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Shunt Capacitor Based Line Reactive Power Compensation Using Phasor Measurement Unit (PMU) Data

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Abstract: To maintain the voltage levels under acceptable limits, reactive power control is the basic requirement, thereby maintaining the stability of the interconnected power system. The ability of the power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance from a given operating point is called voltage stability. Modern power systems are prone to have voltage instability problems. The placement of capacitor banks in the shunt can improve the voltage stability. The magnitude of bus voltage will increase with the use of a capacitor bank. In this work, the simple concept of using a shunt compensator to maintain the system voltage is used. Simulation of power flow without and with the capacitor bank was done using MATLAB Simulink software. Here, PMUs have been used to analyse the system parameters at each bus, thereby giving accurate results.

Keywords: Voltage Stability, Phasor Measurement Unit (PMU), Shunt Compensation, Capacitor Bank.

I. INTRODUCTION

In recent years, there have been several blackouts due to voltage stability problems in many countries. One of the main causes of voltage instability is the shortage of reactive power in the power system. This can be caused due to many reasons This can be improved by increasing the reactive power injection. To prevent voltage instability, several approaches can be considered such as using FACTS Controllers, Placing series and parallel capacitors, Under-voltage load shedding, Rescheduling the generation, etc.

A large number of electrical loads are inherently inductive in nature. Since the inductive loads consume lagging reactive power, the compensation required is supplied in the form of leading reactive power, i.e., in addition to active power (W), the consumers need a certain amount of reactive power (VAR) as well. Those consumers, who, at the same active power, demand a greater amount of reactive power have comparatively poor power factors, i.e., they draw higher current and produce unnecessarily large losses and voltage drops. Fixed capacitor banks are the most economical choices for individual or a group of inductive loads which have a relatively constant demand for reactive power. Examples of such loads include heavy machinery like induction motors, induction furnaces, etc.

Shunt compensation devices are usually employed at either load, substation, or transmission level, depending on the requirement. The compensation can be capacitive or inductive, although in most cases compensation is capacitive. Of all the available choices, connecting shunt capacitors to the line is the most common and economical form of leading reactive power compensation. In this paper, the use of Shunt capacitors is depicted using MATLAB Simulink. The bus voltage magnitude increases to its original magnitude with the use of a capacitor bank.

II. THEORETICAL BACKGROUND

A. Significance of Reactive Power

Reactive power associated with inductive load is lagging VARs (I^2X_L), i.e., reactive power absorbed by the inductive load is positive. Similarly, the reactive power associated with capacitive load is leading VARs (I^2X_C), i.e., reactive power absorbed by the capacitive load is negative. As mentioned in the previous section, the power factor is just a representation of the reactive power required by the load. Since apparent power is made up of active and reactive power both, it falls upon the utility to supply more power. This power transfer, because of the poor power factor, causes more losses in the transmission system. This, in turn, causes power quality to degrade as pf decreases, voltage regulation is poor and the cost of electricity increases.

B. Sources and Compensation

The sources of reactive power include synchronous generators, synchronous motors, shunt capacitors, shunt reactors, series capacitors, SVCs, FACTs devices etc. Among these, shunt capacitors are the most economical choice. Shunt capacitors are installed to meet this need of the system at various locations throughout the power system. The reason that shunt capacitors are installed at the substations is to supply additional reactive power which in turn improves the voltage profile. As the load changes, the voltage at the substation and load buses changes. It is common knowledge that the load power factor is always lagging and therefore, a shunt connected capacitor bank at the substation can increase the voltage level during high loading conditions. These capacitor banks may be permanently connected to the bus, or they can be switched as the need arises.

C. Relation between Voltage and Reactive Power

With a higher level of real power loading, the reactive power demand of the system increases and it may cause voltage reduction at the receiving end bus with no additional support of reactive power. For heavily loaded lines with lower receiving end voltage, the line acts as a drain of reactive power.

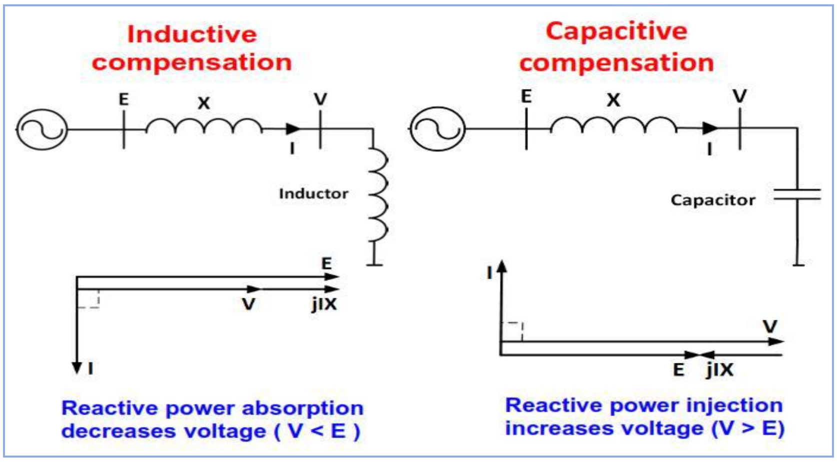

Fig. 1 Effect of Reactive Power on Voltage

As the frequency is a measure of the balance between the load and generation, similarly the transmission voltage levels indicate the balance between the supply and demand of the reactive power in the system. Voltage instability is basically a problem of reactive power mismatch in the power system. This may occur due to steady, transient and dynamic state variations in the system operating conditions, mostly because of:

- Change in loading
- Transformer tap position
- Alteration of alternator outputs
- Switching of capacitor banks, reactors
- Power outages, etc.

D. Voltage Instability Detection:

The conventional methods to detect and prevent voltage instability can be broadly classified into the following types [1]. P-V curve method, V-Q curve method and reactive power reserve, Methods based on the singularity of power flow Jacobin matrix at the point of Voltage collapse, Continuation power flow method, application of reactive power compensation devices, control of network voltage and generator reactive output, coordination of protections [2]. All these methods take different times to detect the voltage instability, based on the measurement and computational speeds for each method.

III. SYSTEM MODELLING

The system is modelled using MATLAB Simulink software. The system consists of an incoming 11 kV feeder. It gets its power from a generator which is set to supply the connected loads. There are two buses with 11 kV and 415 V, which act as the sending end and receiving end of the system. The 415 V bus is feeding a base load. Two additional loads are connected to the feeder, which are switched ON after a predefined time interval. A capacitor bank is also connected to this feeder. The Simulink circuit model is shown in Fig. 2.

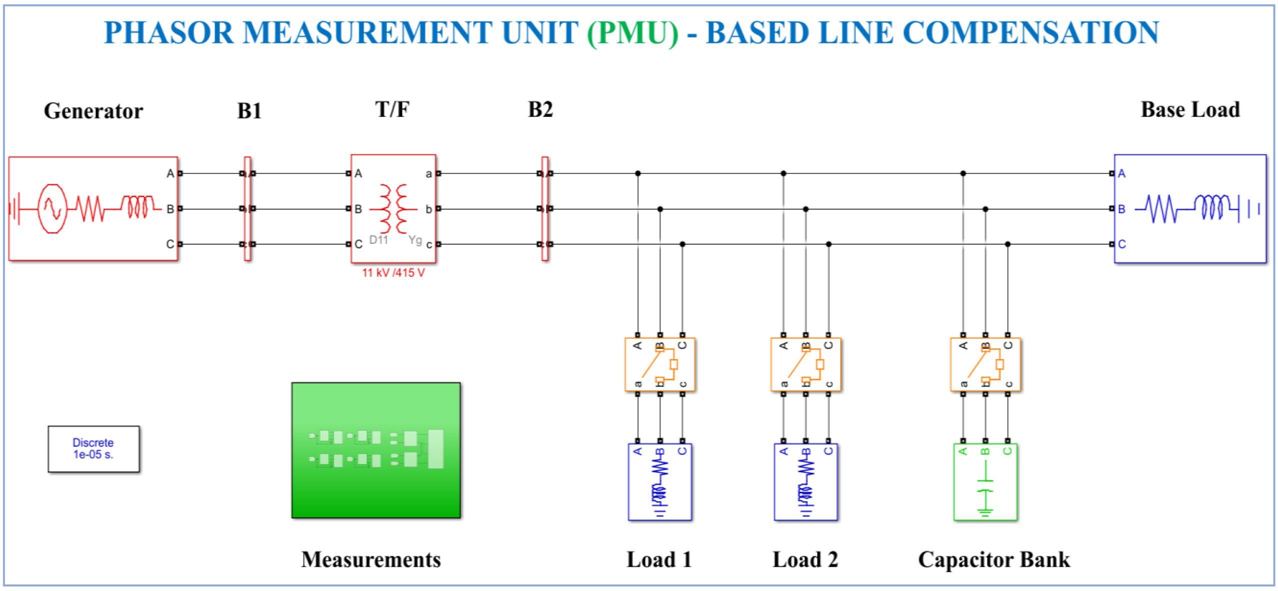

Fig. 2 Simulink Model for Line Compensation

Phasor Measurement Units are used for accurate measurement of parameters. The voltage and current readings for sending and receiving end are taken using PMUs, as shown in fig. 3. The total active and reactive power measured using the bus parameters is computed using the three-phase active and reactive power measurement blocks available in the MATLAB Simulink library.

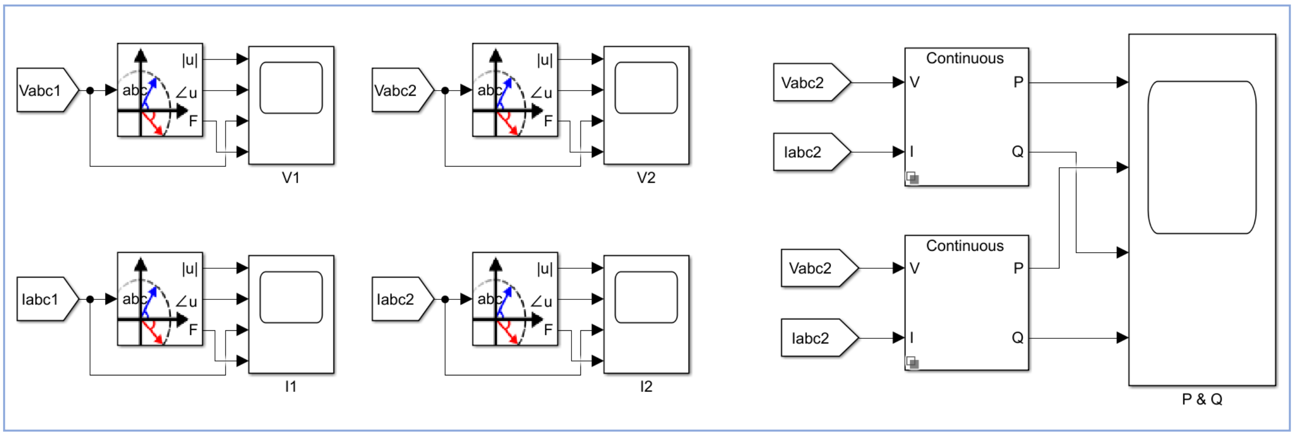

Fig. 3 PMU Based Measurement Subsystem

IV. SIMULATION & CASE-STUDY

The simulation is aimed at demonstrating the use of shunt compensation using a capacitor bank. The total duration of this simulation is T = 1.0 s, which is divided into 3 parts. Initially, a large load is connected to the circuit, which is called the base load. At t = 0.2 s, Load 1 is connected using a circuit breaker. After this, at t = 0.4 s, Load 2 is connected to the same feeder. At t = 0.7 s, a capacitor bank is connected in the shunt along with the loads. This model is simulated in discrete mode, with the sampling time of $t_s = 10^{-5}$ s or 10 µs.

TABLE I LOAD PARAMETERS

Load	P (kW)	Q (kVAr)	S (kVA)	Power Factor
Base	160	16.24	197.77	0.81
Load 1	40	29	49.5	0.81
Load 2	40	29	49.5	0.81

The load parameters used in this simulation are given in Table 1. It can be observed from Table 1, that the additional loads have the same power ratings. With each increment in the load (i.e. Load 1 and Load 2), there is a certain drop in the voltage level of the feeder. In order to compensate for this voltage drop, the capacitor bank which is connected in the shunt is turned ON. This helps in maintaining the voltage profile at its original condition or even improving it, depending on the compensation provided by the capacitor bank.

V. RESULTS

The parameters measured by the PMUs are shown below in the graphical form:

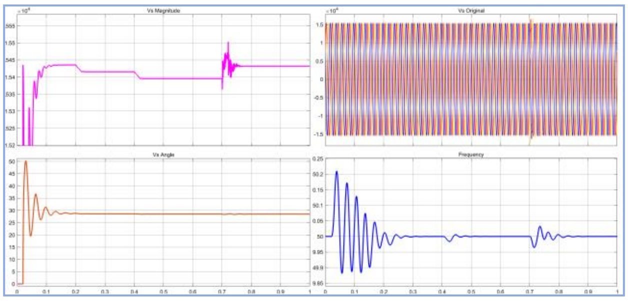

Fig. 4 Sending End Voltage & Frequency

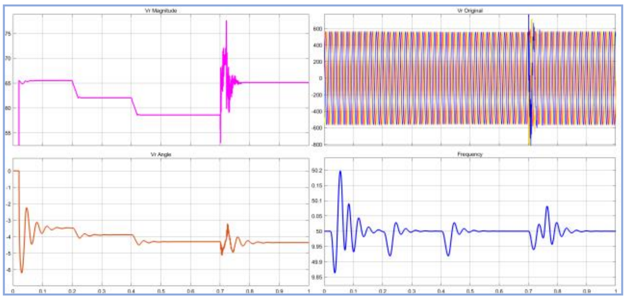

Fig. 5 Receiving End Voltage and Frequency

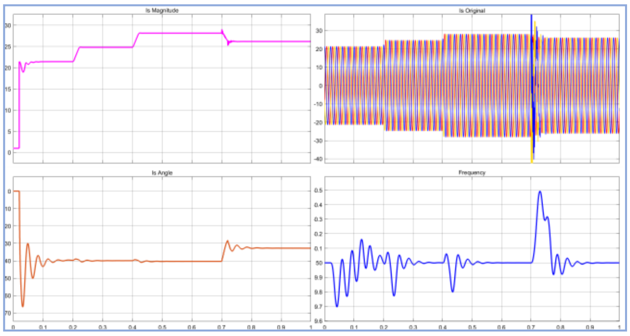

Fig. 6 Sending End Current and Frequency

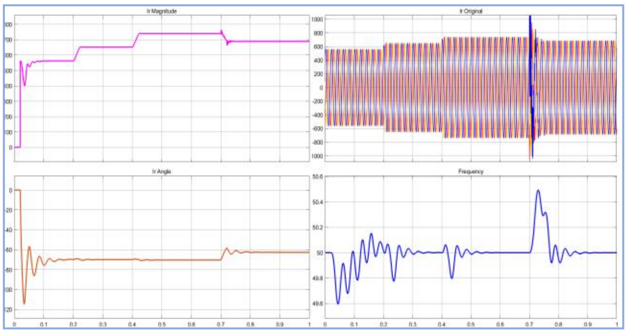

Fig. 7 Receiving End Voltage and Frequency

As seen in the waveforms, the magnitude and angle of voltage and current are calculated individually with the help of PMUs. This data is used to analyse the condition of the system and to take corrective actions based on the data available from the PMUs.

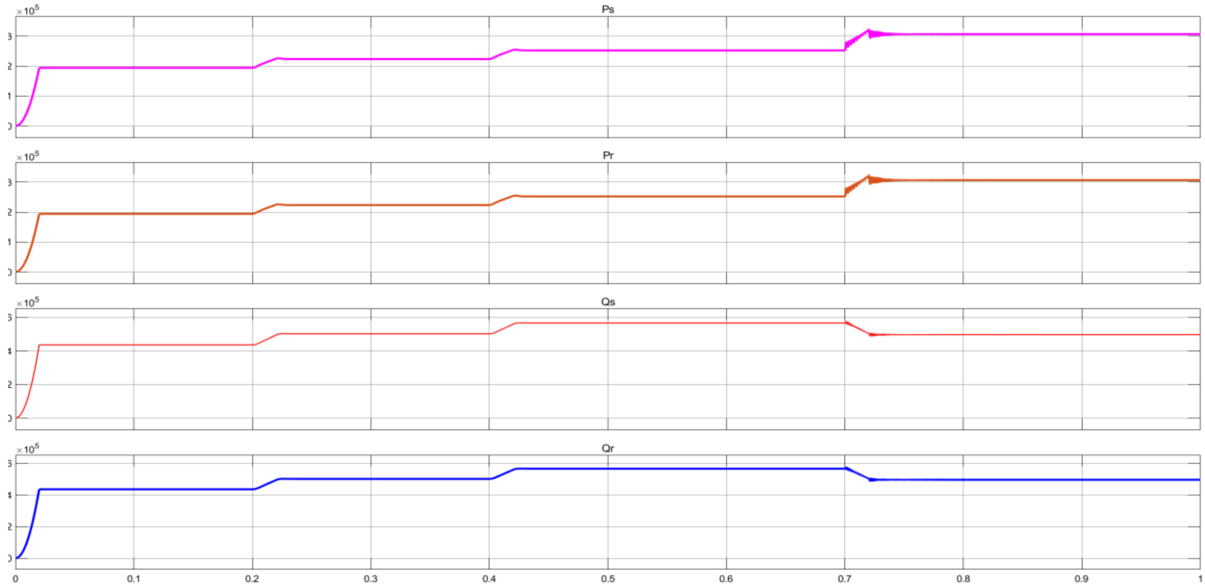

Fig. 8 Sending and Receiving End Active and Reactive Power

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When the load increment takes place, there is a decrease in voltage and an increase in the current magnitude, which is evident from the waveforms shown in Fig. 4 to 7. The active power consumption on both the buses increases as the loading increases. It should be noted that even when the capacitor bank is connected in the shunt, the active power consumption of the system still increases. On the other hand, the reactive power consumption because of the addition of newer loads decreases as soon as the capacitor bank is switched ON, as seen in Fig. 8.

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VI. CONCLUSION

In order to compensate for the increased load, the shunt capacitor bank is employed. As soon as the capacitor bank is connected to the feeder, the voltage level increases and the current decreases. This shows the improvement of the voltage profile. Because of this, the transmission line losses are reduced and thus, the transmission efficiency increases. The scope of future work in this paper includes the use of data obtained from the PMUs for the prediction of voltage instability. Once the instability is detected, efforts can be made to take corrective actions for the same.

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