibility of a voltage collapse by computing the least positive eigenvalues of a stable system. The proximity of a system to voltage collapse is represented by the size of each minimal eigenvalue. If the system's voltage suddenly drops, the weakest bus can be detected using the bus participation factor.

- P-V and Q-V Curves method

Static voltage stability occurs when the power system varies very slowly, leading to a drop in voltage and a shortage of reactive power [9]. Plotting the received power against the voltage along the P-V curve will reveal this phenomena. The P-V curve is the most often used tool for making accurate voltage security predictions. The capacity margin of a power system may be calculated with their help. At each step along the way to the PV curve's peak, the power system's load grows, necessitating a fresh round of power flow calculations. The gap between the breakdown voltage and the running voltage is used as a stability criteria for the voltage supply. The voltage (V) at each bus may be calculated for a given power factor and load state using the P-V curve derived from the power flow solution (equation(3)). [10]:

$$P = P_o(1+\lambda) \quad (3)$$

The active power at the bus following the base case power flow solution is denoted as Po. The loading factor, represented by λ, indicates the extent to which the active power loading has increased. Figure 3 depicts the primary protagonist of the P-V curve.

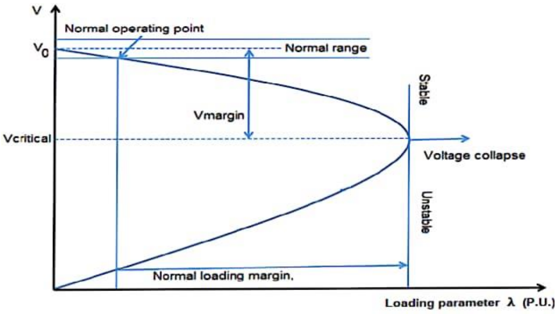

Figure 3. general character of (P-V) curve

Minimum losses method

The STATCOM is consistently linked to the load buses within the electrical system. In each instance, the total losses of the system are measured. These losses are then divided by the total generation and expressed as a percentage. The location that yields the lowest loss ratio is identified as the optimal placement for the STATCOM. As shown by the equation (4) [11-16]:

$$LOSS\% = \frac{total\ active\ power\ loss}{total\ active\ power\ \text{generation}} * 100 \quad (4)$$

Optimal Size of the STATCOM

Prior to determining the optimal STATCOM size at the predetermined location, various STATCOM capacities in the feeble bus within 20-200% of the power system's nominal power are evaluated. The utmost system burden is considered for each of these capacities. For each of these capacities, the utmost system burden is then determined. Clearly, the behavior of the system's load capacity in response to variations in the STATCOM capacity takes the form of a nonlinear function ((C) = f (C)) that can be determined using the MATLAB software and the obtained data. Then, based on equation (5), it is possible to determine the STATCOM capacities that maximize the system load[12].

$$\frac{\partial f(C)}{\partial C} = 0 \qquad (5)$$

Results & Discussion

One of the leading causes of voltage instability in a power system is the reactive power limit. Improving the system's capacity for treating reactive power with FACTS devices prevents voltage instability and, consequently, voltage breakdown. This study will examine the device's (STATCOM) effect on voltage stability. This project's primary objective is to enhance the voltage stability of the Iraqi electrical grid by identifying the optimal location for STATCOM. Due to a circuit's high cost and complexity, it is crucial that FACTS controllers are positioned appropriately for efficient and rapid operation.

Detection of the bus bar with the weakest load based on the CPF, voltage profile, eigenvalues and eigenvectors, and P-V curve method in order to identify the optimal location and size for STATCOM.

Simulation is performed in MATLAB R2020a utilizing the Power System Analysis Toolbox (PSAT) to calculate power flow with and without FACTS controllers; load flow is determined using the Newton Raphson method. In this study, the Iraqi (400 kV) National super Grid System was investigated in order to analyze the voltage stability using the CPF process.

A- Optimal Location For STATCOM

The transmission level of the electrical grid in Iraq comprises a network operating at a voltage level of 400 kV, which has been supplemented with the integration of a 132 kV network. The investigation is confined to the 400 kV network, encompassing its transmission lines and vehicles.

The network being examined consists of a fleet of twenty-four vehicles and thirty-nine transmission cables, spanning a combined distance of 3,750 kilometers.

Figure 4 illustrates One line diagram of the INSGS (400 kV), including bus, line, and generator information. The performance of the lines is determined by the nominal sections and the static admittance of the loads. The representation of grid data is in per-unit (P.U) form, where the base power is 100 MVA and the base voltage is 400 kV. This network (400 kV) consists of twenty-four buses, nineteen generation buses, and eleven cargo buses. According to the power flow analysis, bus no. 1 (MUSP) is a vacant bus.

The determination of the ideal placement for the STATCOM device necessitates the utilization of a bifurcation analysis, The process begins with an initial state of equilibrium and gradually increases the loads by a multiplying factor until the point of failure is reached.

According to the exhibited findings of the CPF analysis in Figure 5, it can be observed that buses 18, 20, and 24 exhibit somewhat lower performance compared to other buses. Among the load buses, bus number 20 has the lowest voltage profile. The voltage magnitude at the moment of maximum loading for bus number 20, which has been identified as the bus with the lowest load, is 0.5443 per unit.

Figure (6) depicts the PV curves for the three weakest load buses, in which the Jacobian matrix of the electrical system becomes singular at = 3.6584 P.U. Therefore, based on the collapse analysis, bus number 20 has been designated as the optimal location for the STATCOM device. The eigenvalues and eigenvectors at the critical loading condition of = 3.6584 PU are displayed in Table 1. At this critical loading factor, it is apparent that there exists an eigenvalue of -0.57947 that converges towards zero. So, the point of separation has now been reached. By figuring out the sizes of the eigenvector parts that match to this smallest eigenvalue, it is determined that bus 20 has the largest magnitude, 0.7826, and is therefore the weakest bus. Also, the weakest bus bar can be specified by the total power loss calculation, wich demonstrate in table (2).

The STATCOM is connected to the load buses (3,5,7,9,10,11,12,13,15,16,17,18,19,20,21,22,23,24) individually, with each connection made to a single bus-bar. For each connection, the ratio of total active power losses to total active power generation is recorded. The bus-bar with the lowest value of losses is identified as the optimal location for the STATCOM.

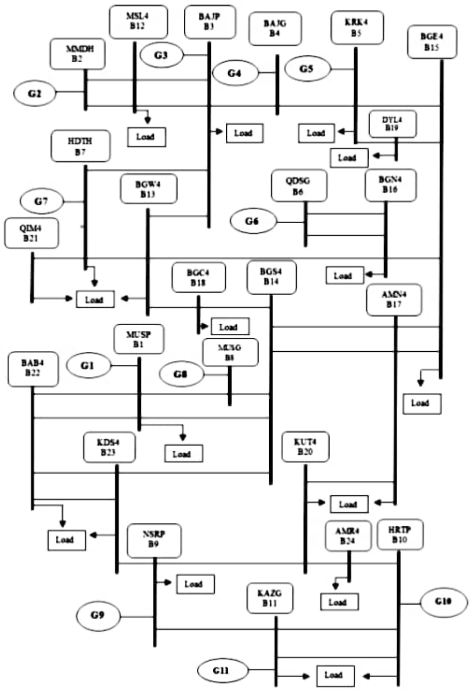

Figure 4. One line diagram of the INSGS (400 kV)

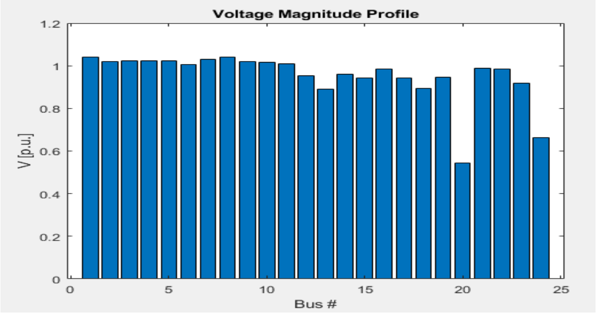

Figure 5. Voltage profile for 24 bus

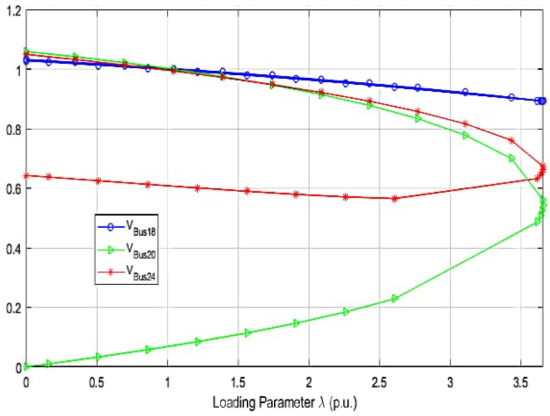

Figure 6. PV curves for the weakest three buses of Iraqi electrical grid

Table 1 : Eigenvalues Of 24 System BUS-BAR

Smallest Eigen value		- 0.579 47			-0.57947
Eigen value	Bus 01	0.0		Bus 13	4.01E-05
	Bus 02	0.0		Bus 14	5.01E-05
	Bus 03	0.0		Bus 15	7.03E-05
	Bus 04	0.0		Bus 16	0.0
	Bus 05	0.0		Bus 17	0.000151
	Bus 06	0.0		Bus 18	5.02E-05
	Bus 07	0.0		Bus 19	8.03E-05
	Bus 08	0.0		Bus 20	0.78262
	Bus 09	0.0		Bus 21	0.0
	Bus 10	0.0		Bus 22	8.05E-05
	Bus 11	0.0		Bus 23	0.000791
	Bus 12	0.0		Bus 24	0.216084

Table 2. Percentage Power Loss at BUSES

Bus.NO	Ratio P loss		Bus.NO	Ratio P loss
3	3.8441%		16	3.9793%
5	4.0169%		17	3.9052%
7	4.1862%		18	3.9041%
9	4.7868%		19	3.9091%
10	6.1683%		20	3.0950%
11	5.7847%		21	3.9352%
12	3.9104%		22	3.9088%
13	3.9166%		23	3.8842%
15	3.9245%		24	4.3511%

B- Optimal Size of STATCOM

The STATCOM is installed at Bus No 20 and its capacity is incrementally increased in defined increments. The lambda values are then measured and analyzed to determine the optimal capacity for the STATCOM, as described in section 4 of the document. The optimal capacity, as indicated in Table 3, is determined to be 700 MVA.

Table 3. capacity of STATCOM with λmax

capacity of STATCOM MVA	λmax
200	3.6621
300	3.7325
400	4.2071
500	4.5529
600	4.7781
700	4.8822
800	4.8824
900	4.8824
1000	4.8824
1200	4.8824

C- INSGS 24-Bus Test System with STATCOM

Figure 7 shows how the voltage profile changes when the STATCOM controller input on bus 20 is changed. The maximum load point (MLP) for this case is found to be max=4.8822 PU. Figure (8) shows an increase in the voltage profile and the highest value of that was seen and makes the system more stable.

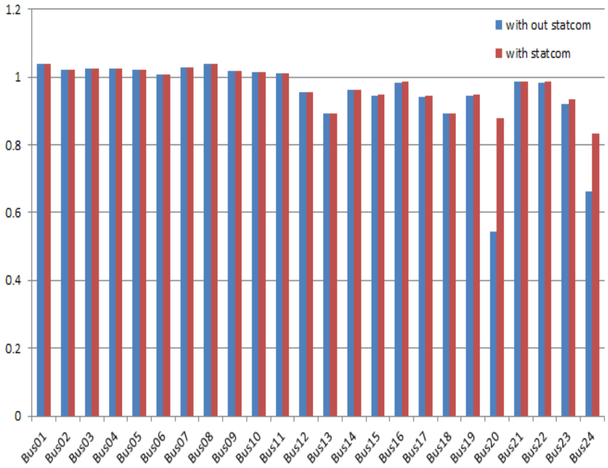

Figure 7. BUS VOLTAGE PROFILE FOR 24 BUS SYSTEM

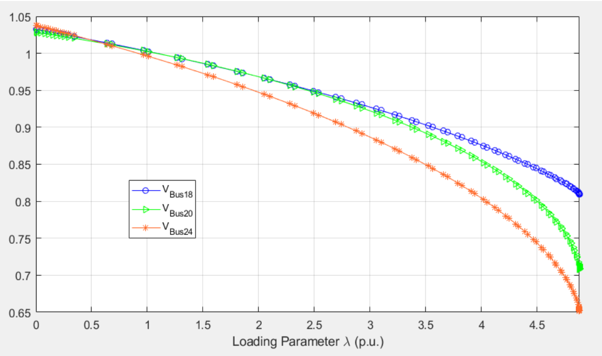

Figure 8. PV Curves With STATCOM for the weakest three buses

Conclusion

Through the simulation of the INSES 24-bus system, it has been determined that bus-bar Number 20 is the weakest bus. Consequently, it is deemed suitable to install a STATCOM at this location. The voltage detection methods are employed to identify the weak bus for the purpose of connecting the STATCOM. The study employed many methodologies, including the P-V curve approach, the eigenvectors and eigenvalues method, and the minimal losses method. Additionally, an appropriate size for the STATCOM was identified.

When the STATCOM was connected to bus 20, The observation revealed an improvement in the voltage distribution and a rise in the factor of load (λ), leading to enhanced system stability.

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