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Analysis of Voltage Collapse in the Largest Grid Substation in Kerala

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Abstract— Kerala State Electricity Board (KSEB) the main power generators in Kerala uses breaker switched capacitor for voltage support and reactive power compensation in the largest Grid substation at Kalamassery. The capacitor bank installed at Kalamassery does not meet the system requirement. This lead to a Voltage Collapse in the Kalamassery area. In order to avoid this problem some FACTS devices are employed at the load centre. FACTS devices are used as a reactive power source and the optimal location for these devices were found out. The criterion used is based on the voltage profile of the system, that is the voltage deviation at each bus with respect to its optimum value is minimized. The modeling of the system was done using Power System Analysis Toolbox(PSAT) and a Power flow analysis was also carried out. The results shows that the method works effectively and is applicable to practical network.

Index Terms— Power System Modeling,STATCOM, Static Condenser, Unified Power Flow Controller(UPFC)

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1 INTRODUCTION

Electric power is the backbone of Industrial world today. Further comfort, convenience and safety of large population all over the world depends upon electric power. Nowadays the growing proportion of energy requirement is being met all over the world by electricity.

It has always been desirable to transmit as much power as possible through transmission lines and cables, consistent with the requirements of stability and security of supply. Power transmission is limited mainly by thermal factors in cables, short transmission lines, transformers and generators, but in long lines and cables the variation of voltage and maintanence of stability also constrain the power transmission. The voltage 'profile' and the stability of a transmission line or cable can be improved using 'reactive compensation'. In the early days reactive compensation took the form of fixed value reactors and capacitors, usually controlled by mechanical switchgear. Since the 1970's power electronic equipments has been developed and applied to extend the range of control, with a variety of methods and products.

For bulk power AC transmission there are two fundamental requirements, 1.Synshronism 2.Voltage profile. It is obvious that the correct voltage level must be maintained within narrow limits at all levels in the network. Undervoltage degrades the performance of loads and causes overcurrent. Overvoltage is dangerous because of the risk of flashover, insulation breakdown and saturation of transformers. Most voltage variations are caused by load changes and particularily by reactive components of current.

In the earlier days there has been an increasing attention to voltage stability assessment using several analysis methods. Hasan and Parniani.M[1] presented a new approach using combination of static and dynamic methods was developed for voltage stability assessment. Hao Wang[2] proposed a mathematical model of reactive power optimization including comprehensive consideration of the practical constraints and reactive power regulation means for optimization is established. Kincic and Papic.M[3] proposes a new concept in transmission system planning that consists of intentional deregulation of transmission voltages and transfer of voltage support of transmission lines from transmission to distribution level with regulation of distribution voltages. Mantawy and . Al-Ghamdi[4] presents a new algorithm for optimizing reactive power using Particle Swarm Algorithm and it has been applied to IEEE 6-bus system.

In this paper the bus system at Kalamassery under KSEB is used as the test system. First, a severity ranking is carried out on the test system to specify faint buses, generators and links in terms of voltage stability. Based on this ranking the most severe conditions for generator and load increment are defined.

This paper is organized as follows: The modeling of the test system under consideration is described in section II. The objective of the thesis is explained in section III. The model of the FACTS device to be connected is described in section IV. The results and discussions for test system with FACTS devices is explained in section V. Section VI explains model of the test system with Static condenser. Finally a conclusion is deduced in section VII.

2. MODELING OF THE TEST SYSTEM

An electric power system consists of three main divisions namely generating system, transmission system and distribution system. The generation of electricity involves conversion of energy from a non electrical form to an electrical form. For the generation of electrical energy, generators are widely used.

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A power system with more than one generator is known as a multimachine power system.

Large and long transmission networks are wheeling the generated power from the sending end stations to substations in the load centres. Generally a power system is divided into several subsystem based upon operating voltage level. Highest on the voltage scale being the transmission network termed as Grid**,** subtransmission and distribution system voltage levels occupy the subsequent places in the descending order on the voltage scale.

The calculations involved in a power system is dealing with more than one voltage level which can be very tedious, therefore a set of values known as base values are defined for each voltage level and each variable is expressed as a fraction of its respective base. In this case, each value is represented by a per unit (p.u) quantity. Using the per unit system, the voltage deviations at each bus are expressed as a deviation from the nominal value of 1p.u.

The multi machine power system used for this study is developed with the help of PSAT and it is shown in Fig.1. It corresponds to a part of KSEB power network and consists of the following.

- 28 buses
- 2 generators
- 18 transformers
- 12 transmission lines at 110KV
- 2 transmission lines at 66KV
- 17 load buses

Kalamassery Substation is the largest Grid substation in Kerala with a transformer capacity 720MVA at 220/110KV level, 126MVA at 110/66KV level and 22.5MVA at 110/11KV level.At Kalamassery Substation, the main 220KV incoming feeders are from Brahmapuram Diesel Power Plant and Moolamattom Hydro Power Plant represented as BRKL NO.I & NO.II & IDKL NO.I& NO.II. There are four main voltage levels at Kalamassery, they are 220/110/66/11KV.

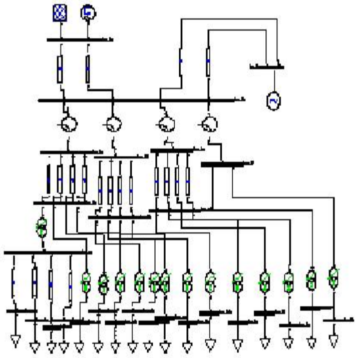

Fig.1 Test system without any compensation

The voltage profile of the test system without any compensation is shown in Fig.2

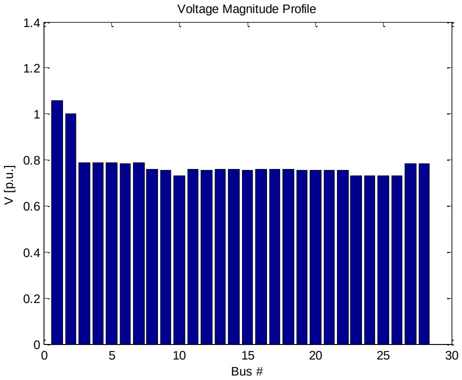

Fig.2 Voltage profile without any compensation

3. OBJECTIVE OF THE THESIS

One of the most fundamental concepts in AC power transmission is ‘stability’. Stability of an AC power system is denoted by its capability to recover from planned and random electrical disturbances. Voltage stability is one of the major criterion for successful AC power transmission. Transmission lines are frequently subjected to undervoltage and overvoltage problems and their performance is thus affected. In reactive power constrained systems heavy loading may create undervoltage or voltage collapse degrading the performance of Induction motors.

For any network the voltage profile must remain within +/-5% of the rated value for better and efficient operation of electrical equipments. The voltage variation is mainly due to imbalance in the generation and consumption of reactive power in the system. In general if the load requirements increase, the voltages at the corresponding buses may drop below 0.95p.u. and consequently an additional voltage support is needed at that particular bus.

For this study the bus numbers for the test system without FACTS device are ordered from 1 to 28. For each possible location of the FACTS device a power flow analysis is performed in order to determine the voltage deviations at each bus with respect to a value of 1p.u. From the result we can see that a voltage collapse is seen in the entire test system(Fig.2).

4. MODEL OF FACTS DEVICES

4.1 Model Of STATCOM

A Static synchronous compensator(STATCOM) is a regulating device used on alternating current transmission networks.Static Compensators are those which has no rotating parts and are used for surge impedence compensation. These are used for load compensation which maintain constant voltage under rapidly varying loads and they improve power system stability and system power factor. The steady state model of STATCOM was shown in Fig.3

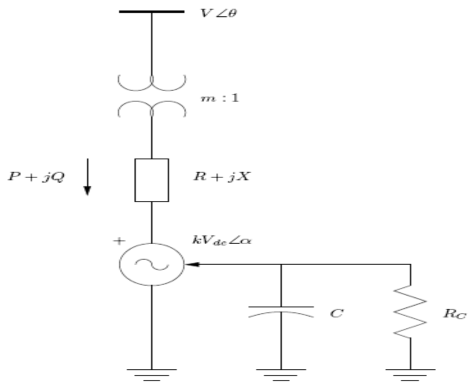

Fig.3 STATCOM Model

The equation for active and reactive power injected is given by

$$P = V^2G - kV_{dc}Vg\cos(\Theta-\alpha) - kV_{dc}VB\sin(\Theta-\alpha) \qquad (5)$$

$$Q = -V^2B + kV_{dc}VB\cos(\Theta-\alpha) - kV_{dc}VG\sin(\Theta-\alpha) \qquad (6)$$

4.2 Model Of UPFC

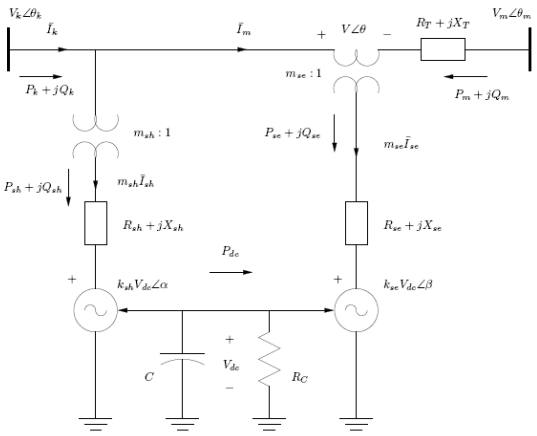

Fig.4 UPFC Model

The UPFC is the most versatile FACTS controller de veloped so far. It has the ability to adjust three control parameters, the bus voltage, transmission line reactance, and phase angle between two buses either simultaneously or independently. It can independently and very rapidly control both real and reactive power flows in a transmission line. It comprises two VSC coupled through a common DC terminal. One VSC is connected in shunt and the other is inserted in series with the transmission line through an interface transformer.

The model shown in Fig.4 is completed by the algebraic equation expressing the reactive power injected at the node. It can be written as

$Q_k = Q_{sh} + \Sigma(V_k I_m)$ where V_k = sending end voltage,
I_m = current through the shunt
Q_k = reactive power injected at bus 'k'
Q_{sh} = reactive power injected through the shunt

5. RESULTS AND DISCUSSION

5.1 Test System with STATCOM

Power flow calculation using PSAT was done on the buses in the test system with STATCOM connected to different bus (other than slack bus and buses connected to transformers), voltage settings of slack bus are considered for minimising the active power loss. Loads were modeled as constant power loads (PQ load) and were solved by using Newton Raphson Power flow Routine. The program was coded in MATLAB. Fig.5 shows the test system with STATCOM at bus 15

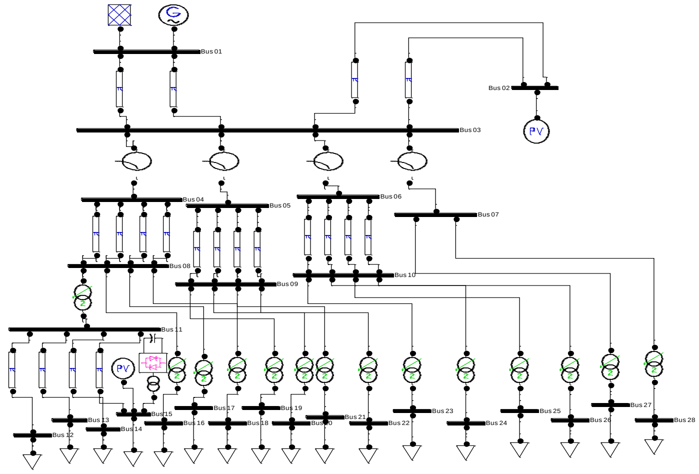

Fig 5. Test system with STATCOM at bus 15

The voltage profile of the test system with STATCOM at bus 15 is shown in Fig 6. An improved voltage profile was obtained for bus number 15 as STATCOM provides compensation at that bus. Similariy an improved voltage profile can be obtained for all other buses.

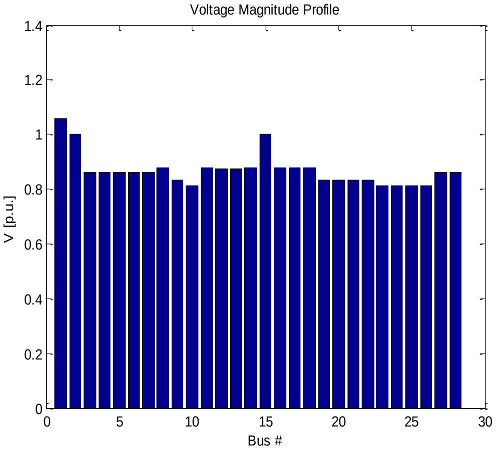

Fig 6. Voltage profile of the test system with STATCOM

Table.1 Loss Reduction using STATCOM

	Active power losses(p.u)	Reactive power losses(p.u)
Losses without any compensation	0.31233	0.49676
STATCOM at bus 12	0.27615	0.43861
STATCOM at bus 13	0.27649	0.43911
STATCOM at bus 14	0.27662	0.4393
STATCOM at bus 15	0.27602	0.4384

The table.1 shows the reduction in losses at different bus locations by connecting a STATCOM. From the table we can see that the optimal location is at bus 15.

5.2 Test System with UPFC

Power flow calculation using PSAT was done on the buses in the test system. Fig.7 shows the test system with UPFC at bus 15. UPFC have been connected to different bus (other than slack bus and buses connected to transformers), voltage settings of slack bus are considered for minimising the active power loss. Loads were modeled as constant power loads (PQ load) and were solved by using Newton Raphson Power flow Routine. The program was coded in MATLAB. The results shows that losses are found to be reduced at bus number 15 and an improved voltage profile is obtained for the entire system.

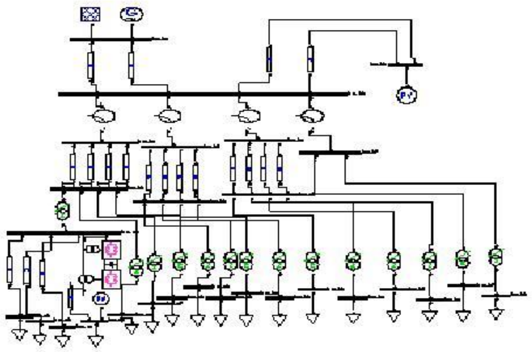

Fig.7 Test System with UPFC at bus 15

The voltage profile of the test system with UPFC at bus 15 is shown in Fig 8. Similarily an improved voltage profile can be obtained for all other buses.

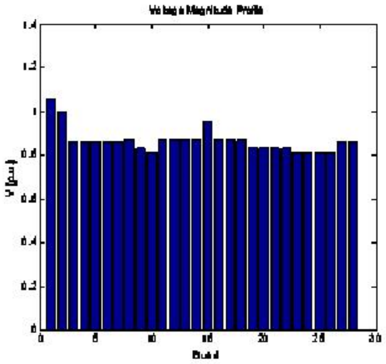

Fig.8 Voltage profile of the test system with UPFC

Table.2 Loss Reduction using UPFC

	Active power losses(p.u)	Reactive power losses(p.u)
Losses without any compensation	0.31233	0.49676
UPFC at bus 12	0.23265	0.39765
UPFC at bus 13	0.23281	0.39814
UPFC at bus 14	0.23302	0.39873
UPFC at bus 15	0.23261	0.39755

The table.2 shows the reduction in losses at different bus locations by connecting a UPFC. From the table we can see that the optimal location is at bus 15.

6. MODEL OF THE TEST SYSTEM WITH STATIC CONDENSER (STATCON)

STATCON or static synchronous condenser exhibit characteritics similar to conventional synchronous condensers without any moving parts. The basic elements of a STATCON is an inverter, a d.c capacitor, and a transformer to match the line voltage. Power flow calculation using PSAT was done on the buses in the test system. Fig.9 shows the test system with STATCON at bus 15. STATCON have been connected to different bus (other than slack bus and buses connected to transformers), voltage settings of slack bus are considered for minimising the active power loss. Loads were modeled as constant power loads (PQ load) and were solved by using Newton Raphson Power flow Routine. The program was coded in MATLAB.

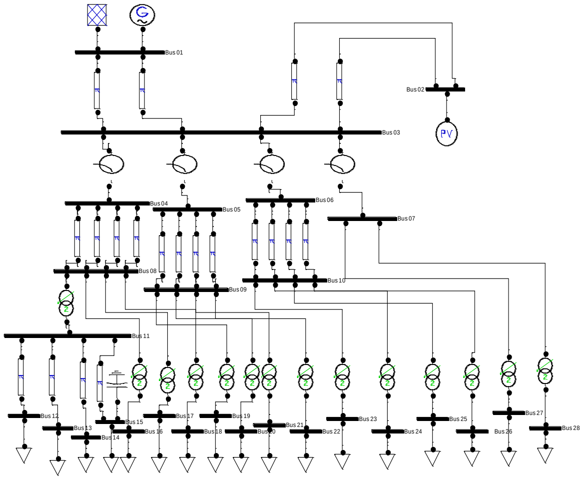

Fig 9. Test System with Static Condenser at bus 15

The voltage profile of the test system with Static Condenser at bus 15 is shown in Fig 10. An improved voltage profile can be observed in the entire system.

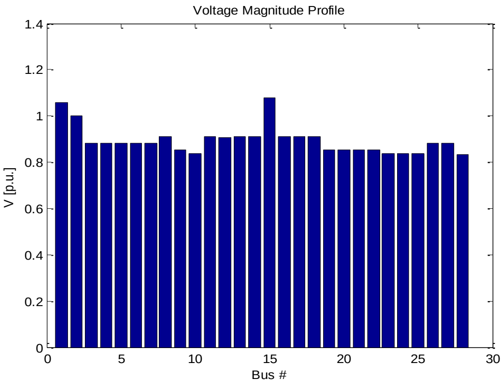

Fig 10.Voltage profile of the test system with Static Condenser.

Table.3 Loss Reduction using STATCON

	Active power losses(p.u)	Reactive power losses(p.u)
Losses without any compensation	0.31233	0.49676
STATCON at bus 12	0.30894	0.48993
STATCON at bus 13	0.30992	0.49142
STATCON at bus 14	0.31129	0.49355
STATCON at bus 15	0.30877	0.48967

7. COMPARISON OF ABOVE RESULTS

From the above results it was found out that bus number 15 is the optimal location to connect a reactive compensator. The losses at bus 15 while connecting each device is compared as shown below in Table.4

Table.4 Loss reduction comparison

DEVICE	ACTIVE POWER-LOSSES(p.u)	REACTIVE POWER LOSSES (p.u)
Without any compensation	0.31233	0.49676
STATCOM	0.27602	0.4384
UPFC	0.23261	0.39755
STATCON	0.30877	0.48967

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