Study of Capacitor Allocation in a Radial Distribution System

Tarandeep Kaur Gill, Neha

Guru Nanak Dev Engineering College, Ludhiana, Punjab, India

gilltarandeep71@gmail.com, kaushalneha1988@gmail.com

Gagandeep Kaur Gill

Bhutta College of Engineering and Technology, Ludhiana, Punjab, India

gillg0039@gmail.com

Abstract

A distribution system is an interface between the bulk power system and the consumers. Among these systems, radial distribution systems are popular because of low cost and simple design. In distribution systems, the voltages at buses reduces when moved away from the substation, also the losses are high. The reason for decrease in voltage and high losses is the insufficient amount of reactive power, which can be provided by the capacitors.

Keywords- Active power, Reactive power, Resistance, Reactance, Impedance.

Introduction

Electrical energy is produced through an energy conversion process. The electric power system is a network of interconnected components which generate electricity by converting different forms of energy (potential energy, kinetic energy, or chemical energy are the most common forms of energy converted) to electrical energy. The electric power system consists of three main subsystems: the generation subsystem, the transmission subsystem, and the distribution subsystem Figure 1. Electricity is generated at the generating station by converting a primary source of energy to electrical energy. The voltage output of the generators is then stepped-up to appropriate transmission levels using a step-up transformer. Electrical power is transmitted by high voltage transmission lines from sending end substation to receiving end substation. At the receiving end substation the voltage is stepped down to a lower value (say 66kV or 33kV or 11kV). The secondary transmission system transfer power from this receiving end substation to secondary substation. A secondary substation consists of two or more power transformers together with voltage regulating equipments, buses and switchgear. At the secondary substation voltage is stepped down to 11kV. The sub-transmission system designates the circuits, which deliver energy from the transmission subsystem to the distribution subsystem. Usually the transmission substations supply the sub-transmission system, but it is still referred to as the sub transmission. Many sub-transmission systems were previously transmission lines. Load growth and demand for more power resulted in the transmission voltage being too low. The consumer receives power from the distribution system.

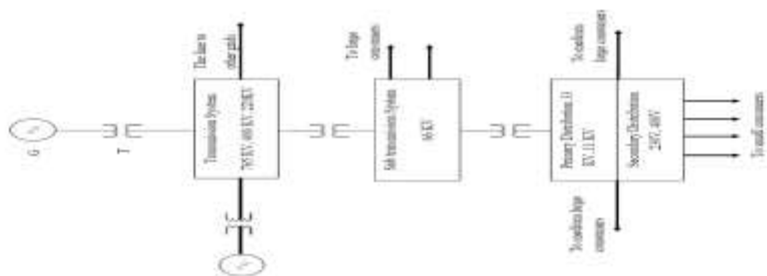

Figure 1: Single Line Power System Network

Connection Scheme of Distribution System

There are three fundamentally different ways to lay out a power distribution system used by electric utilities, each of which has variations in its own design are Radial , Loop and Network Figure 2.

Radial Feeder System

Most power distribution systems are designed to be radial, to have only one path between each customer and the substation. The power flows exclusively away from the substation and out to the customer along a single path, which, if interrupted, results in complete loss of power to the customer. Radial design is by far the most widely used form of distribution design. Its predominance is due to two overwhelming advantages: it is much less costly than the other two alternatives and it is much simpler in planning, design, and operation. Each radial feeder serves a definite service area. Many radial feeder systems are laid out and constructed as networks, but operated radially by opening switches at certain points throughout the physical network configuration so that the resulting configuration is electrically radial. Each service transformer in these systems feeds power into a small radial system around it, basically a single electrical path from each service transformer to the customers nearby. Regardless of whether it uses single-phase laterals or not, the biggest advantages of the radial system configuration, in addition to its lower cost, are the simplicity of analysis and predictability of performance. Because there is only one path between each customer and the substation, the direction of power flow is absolutely certain and thus voltage profiles can be determined with a good degree of accuracy without resorting to exotic calculation methods, equipment capacity requirements can be ascertained exactly; fault levels can be predicted with a reasonable degree of accuracy; and protective device: breaker, relays and fuses can be coordinated in an absolutely assured manner, without resorting to network methods of analysis.

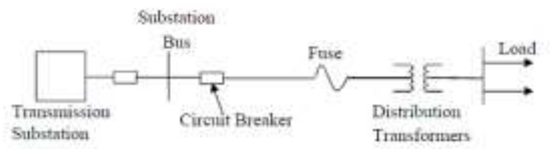

Figure 2: Single Line Diagram of Radial distribution System

Need of Capacitor

The most common of the three loads on modern system is the Inductive load. Typical example including transformers, fluorescent lightning and AC induction motor. All inductive loads require two types of powers to work properly:

- Active power(KW): actually performs the work
- Reactive power(KVAr): sustains the electromagnetic field

Considerations When Applying Capacitors on Distribution Systems

The analysis of a distribution system is an important area of activity, as distribution systems provide the vital link between the bulk power system and the consumers. A distribution circuit normally uses primary or main feeders and lateral distributors. A main feeder originates from the substation and passes through the major load centers. Lateral distributors connect the individual transformers at their ends. Many distribution systems used in practice have a single circuit main feeder and are defined as radial distribution systems. Radial distribution systems are popular because of their simple design and generally low cost. The modern power distribution network is constantly being faced with an ever-growing load demand; this increasing load is resulting into increased burden and reduced voltage. The distribution network also has a typical feature that the voltages at buses (nodes) reduces if moved away from substation. This decrease in voltage is mainly due to insufficient amount of reactive power. Even in certain industrial areas under critical loading, it may lead to voltage collapse. Thus to improve the voltage profile and to avoid voltage collapse reactive compensation is required. It is well known that losses in a distribution system are significantly high compared to that in a transmission system. The need of improving the overall efficiency of power delivery has forced the power utilities to reduce the losses at distribution level. Many arrangements can be worked out to reduce these losses like network reconfiguration, shunt capacitor placements etc. The shunt capacitors supply part of the reactive power demand, thereby reducing the current and MVA in lines. Installation of shunt capacitors on distribution network will help in reducing energy losses, peak demand losses and improvement in the system voltage profile, system stability and power factor of the system.

Benefits of capacitors

The proper application of capacitors serves to reduce the system currents and raise the system voltage. This accomplishes following benefits are Reduces loading of thermally limited equipment, Reduced system voltage drop, Reduces system losses, Improvement of stability.

Reactive power compensation

Reactive power compensation is an important issue in electric power systems, involving operational, economical and quality of service aspects. Consumer loads impose real and reactive power demand, depending on their characteristics. Real power is converted into “useful” energy, such as light or heat. Reactive power must be compensated to guarantee an efficient delivery of real power to loads. The reactive power is essential for creating the needed coupling fields for energy devices. It constitutes voltage and current loading of circuits but does not result in average (active) power consumption and is an important component in all ac power networks. Reactive power control for a line is often called Reactive Power Compensation. External devices or subsystems that control reactive power on transmission lines are known as Compensators. The objectives of line compensation are to increase the power transmission capacity of the line, and/or, to keep the voltage profile of the line along its length within acceptable bounds to ensure the quality of supply to the connected customers. Because reactive power compensation influences the power transmission capacity of the connected line, controlled compensation can be used to improve the system stability by changing the maximum power- transmission capacity.

Shunt Compensation

When fixed inductors and/or capacitors are employed to absorb or generate reactive power, they constitute passive control. Shunt devices may be connected permanently or through a switch. Shunt reactors compensate for the line capacitance, and because they control over voltages at no loads and light loads, they are often connected permanently to the line, not to the bus. Shunt capacitors are used to increase the power transfer capacity and to compensate for the reactive voltage drop in the line. The applications of shunt capacitors require careful system design. The circuit breakers connecting shunt capacitors should withstand high-charging in-rush currents. The addition of shunt capacitors creates higher frequency resonant circuits and can therefore lead to harmonic over voltages on some system buses.

Series Compensation

Series capacitors are used to partially offset the effects of the series inductances of the lines. Series compensation results in the improvement of the maximum power-transmission capacity of the line. The reactive power absorption of a line depends on the transmission current, so when series capacitors are employed, automatically the resulting reactive power compensation is adjusted proportionately. Also, because the series compensation effectively reduces the overall line reactance, it is expected that the net line-voltage drop would become less susceptible to the loading conditions. In an interconnected network of power lines that provides several parallel paths, for power flow between two locations, it is the series compensation of a selected line that makes it the principal power carrier. A practical upper limit of series compensation may be as high as 0.75 pu.

Synchronous Condensers

Synchronous condensers or synchronous compensators were the only fully controllable reactive power devices available for power systems until mid 1970s. A synchronous condenser is a synchronous machine, the reactive power output of which can be continuously controlled by varying its excitation current. When the synchronous machine is connected to the ac system and is under excited, it behaves like an inductor, absorbing reactive power from the ac system. However, when it is overexcited, it functions like a capacitor, injecting reactive power into the ac system.

Effects of Reactive Power Compensation

Reduced Power System Losses

The reduction in power system losses, due to the installation of capacitor banks, can result in an annual gross return of as much as 15 percent on the capacitor investment. Although it is seldom sufficient to justify the installation of capacitor banks on the economic benefits of power loss reduction alone, it is certainly an added benefit. In most industrial plant power distribution systems, the power losses vary from 2.5 to 7.5 percent of the load kWh. This depends upon hours of full load and no-load plant operation, wire size, and length of the main and branch feeder circuits. Capacitors are effective in reducing only that portion of the losses that is due to the KVAr current. Losses are proportional to the current squared, and since current is reduced in direct proportion to power factor improvement, the losses are inversely proportional to the square of the power factor. Hence, as power factor is increased with the addition of capacitor banks to the system, the magnitude of the losses are reduced. Losses account for approximately one third of one percent of the KVAr rating.

Release of Power System Capacity

When capacitors are placed in a power system, they deliver KVAr's. This introduces furnishing magnetizing current for motors, transformers and other similar plant, thus reducing the current from the power supply. Less current means less KVA or load placed on the transformers and main branch feeder circuits. This means capacitors can be used to reduce overloading or permit additional load to be added to existing feeders. Release of system capacity by power factor improvement and especially with capacitors is becoming extremely important due to the associated economic and system benefits.

Location of capacitors in the system

The benefits from installing PF improvement capacitors in an electrical system derive from the reduction of reactive power circulating in the system. This result in power bill savings, release of system capacity, voltage improvement and reduction of losses. To obtain maximum benefit, capacitors should be located as close to the load as possible. Although maximum operating benefits are obtained when capacitors are located near the load, economics and practicality should be considered when selecting the location to connect the capacitors. Consider that a diversity factor of 50% is determined for the cyclic load in operation at a given time. To take advantage of this condition a capacitor bank can be insta1le.d at a convenient location in the system with a WAR rating of only one half of the total WAR required if each individual load is provided with a capacitor. Another important element to be included when performing an economical evaluation to select the proper capacitor installation is the cost of the switching device when required. It accomplishes high PF from the initial unit installation without the need of performing any calculations; it places the right amount of reactive power at the correct location as equipment is added, - removed or relocated within the plant; it releases the main distribution equipment of excess load and it assures that the capacitors are on line only when the motor is energized.

When capacitors are directly connected to a substation distribution bus, multi-step capacitor banks with automatic switching may be considered. The choice of parameter to control the automatic switching will depend on the nature of the load. The most frequently used control parameters are time, voltage and KVAR. The usual reference for designing an automatic capacitor switching scheme is a reactive power profile of the load. The size and number of switching steps of the capacitor bank are tailored to the charted KVAR flow profile at the connecting point. The system benefits due to the shunt capacitors include Reactive power support, Voltage profile improvement, Line and transformer loss reduction, Release of power system capacity, Savings due to increased energy loss.

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Author’s Profile

Tarandeep Kaur Gill was born on November 23, 1987. She received her B.Tech in Electrical engineering degree from Guru Nanak Dev Engineering College, Ludhiana, Punjab, 2010 and

M.Tech in Power Engineering degree from Guru Nanak Dev Engineering College, Ludhiana, Punjab, India, 2012.