Voltage Control Mangement

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Abstract

A power system is said to be well designed if it gives a good quality of reliable supply. By good quality is meant the voltage levels within the reasonable limits. Practically all the equipment on the power systems are designed to operate satisfactorily only when the voltage levels on the system correspond to their rated voltages or at most their variations are within tolerance limit. For satisfactory operation of motors, lamps and other loads, it is desirable that consumers are supplied with substantially constant voltage. If the limits of voltage provided by the power utility are too broad, it may cause erratic operation or even malfunctioning of consumers appliances. The voltage variations in a power system must be kept to minimum level in order to deliver good service to the consumers. With the trend towards larger and larger interconnected systems, it has become necessary to employ appropriate methods of voltage control. Hence the necessitation of this paper on the various methods of voltage control such as synchronous compensator, shunt capacitor and reactors, series capacitors, tap changing transformer, booster transformer, and maintenance.

Keywords- Voltage-control, Voltage-variations, power system, methods, consumers

1. Introduction

An electrical power system consists of three major divisions (generation, transmission and distribution). The distribution system connects all the individual loads to the transmission lines. All equipment connected to the power utility system is designed to be used within a certain voltage range. Because voltage drop exists in each part of the system, the consumer who is electrically farthest from the substation, receives the lowest voltage. Since all consumers have appliances and equipment of the same standard of service voltage, it is necessary to provide them with the same service voltages. A compromise is needed, however between what voltage range equipment will operate Satisfactorily . To this end, the statutory limit of voltage variation is ±6 percent of declared voltage at consumer terminals. If the limits of voltage provided by the power utility are too broad, the cost of equipment especially sensitive ones will be high because they will have to be designed to operate satisfactorily within those limits. On the other hand, if the voltage limits required for satisfactory operation of the equipment are too narrow, then the cost of providing the power without exceeding these limits will also be high.Voltage changes continuously according to the varying electrical demand, transmission lines utilization, system control by the control centers, and emergency situations occurred in the system.

Since customers require voltage quality, at delivery points, to meet the agreed criteria, it is the control centers' responsibility to control the voltage so that it can satisfy the needs of the consumers.If the voltage variation is more than a specified value, the performance of the equipment suffers and the life of most of the equipment is also sacrificed. Too wide variation of voltage may cause erratic operation or even malfunctioning of consumer's equipment and also the equipment in the power system. Example, the torque of an induction motor (which forms about 70 percent of the total load on the system) varies as the square of the terminal voltage, comforts at homes are jeopardised and so on. Thus the necessity of controlling the voltage on the system is very important. The voltage controlling problems are needed to be solved by each control centers. This can be achieved by providing sufficient reactive power sources for controlling voltage level as specified by the nations' standard. The voltage controlling problems can be divided into two situations, which are normal situation, and emergency situation. When power is supplied to a load through a transmission line keeping the sending end voltage constant, the load voltage undergoes variations depending upon the magnitude of the load and the power factor of the load. The voltage variation at a node is an indication of the unbalance between the reactive power generated and consumed by the node. The higher the load with smaller power factor, the greater is the voltage variation. Whenever the voltage level of a particular bus undergoes

1. To reduce losses in the distribution and sub transmission system.

2. To improve the voltage regulation so as to bring it within the prescribed limit.

variation, this is due to the unbalance between the two

vars at that bus.

The causes for high losses and poor voltage regulation in the distribution and sub transmission system are:

1. Low power factor of the consumer installations.
2. Long and over loaded Low Tension (L.T) lines.
3. Distribution transformers' centers located away from the load centers.
4. Long and overloaded 11kV and sub transmission lines.
5. Poor voltage regulation on 11 kV and Low Tension lines, voltage drops being extended beyond permissible.
6. Under loading of distribution transformers.

The system improvement has to be planned properly with the following objectives in mind.

3. To improve the power factor in the sub transmission and distribution system so as to get optimumutilization of /sub transmission/distribution capacities. [1]

1.1 Simple Analysis

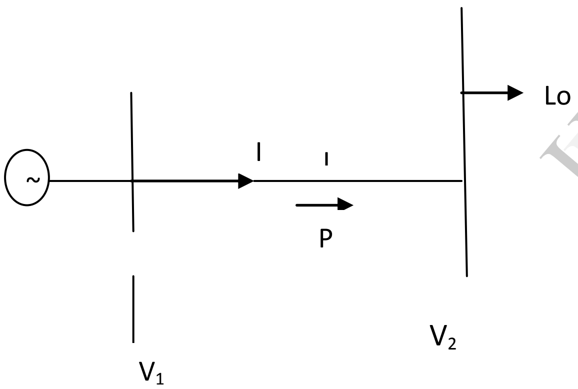

Figure 1 Load connected to the source through a line

To understand the unbalance between two nodes, refer to figure 1 where node one is a generator node with reference voltage V_1 and node two is the load node with voltage V_2 . the two bus bars are interconnected through a short line.

Assuming the interconnector to be lossless (R = 0) and the voltage V_1 constant (by adjusting the excitation of the generator), the following relations hold:

$V_2 = V_1 - IZ$..(1)

$V_1^* I = P - jQ$ (assuming inductive load)..................(2)

From equation (2),

$I = \frac{P-jQ}{V_1^*}$

Where $V_1^* = V_1$, V_1 being the reference vector

Substituting for I in equation (1)

$V_2 = V_1 - j\frac{P-jQ}{V_1}X$

$V_2 = \left[V_1 - \frac{Q}{V_1}X\right] - j\frac{P}{V_1}X$............................(3)

The vector diagram for this relation is given in figure 2

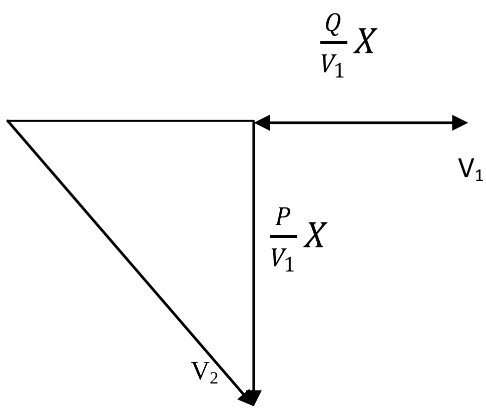

Figure 2 Phasor diagram for system in figure 1

From the above, it is clear that the load voltage is not affected much due to the real component of the load P as it is normal to the vector V_1 whereas the drop due to reactive component of load is directly subtracted from the voltage V_1. Assuming the voltage drop due to real power is negligible, the voltage drop is directly proportional to the reactive power Q. The relation is given by

$$V_1 = V_1 - \frac{Q}{V_1}X \quad \text{.....(4)}$$

[2]

In order to keep the receiving end voltage V_2 fixed for a particular sending end voltage V_1 the drop (the product of the reactive power Q and the reactance X multiply by the inverse of the sending end voltage V_1 must remain constant.

Since in this case the only variable quantity is Q, it is this reactive vars which must be locally adjusted to keep this quantity fixed *i.e*. let Q be the value of the reactive vars which keeps V_2 to a specified value, any deviation in Q at node 2 must be locally adjusted.

2 Importance of Voltage Control

As stated earlier, when the load on the supply system changes, the voltage at the consumer's terminals also changes. The variations of voltage at the customer's terminals are undesirable and must be kept within prescribed limit for the following reasons:

(i) In case of lighting load, the lamp characteristics are very sensitive to changes of voltage. For instance if the supply voltage to an incandescent lamp decreases by 6% of rated value, then illuminating power may decrease by 20%. On the other hand, if the supply voltage is 6% above the rated value, the life on the lamp may be reduced by 50% due to rapid deterioration of the filament.

(ii) In case of power load consisting of induction motors, the voltage variations may cause erratic operation. If the supply voltage is above the normal, the motor may operate with a saturated magnetic circuit with consequent large magnetising current, heating and low power factor. On the other hand, if the voltage is too low, it will reduce the starting torque of the motor considerably.

(iii) Too wide variation of voltage cause excessive heating of distribution transformers. This may reduce their ratings to a considerable extent.

With the trend towards larger and larger interconnected system, it has become necessary to employ appropriate methods of voltage control [3]

3 Methods of Voltage Control

In power system, there are several methods of voltage control. In each methods the system voltage is changed in accordance with the load to obtain a fairly constant voltage at the consumer's end of the system**.** Control of voltage levels is accomplished by controlling the production, absorption, and flow of reactive power at all levels in the system. The generating units provide the basic means of voltage control; AVRs control field excitation to maintain a scheduled voltage level at the terminals of the generator. Additional means are usually required to control voltage throughout the system.

The devices used for this purpose are classified as:

- ❖ Sources or sinks of reactive power, such as shunt capacitors, shunt reactors, synchronous condensers, and static var compensators (SVCs).
- ❖ Line reactance compensators, such as series capacitors.
- ❖ Regulating transformers, such as tap-changing transformers and boosters.

In earlier times the voltage control was done by adjusting the excitation of the generator at the sending end. The larger the reactive power required by the load, the more is the excitation to be provided at the sending end. There are limits for the excitation as well. Excitation below a certain limit may result in unstability (if the machine is connected to synchronous load) of the system and excitation above certain level will result in over heating of the rotor. Therefore, in any case, the amount of regulation by this method is limited by the permissible voltage rise at the sending end and by the difficulty of designing efficient generating plant when the range of excitation is so wide. The following are the various ways voltage can be controlled. [4]

(i) Synchronous Compensator

A great advantage of the synchronous capacitor is its flexibility for use for all load conditions because it supplies vars when over excited, that is during peak load conditions and it consumes when under excited during light load conditions.

There is smooth variation of reactive vars by synchronous compensators as compared with step by step variation by the static compensators

Synchronous machines can be over loaded for short periods whereas static capacitors cannot. For large outputs the synchronous compensators are much better than the static capacitors from economic point of view otherwise a combination of shunt capacitors and reactors is required hence costlier and also the control is not smooth as is achieved with synchronous compensator. Synchronous condensers and SVCs provide active compensation; the reactive power absorbed/supplied by them is automatically adjusted so as to maintain voltages of the buses to which they are connected.

(ii) Shunt Capacitor and Reactors:

Shunt capacitors are employed across an inductive load where as reactors are employed across capacitive loads or lightly loaded line. In both cases the effect is to supply the requisite reactive power to maintain receiving-end voltage constant (shunt capacitors across an inductive load supply part of the reactive vars required by the load whereas shunt reactors lines absorbs some of the lagging vars). Capacitors are connected either directly to a bus bar or through a tertiary winding of the main transformer and are arranged along the drops. The drop back of the method of voltage control is that as the voltage falls, the correction vars also falls ie when it is most needed, its effectiveness falls. Similarly, on light loads when the corrective vars requirement is comparatively less, the capacitor output is large. Shunt capacitors and reactors, and series capacitors provide passive compensation. They are either permanently connected to the transmission and distribution system, or switched. They contribute to voltage control by modifying the network characteristics. Shunt capacitors are used to compensate for the XI^2 losses in transmission system and to ensure satisfactory voltage levels during heavy loading conditions. Switching of capacitor banks provides a convenient means of controlling transmission system voltages. The principal advantages of shunt capacitors are their low cost and their flexibility of installation and operation. The principal disadvantage of shunt capacitors is that their reactive power output is proportional to the square of the voltage. The reactive power output is reduced at low voltages when it is likely to be needed most [5]

4 Application to Transmission System

Shunt capacitors are used to compensate for the XI^2 losses in transmission system and to ensure satisfactory voltage levels during heavy loading conditions. Switching of capacitor banks provides a convenient means of controlling transmission system voltage

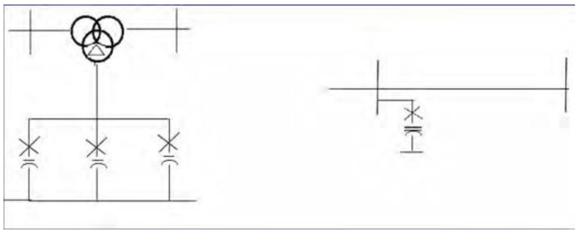

Figure 3 Capacitor bank connections
(a) Tertiary connected capacitor (b) HV Capacitor Bank [6]

(iii) Series Capacitors

Series capacitors are connected in series with the line conductors, as shown in the figure 3.

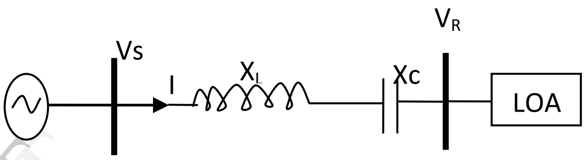

Figure 4 Capacitor connected to Inductor

They reduce the effect of inductive reactance between the sending-end and receiving end of the line. One draw-back of the method is that high voltage is produced across the capacitor terminals when short circuit current flows through them. Therefore special protective devices (such as spark gaps with high speed contactors) are used for the protections of the capacitor under such condition.If the load VAR requirement is small, series capacitors are of little use. With series capacitors the reduction in line current is small. Hence, if thermal considerations limit the current, little advantage is obtained and shunt compensation should be employed. The shunt capacitors improves the power factor of the system whereas the series capacitors have little effect on the power factor. For long transmission lines where the total reactance is high, series capacitors are effective in improving stability of the system.

(iv) Tap Changing Transformer

By changing the transformation ratio, the voltage in the secondary circuit is varied and voltage control is obtained. This constitutes the most popular and wide spread form of voltage control at all voltage levels. Considering the operation of a radial transmission system with two tap changing transformer as shown in the equivalent single-phase circuit of figure 5. Here, t_s and t_r are functions of

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the nominal transformation ratios, (the tap ratio multiply by the inverse of nominal ratio). For example, a transformer of nominal ratio 6.6 to 33kV when tapped to give 6.6 to 36KV has a t_s = 36/33 = 1.09. V_1 and V_2 are the nominal voltages, at the end of the line the actual voltages are T_sV_1 and T_rV_2. It is required to determine the tap changing ratios required to completely compensate for the voltage drop in the line. The product t_st_r will be made unity. This ensures that overall voltage level remains in the same order.

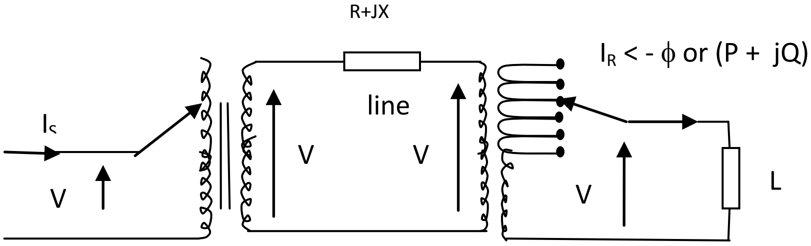

Figure 5a**:** Coordination of two tap changing transformers in a radial transmission link.

Also, the minimum range of taps on both transformers is used.

Note all values are in per unit, t is the off-nominal tap ratio.

Transferring all quantities to the load circuit, the line impedance becomes

$(R + jX)\,t_r^2$, $V_s = V_1t_s$ and as the impedance has been transferred $Vr = V_1t_s$.

The input voltage to the load circuit becomes V_1t_s/t_r and the equivalent circuit is as shown in figure 5c.

The arithmetic voltage drop.

$$= \left(V_1 t_s / t_r\right) - V_2 \;= \frac{RP + XQ}{t_r^2 V_2}$$

where, $t_r = 1/t_s$,

$$t_s^2 V_1 V_2 - V_2^2 = (RP + XQ)t_s^2$$

and

$$V_2 = \frac{1}{2}\left[t_s^2 V_1 \pm t_s (t_s^2 - 4(RP + XQ)\right]^{\frac{1}{2}} \qquad (5)$$

Hence if t_s is specified, there are two values of V_2 for a given value of V_1.

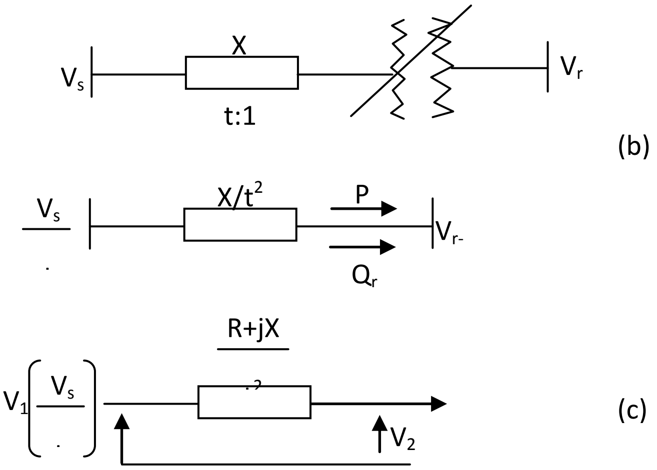

Figure 5 (b) and (c) equivalent circuits for dealing with of nominal tap ratio, (b) single transformer (c) two transformers. [7]

(iv) Booster Transformer

Sometimes it is desired to control the voltage of a transmission line at a point far away from the main transformer. This can be conveniently achieved by the use of a booster transformer as shown in figure 5. The secondary of the booster transformer is connected in series with the line whose voltage is to be controlled. The primary of this transformer is supplied from a regulating transformer fitted with on-load tap-changing gear. The booster transformer is connected in such a way that its secondary injects a voltage in phase with the line voltage. The voltage at AA is maintained constant by tap-changing gear in the main transformer. However, there may be considerable voltage drop between AA and BB due to fairly long feeder and tapping of loads. The voltage at BB is controlled by the use of regulating transformer and booster transformer. By changing the on the regulating transformer, the magnitude of the voltage injected into the line can be varied. This allows to keep the voltage at BB to the desired value. [3]

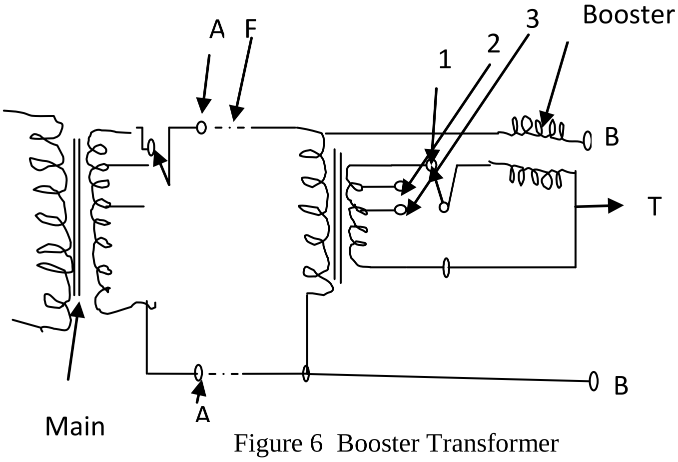

Figure 6 Booster Transformer

(v) Maintainability

System maintenance includes inspection, preventive maintenance and overhaul. Well managed maintenance practices should result in fewer forced outages, win consumer goodwill and lower maintenance costs/KWh of the energy supply. The infrastructure for good maintenance should provide requisite technical training power system operators, supervisors; suitable maintenance and operating manuals; tool kits and maintenance materials. At present, most of the present power system maintenance is carried out as fire fighting, break down maintenance or corrective maintenance. Low tension capacitors at distribution transformers often disconnected, vars equipment allowed to totally breakdown without due attention are the usual violation. If these issues are not given attention , voltage level is drastically affected. **[8]**

The successful implementation of maintenance should be based on the following considerations.

- ❖ The system is well planned, properly erected with good quality material and well trained and adequately equipped maintenance staff.
- ❖ The minor defects noticed during inspection should be rectified at the time of inspection
- ❖ In case of the occurrence of any abnormal situation, the equipment should be immediately disconnected from service and the matter reported to higher authority for further action.
- ❖ A correct record of all test result should be maintained.
- ❖ Maintenance of transformers and its local distribution system should be carried out together to ensure a healthy system.
- ❖ There must be inspection check list to know the areas abnormal voltage . [9]

5 Conclusion

Maintaining adequate voltage level as agreed by standard cannot be overemphasised in any power system network. The three major division in power system network are the generation, transmission and distribution each of these have their roles to play to ensure that quality power is deliver to the end user. To ensure that the customers enjoy quality power supply, the above steps must be in place for effective voltage delivery. One of the most important aspect that causes voltage drop in most cases is lack of maintenance culture. The moment equipment is out of the range of designed specifications, due to lack of maintenance or ageing, the equipment is bound to have negative effect on the entire system. Hence the inclusion of maintenance as a way of improving voltage supplies.

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