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Smart Grid Voltage Regulation: A Necessity for a Safe, Stable and Reliable Power System

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ABSTRACT

Voltage regulation is found on nearly every distribution circuit and it is important to maintain a consistent voltage so that lighting, appliances, motors, and the power system itself can work as efficiently as possible. Distribution grids were originally intended for a one-way distribution of energy from higher voltage levels down to end consumers, but they are now also being used to collect energy generated in decentralized locations and sometimes even to feed it back into the grid from lower to higher voltage levels(smart grids). New kinds of consumers, such as heat pumps and electric cars, in the distribution grid imply new tasks not envisaged when the distribution grids were planned. The Voltage range infringements resulting from the paradigm shift in the grids is the most frequent challenge faced today. Thus, this work examined this challenge on distribution grids and proposed the use of Voltage regulation equipments to monitor and control voltage regulators installed, to enable advanced capabilities such as remote engineering access, built-in logic, and advanced control based on voltage profile, time-of-day, or other dynamic event, etc on the distribution grids.

Keywords: Regulation; Reliability; Interruption; Voltage Level; Distribution Grids

1.0 INTRODUCTION

One of the utility's core responsibilities is to maintain consumer's terminal voltage within a suitable range. Hence the utilities must regulate the voltage subject to economic as well as technical considerations. The voltage drop in distribution circuits occur due to current flowing through the line impedances. Voltage drop is higher with lower voltage distribution systems, poor power factor, single-phase circuits, and unbalanced circuits. Electric utilities commonly use both voltage regulators and shunt capacitors to maintain voltages within the specified limits. The shunt capacitors operate in discrete steps while voltage regulators are transformers with variable taps. The voltage change is obtained varying the tap position by a control circuit in the case of voltage regulators. Thus a voltage regulator is used to hold the voltage of a circuit at a predetermined value, within a band which the control equipment is capable of maintaining and within accepted tolerance values for distribution purposes. Voltage Regulators (VR) may be installed at substations or on distribution feeders on poles, pads, or platforms or in vaults. The shunt capacitors can be fixed or switched type; they are considered integer multiple of a capacitor unit. Regulators have fixed nodal position for all load levels and are characterized by pre-assigned discrete sizes.

2.0 CONTROL OF GRID VOLTAGE REGULATION

To keep distribution-circuit voltages within permissible limits, means must be provided to control the voltage, either to increase the circuit voltage when it is too low or to reduce it when it is too high. There are several ways to improve the system's overall voltage regulation.

- Use of generator voltage regulators.
- Application of voltage-regulating equipment in the distribution substations.
- Balancing of the loads on the primary feeders.
- Increasing of primary voltage level.

Voltage regulation is carried out to maintain a fixed voltage under different load. Voltage regulation is a limiting factor to decide the size of either conductor or type of insulation.

Due to the development of Distributed Generation (DG), which is installed in Medium-Voltage Distribution Networks (MVDNs) such as generators based on renewable energy (e.g., wind energy or solar energy), voltage control is currently a very important issue.

The voltage of MVDNs is now regulated acting only on the On-Load Tap Changer (OLTC) of the HV/MV transformer.

The OLTC control is typically based on the compound technique, and this method does not guarantee the correct voltage value in the network nodes when the generators deliver their power.

When a generator injects power in the network, the voltage tends to rise. In HV networks, this phenomenon happens mainly when reactive power is injected, because the resistance is negligible if compared with the inductive reactance. Instead, in MVDNs the resistance is not negligible and the result is that an injection of active power also increases the voltage.

2.1 Load models

In power flow studies, the common practice is to represent the composite load characteristic as seen from power delivery points. In transmission system load flows, loads can be represented by using constant power load models, as voltages are typically regulated by various control devices at the delivery points.

In distribution systems, voltages vary widely along system feeders as there are fewer voltage control devices; therefore, the V–I characteristics of load are more important in distribution system load flow studies.

Load models are traditionally classified into two broad categories:

- Static models and
- Dynamic models.

Dynamic load models are not important in load flow studies while static load models, on the other hand, are relevant to load flow studies as these express active and reactive steady state powers as functions of the bus voltages (at a given fixed frequency). These are typically categorized as follows:

- Constant impedance load model (constant Z). A static load model where the power varies with the square of the voltage magnitude. It is also referred to as constant admittance load model.
- Constant current load model (constant I). A static load model where the power varies directly with voltage magnitude.
- Constant power load model (constant P). A static load model where the power does not vary with changes in voltage magnitude. It is also known as constant MVA load model.

3.0 VOLTAGE REGULATION AND POWER FLOW EQUATIONS

Power flow studies are of great importance in planning and designing future expansions of power systems. The main information obtained from power flow studies is the magnitude and angle of the phasor voltage at each node, and the real and reactive power flowing in each line. With this information, the voltage regulation of any feeder in the system can be easily computed.

3.1 Power Flow

In general, if a node in a power system is considered, the following equations can be readily written by considering the real and reactive power balance:

Pk = Pgk − PLk,
Qk = Qgk − QLk

Where Pgk and Qgk are the real and reactive power generated at node k; PLk and QLk are the real and reactive power loads at node k, which could be constant or a function of the bus voltage magnitude; and Pk and Qk are the real and reactive power injected into the system.

3.2 Voltage Regulation

Once a load flow solution is obtained, the voltage regulation of any feeder can be calculated as follows:

$$V_{Reg.} = \frac{Vs - Vr}{Vr} \times 100.$$

Where Vs is sending-end voltage and Vr is receiving-end voltage.

In distribution systems, this regulation may be typically improved by using one or more of the following techniques:

- Increased size of feeder conductor.
- Transferring loads to new feeders.
- Activating voltage regulating equipment at the substations bus such as capacitors or LTCs.
- Increasing primary voltage.
- Balancing of loads on primary feeders.
- Installing new substations and primary feeders.
- Installing shunt capacitors or SVCs on primary feeders.

The most economical way of improving voltage profiles along a feeder, and thus voltage regulation and overall system performance, is by using shunt capacitors.

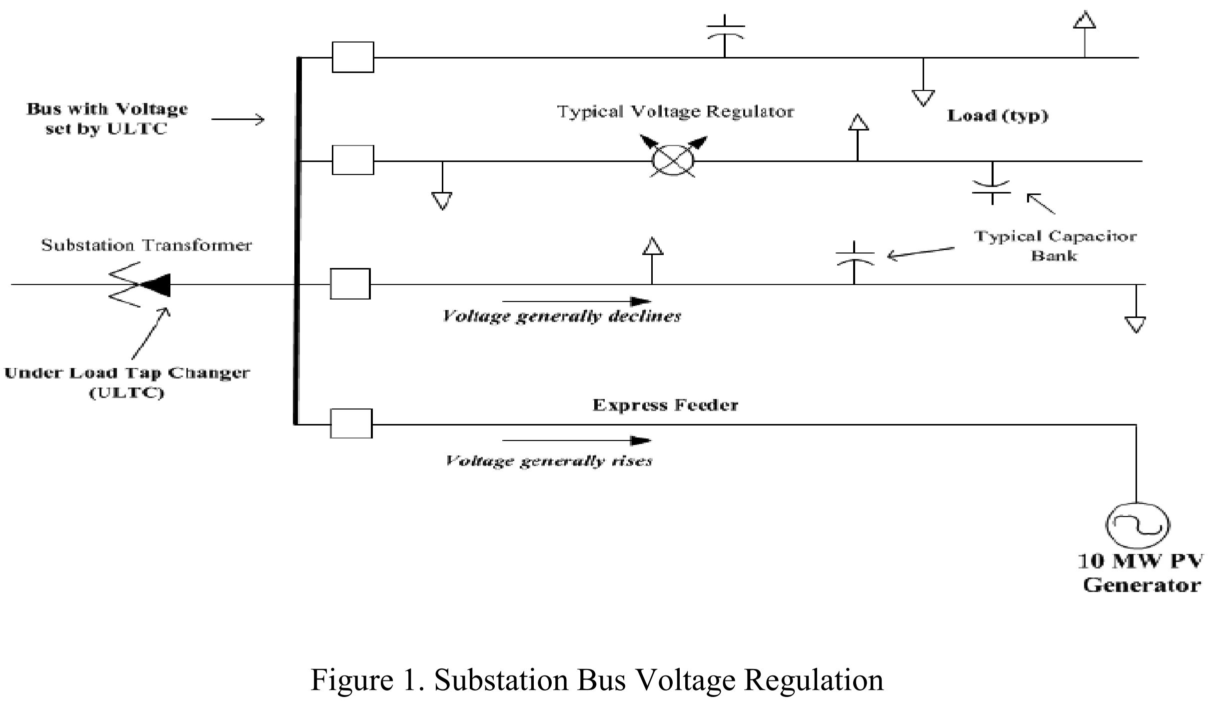

Figure 1. Substation Bus Voltage Regulation

Shunt capacitor compensation improves system voltage regulation for all types of loads. However, different sizes of shunt capacitors are required for different types of static load models to achieve proper voltage regulations. By properly selecting the load models, efficient designs can be obtained for var compensation in distribution systems.

4.0 COMPLICATIONS DUE TO DISTRIBUTED GENERATION

Distributed generation, in particular photovoltaics connected at the distribution level, presents a number of significant challenges for voltage regulation.

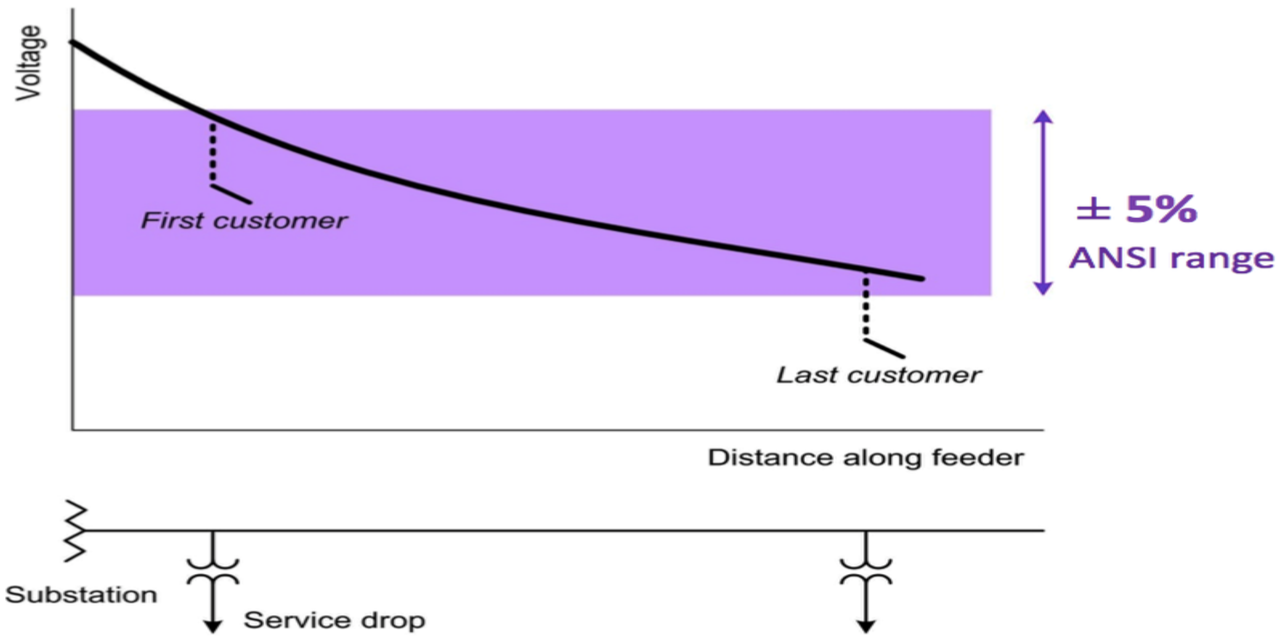

Figure 2. Typical voltage profile expected on a distribution feeder with no DG.

Conventional voltage regulation equipment works under the assumption that line voltage changes predictably with distance along the feeder. Specifically, feeder voltage drops with increasing distance from the substation due to line impedance and the rate of voltage drop decreases farther away from the substation. However, this assumption may not hold when DG is present. For example, a long feeder with a high concentration of DG at the end will experience significant current injection at points where the voltage is normally lowest. If the load is sufficiently low, current will flow in the reverse direction (i.e. towards the substation), resulting in a voltage profile that increases with distance from the substation. This inverted voltage profile may confuse conventional controls. In one such scenario, load tap changers expecting voltage to decrease with distance from the substation may choose an operating point that in fact causes voltage down the line to exceed operating limits.

5.0 CONCLUSION

Power quality problems ultimately affect the end user due to different voltage levels caused by distributed generation. However, there are many other parties involved in creating, propagating, and solving power quality problems. Power quality standards must provide guidelines, recommendations, and limits to help assure compatibility between end use equipment and the system where it is applied.

There is active interest in this country as well as the rest of the world to establish power quality standards to deal with these problems by the modification of the smart grid voltage regulation.

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