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CIGRE US National Committee
2013 Grid of the Future Symposium

VOLTAGE CONTROL IN MEDIUM VOLTAGE LINES WITH HIGH PENETRATION OF DISTRIBUTED GENERATION

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SUMMARY

Managing the voltage profile within acceptable parameters along Medium Voltage lines is a recurrent problem in electricity distribution grids. In addition to the traditional problems of varying load and environmental conditions influencing the voltage levels we now have the addition of distributed generation systems (DG). These systems, which are growing in importance nowadays, render the original design calculations (based on voltage drops in line elements in a radial topology) as invalid.

Smartgrid deployments in dense urban distribution networks include the installation of monitoring, control and communication in every secondary substation. As a result of this, the information about the status of each MV line is available at the utility SCADA or Distribution Management System (DMS). On the other hand, in suburban and rural areas it is less common to have an extensive coverage of monitoring nodes, due to the cost and the fact that the MV/LV transformers are smaller in size and pole mounted, without needing a secondary substation. However, rural and suburban MV lines are where distributed generation, in many of its forms, will have greatest presence. These generators may produce more power than the average line power, and this can result in significant voltage swings in the lines, when for example, high generation is combined with light load (or the opposite condition). As a result of this, the status of MV lines in areas with a strong presence of distributed generation is challenging to manage.

This technical article proposes a system to mitigate this problem by integrating technologies for MV monitoring, control, communications and metering which are already available today. Firstly, a detailed technical description is provided, and then the feasibility of the proposed solution is analyzed in certain scenarios and MV network topologies. Finally the limitations, implementation options and expected performance are described.

KEYWORDS

Distributed, Generation, Algorithm, Control, Voltage, Tap, Changer, Load, PLC, DLMS, PRIME.

1. INTRODUCTION

In order to solve the problem of stabilizing voltage levels in radial MV lines with high penetration of distributed generation, a conceptually simple and easy to implement system is proposed, using technology and devices which are already available for other purposes. This system controls the voltage level at the MV substation by means of an automatic On Load Tap Changer (OLTC), controlled by a Remote Terminal Unit (RTU). The RTU not only controls the OLTC, but also obtains the voltage levels at defined points along the MV line, and executes the required algorithm to control the OLTC. Voltage measurements can be obtained using smart meters distributed in the LV domain, mounted in the secondary side of MV/LV transformers where the distributed generation is connected to the grid. These smart meters will be polled within a fixed period, in the order of 1 minute. This requirement comes from the fact that photovoltaic-based distributed generation may change its output significantly (10% to 90% in several seconds), in the presence of partly cloudy skies with intense solar radiation.

Distributed measurements can also be obtained from the MV, (indirectly via Current Transformers / Voltage Transformers). In order to obtain the measured values, a protocol based on the standard IEC EN62056-1-0, Electricity Metering Data Exchange (DLMS / COSEM) (Device Language Message Specification / Companion Specification for Energy Metering) [2] is proposed, as it is the de-facto standard for smart meters in Low Voltage in many regions of the world. The system as proposed does not interact with generators, and as such it has some limitations, but on the other hand its technical feasibility and overall implementation viability is superior, as it is fully contained within the electricity distribution company and its infrastructure.

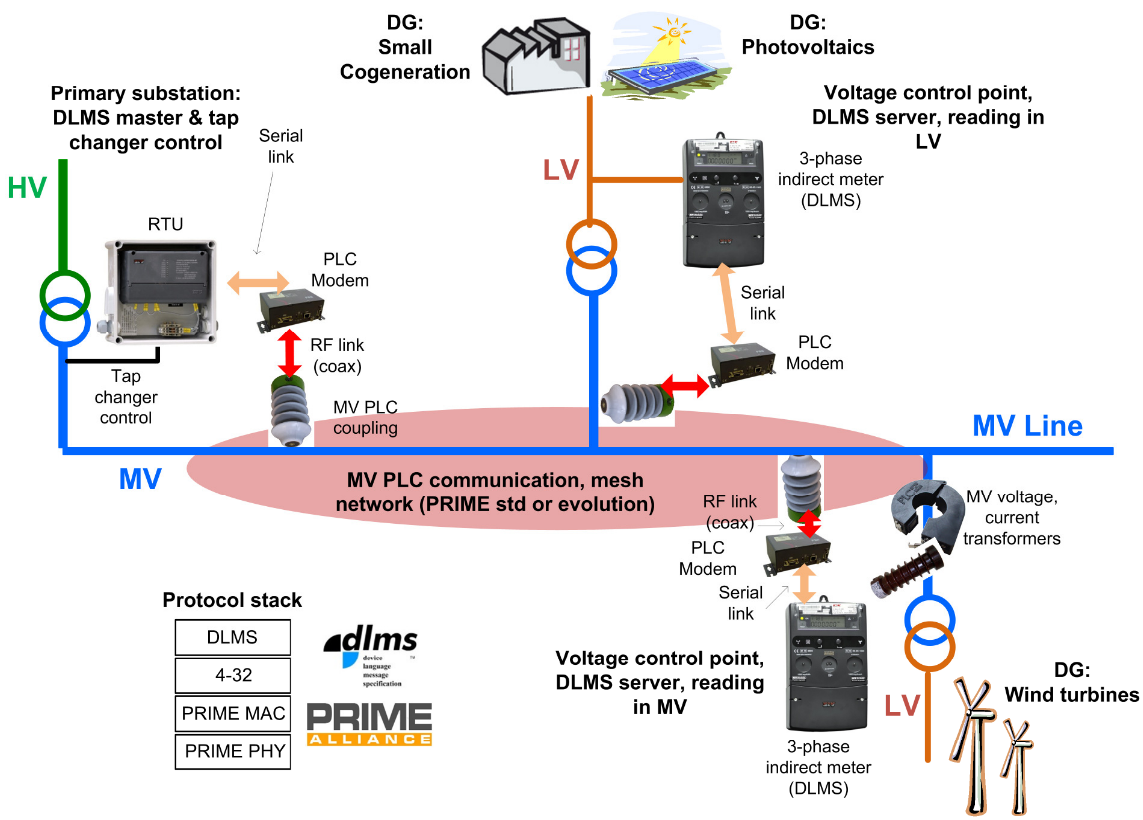

Figure 1. Voltage control system for MV lines with high penetration of DG

2. MEASUREMENT ACQUISITION

Measurements at the distributed nodes along the line can be obtained in two different ways:

- Low Voltage Measurements, obtained directly with a standard three-phase smart meter. In this case the measurement used in the algorithm must be multiplied by the transformation ratio of the MV/LV transformer for the particular location. This system allows the use a much simpler and cost effective measurement device. Although the measurement may not be as accurate due to the transformation ratio multiplying the base error, it can be sufficient for the proposed algorithm.
- Medium Voltage measurements, obtained indirectly using an intermediate voltage transformer connected to an indirect three-phase smart meter. In this case the measurement used for the control algorithm is the same as the one directly captured by the device and has better accuracy (1% or better). However, the cost of the equipment at each measurement point is significantly higher.

In either of the proposed mechanisms, the equipment used in each measurement point is entirely off the shelf. This results in a significantly lower total cost for the proposed solution due to the economy of scale derived from the reuse of equipment from other measurement applications. The required measurement accuracies must be consistent in all the distributed control nodes; typically 0.5%.

One of the key aspects in validating the proposed solution is that the synchronization of the system must be sufficiently accurate, in the order of subcycle precision. That is, the algorithm should be able to use timestamped voltage measurements, to make decisions based on comparable measurements acquired within a reasonably short time window. This requires time synchronization of the measurement points (meters) with the same clock used by the RTU that runs the algorithm for the OLTC control. Although DLMS / COSEM systems incorporate a timing mechanism, the precision may not be sufficient. Typically this depends on the latency of the point to point PLC communication network and it is generally in the order of one or more seconds. However more precise synchronization mechanisms are proposed [1] which allow improved synchronization accuracy to subcycle values of around a millisecond which more than satisfies the requirements of this system.

In order to obtain the measured values, a protocol based on the standard IEC EN62056-1-0, Electricity Metering Data Exchange (DLMS / COSEM) [2] is proposed, which is widely accepted in new metering systems. This protocol may be somewhat heavy considering the size of messages that must be sent using a limited bandwidth communication channel, but given the size of the proposed system this does not present any real limitation (see analysis in section 5).

3. COMMUNICATION BETWEEN SYSTEM ELEMENTS

A very interesting alternative for telecommunications for this voltage control application is to use PLC communications (powerline communications) over the Medium Voltage wires. PLC communications is an attractive alternative for utilities for two reasons [3]:

i. It allows them to have full control of the communications infrastructure.
ii. A large investment is not necessary because it reuses the electrical distribution infrastructure as telecommunications infrastructure.

For many years, High/Medium Voltage lines have been used to carry voice and data services using wave carrier communications technology.

The architecture of the proposed communications system is shown in Figure 2. It comprises one master node, which could be part of the substation automation system, and slave nodes at each MV location where control is required (principally those with distributed generation).

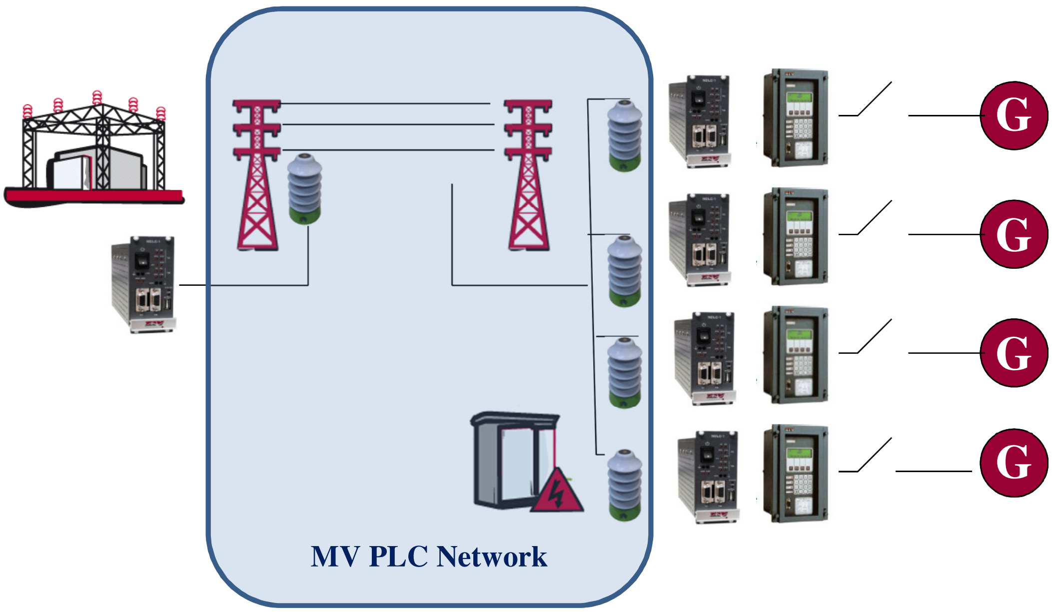

Figure 2. Communications Architecture using Medium Voltage PLC.

Communications nodes to be deployed along the Medium Voltage line should provide two types of telecommunication services:

- "Telemetering" Service for transporting data V, P, Q collected by meters (Low or Medium Voltage)
- Fast Signals. Sending fast signals between Medium Voltage installations that are on the same substation feeder to facilitate safe operation of distributed generation that is connected to the same Medium Voltage segment.

MV Communications PLC can carry these services using quality of service techniques that will properly manage the traffic priorities depending on their importance.

The network topologies found in Medium Voltage distribution are quite varied, so the proposed solution must accommodate these variations. Where some slave communication nodes have no direct connection to the master node, it is necessary for intermediate slave nodes to act as repeaters as well as carrying the associated services for their own location (telemetering and fast signals).

There already exists, various technologies in the more complicated Low Voltage distribution environment which demonstrate the viability of using PLC as an effective communications network. A key example is the PRIME technology [4] which enables a central point (in this case the concentrator installed at the secondary substation) to manage hundreds of meters over PLC communications. The PLC communicates both status/measurements and open/close commands (switch integrated in electricity meters). Just as in our Medium Voltage application, many meters in LV networks do not have a direct connection to the meter concentrator, so, those that have direct connection must operate as repeaters for those that don't.

In conclusion, both the experiences of PLC communications in HV and EHV cables and the experiences of using the PLC as a telecommunications network in LV grids, confirm the feasibility of using PLC communications at MV to enable voltage control applications as described in this article.

4 ALGORITHM FOR VOLTAGE CONTROL

Maintaining the voltage level within defined limits is one of the major concerns for utilities, especially due to the increasing deployment of distributed generation (DG). Distributed generators can produce voltage increases in excess of the limits of the Medium Voltage grid, thereby presenting a risk to consumers' equipment and the grid itself.

The factors that determine the changes in the voltage profile of the distribution network are the loads, the line impedances, the power generated by the DG and the distance from the DG to the substation. In fact, one of the greatest barriers to the integration of DG in distribution networks is the increase in voltage that is generated by the additional power injected onto the grid.

The equipment currently available in the distribution network for voltage control is not sufficient to manage the increased penetration of DG, making it necessary to install new devices that allow remote control of the DG and provide voltage measurements at relevant points on the distribution grid.

An intelligent proposal for integrating DG is to provide specific solutions for each generator and key points on the grid. These solutions require the installation of equipment for obtaining measurements, control of distributed generators, and communication systems to the primary substations or to a centralized Distribution Network Control System. We consider five different alternatives to implement solutions to the proposed problem [5] [6]:

- Automatic disconnection of DG
- Local control of voltage
- "Decoupling" voltage
- Coordinated voltage control
- Distributed voltage control

Table 1 shows the different assets used in each of the alternatives. This paper proposes the use of "Distributed voltage control" for its simplicity and performance, although we will explain briefly each of the alternatives.

Alternative	Asset			
	OLTC	DG	Loads	Decoupling elements
Automatic disconnection	Fixed setpoint	-	-	-
Local control of voltage	Fixed setpoint	✓	-	✓
“Decoupling” voltage	Fixed setpoint	-	-	✓
Coordinated voltage control	Variable setpoint	✓	✓	✓
Distributed voltage control	Variable setpoint	-	-	✓

Table 1. Alternatives for Voltage Control

Automatic disconnection of the DG
This is the solution that is being used currently and it is based exclusively on the use of an on-load tap changer (OLTC) in primary substation. If the voltage limits are still exceeded after the action of the OLTC, the DG will automatically disconnect through its overvoltage protection.
Advantages: Well proven solution.
Disadvantages: Limited capacity to integrate DG

Local control of voltage
In this alternative, in addition to the use of the OLTC as in the traditional method, some generators locally control the voltage by controlling the P and Q generated.
Advantages: Easy to implement, control of P and Q is available in many DG, and it is scalable.
Disadvantages: It is difficult to choose which DG to control, and there is no coordination between the control elements.

Voltage “Decoupling”
This alternative uses established devices like the OLTC and automatic voltage regulators to "decouple" the voltage between points on the network.
Advantages: Isolates problematic areas.
Disadvantages: Inflexible and difficult to scalable.

Coordinated voltage control
This alternative is the most complex control mechanism of all possible solutions described.
A control device controls both the OLTC at the primary substation and the generators that are part of coordinated control scheme. This control is based on measurements received from: critical nodes on the network, the primary substation and the distributed generators.
Advantages: This is a coordinated efficient system, making effective use of all resources, and it is scalable.
Disadvantages: It is a complex system, with significant requirements for the communications system, and requires careful selection of the critical nodes and the controllable DGs.

The last option to be described is the solution proposed by this paper. It is the **distributed voltage control**.

In this option, either an RTU or an automatic voltage regulator (AVR) installed in the primary substation controls the OLTC based on the real time voltage values measured in the substation and in certain critical network nodes (see figure 3).

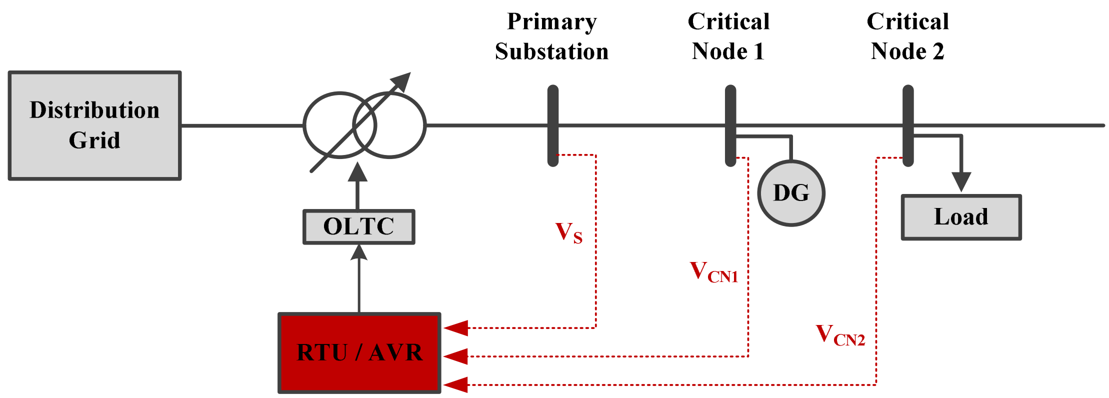

Figure 3. Distributed Voltage Control

In case a voltage deviation crosses the operational thresholds in any monitored node, the OLTC will change the transformer tap position. In case the detected voltage level is outside the limits in more than one monitored node, and the deviations are in opposite directions, the control algorithm will not operate.

The algorithm is designed to maintain the MV voltage level within certain pre-defined limits in steady-state which proposes a control cycle operating in the order of minutes. Special care must be taken when choosing the location of critical nodes. Based on Grid topology studies, critical nodes should be selected to ensure, as much as possible, that maintaining the voltage levels within limits at these critical nodes, will maintain the voltage within limits across the whole network.

This solution involves a telecom infrastructure between the critical nodes and the RTU controlling the OLTC with some specific requirements in terms of latency and throughput so that all voltage measurements are received in time by the AVR/RTU.

Advantages: This option is simple and scalable.
Drawbacks: It requires a telecom infrastructure and its performance depends on the grid topology.

5. SYSTEM PERFORMANCE

In order to analyze the feasibility of the proposed solution, some calculations will be presented below to assess the system performance. The OLTC control algorithm is expected to operate with a control cycle in the order of minutes so for the purposes of this we will define the worst case scenario where the OLTC voltage control algorithm is run every minute.

This means that the RTU/AVR will gather all the voltage levels from all the critical nodes every minute, referenced with the same instance in time so the calculations can be performed inside the same cycle.

The performance of the telecoms infrastructure will depend on both, the telecoms technology and the number of nodes involved in the system. If we use powerline telecoms based on PRIME, the most robust modulation mode provides up to 20kbps (physical layer) which provides an application data rate of about 3kbps in real terms (application level).

The exchange of information necessary to obtain the instantaneous timestamped voltages with Protocol DLMS/COSEM is an exchange of information in the order of 160 bytes (approx. 1.6 kbits). The typical latency of these systems with standard meters is in the order of 300ms. Therefore, at a data rate of 3kbps, the required information can be collected in less than one second (approx. 800ms).

This implies that the proposed system, operating in a one minute cycle could obtain the voltage levels from about 60 – 80 critical nodes, which is a high number for an MV feeder.

Therefore, the proposed system is adequately dimensioned to ensure its functional feasibility.

6. CONCLUSIONS

Main conclusions derived from our work are:

- It is possible to implement complex grid applications such as, the voltage level control in lines with high-penetration of DG, based on products and technologies already available in the market (COTS).
- The proposed system meets the technical requirements of the application, and at a significantly lower cost to other systems, as it is based on existing products and technologies already in the market
- Management of the voltage in MV lines with presence of distributed generation is a growing problem and will probably be even more important in the coming years due to the grid evolution. This will require an update to the distribution infrastructure, since the current network was not designed for bi-directional energy flow.

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