VOLTAGE CONTROL STRATEGY IN WEAK DISTRIBUTION NETWORKS WITH HYBRIDS GENERATION SYSTEMS

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ABSTRACT

In radial and structurally weak systems, the number of variables on which depends the voltage control process is very large. Even more if it contains hybrids generation systems. For this reason it is analyzed an automatic control mechanism that frees the system operator of to evaluate all control actions that optimize the process in real time.
From the analysis of the relative impact that each control action has on voltages of the nodes, a technical and economical optimization algorithm is implemented.

INTRODUCTION

The structural characteristics of electrical systems can take many variants. In the case of very large geographic areas, such systems are usually developed with long radial configurations. In consideration of this particularity, the biggest challenge from an operational point of view is the "voltage control" in each of its nodes.

The network integration of distributed generation (DG) adds control elements to traditional equipment, reactive power compensation and the taps changers in transformers. Therefore, if the generation park is comprised of manageable plants (turbo generators, moto generators, etc.) and unmanaged plants (photovoltaic or wind), the voltage control process optimization requires a hierarchical multivariable coordination in real time.

The aim of this work is to define the voltage control strategy in the electrical system through coordination of actions on all elements that can participate in optimizing voltage levels while minimizing operating costs thereof.

CONTROL STRATEGY

In addition to the frequency, voltage must also be kept within defined limits, especially in distribution due to the high negative impact on customers at that level and then at low voltage.

This paper proposes to apply a control strategy based in static voltage maintenance by injecting or absorbing reactive power inherent in each of the network components as well taps changers of the HV/HV and HV/MV transformers.

Figure 1 shows a generic network that will serve to describe the control system is shown.

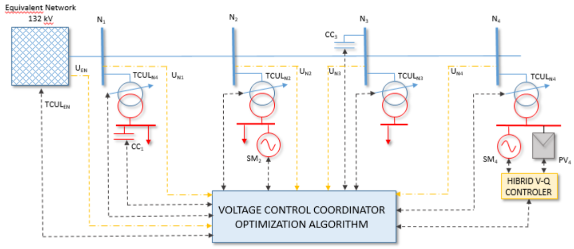

Figure 1: Control Strategy. Monitoring variables and actions on components.
(EN: Equivalent Network, TCUL: Tap Changer Under Load, CC: Capacitive Compensation, SM: Synchronous Machine, PV: Photovoltaic Plant)

For the formulation of the algorithm, on what control strategy is based, it is necessary to first define hierarchies of control. The classification is based on whether the action on the control variable has general or partial effect on the system. For example, raising the voltage to the limit regulation band in the Equivalent Network (EN) node involves an increase in the profile of all nodes in the system. Moreover, uploading a tap on the T_{CULN3} circumscribe the action to the station node in 13.2 kV. Finally, a greater contribution from the hybrid system SM_4-PV_4 involves improving the voltage at node N_4, but also in the adjacent previous $N_{3.}$

Therefore:
Hierarchical Level 1 (HL1) taps changer of power transformer NE. It affects all system nodes.

Hierarchical Level 2 (HL2): SM_2 distributed generation plants and hybrid plant synchronous generator + PV (SM_4 + PV_4) of N_4. We will also include in this capacitive compensation CC_3. It affects some nodes of the system.

Hierarchical Level 3 (HL3): medium voltage capacitive compensation CC_2. This affects the system node in which said compensation is connected. This level will also include taps changers HV-MV transformers.

Conceptually, there is an optimization algorithm receiving the voltages nodes from field (remote terminal unit in substations), the state of capacitive compensators, the position of tap changers transformers and active and reactive power injected by the plants.

With this information, runs automatically control actions based on hierarchical levels mentioned above optimizing the voltage profiles of each node at the lowest operating cost.

PROBLEM FORMULATION

The mathematical formulation corresponds to a general numerical optimization problem with constraints:
Objective Function optimize: f (u, x)
Held on to the restrictions:

$$g (u, x) = 0 \text{ y } h (u, x) \geq 0$$

Where:
- u represents the control variables of the system.
- x denotes the set of state variables or system dependent.
- g (u, x) represents equality constraints such as load flow equations,
- h (u, x) includes the inequality constraints, such as the physical limits of the control variables and the operating limits of the system units.

The control variables used are: active and reactive power output of generators, including PV hybrid system, taps regulating transformers including the source node and reactive power of capacitive compensation banks.

The most representative state variables are: the voltage modules across the nodes of the system and the power transmitted by the lines.

The considerated restrictions are:
- Pmax, Qmax y Qmin of the generators
- Umax y Umin of each node
- TAP max y TAP min voltage regulators transformers (AVR)

The following hypotheses are also considered:
- Automatic voltage regulator transformers are normally enabled. Thus, if the profile in the high voltage level is adequate, regulation is secured in medium voltage.
- The high voltage capacitive compensation is normally connected, except in periods of low demand. Also the compensation capacitor banks of each medium voltage transformer station are normally connected. They may not be applicable in periods of very low demand in order to reduce distribution profiles.
- PV plant will be connected and disconnected automatically depending on the insolation characteristics corresponding to solar hours of every year period. It is also considered the hypothesis that these kind of plants have dispatch priority into of system generators compared to conventional thermal plants.
- Synchronous generators may be dispatched by general requirements system or by request of the regional network operator.
- From the economic point of view, the optimization is achieved leaving synchronous generators as a last resort because its action involves fuel consumption and therefore higher operating costs.

SIMULATION OF CONTROL SHARES

Based on all the above hypotheses in the problem formulation, we proceed to determine the effect of the network components on each voltage of node. For this, simulations of system status with NEPLAN electrical applications software are made.

First, switching taps in the source node for a peak demand scenario are analyzed, which implies the most unfavorable condition as far as regards voltage profiles.

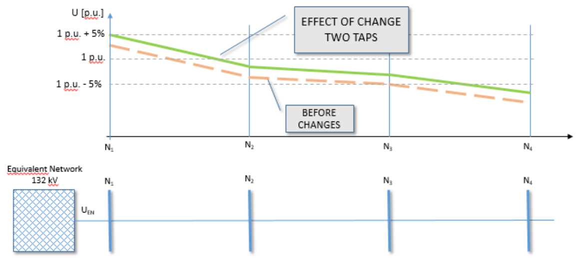

Figure 2: Effect of change stop at node NE Equivalent Network (source node).

Thus, the effect of the action of the component on which they acted in relation to the voltage profiles are measured for each node.

Figure 2 shows how all the voltages of nodes change, which confirms that this action belongs to the hierarchical level 1 (HL1) control.

Similarly, the impact compensator connection Capacitive CC_3 is simulated.

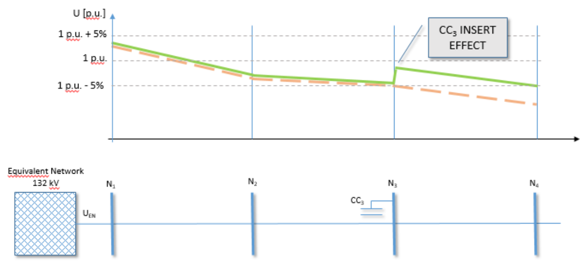

Figure 3: Effect of the insertion of the capacitive compensator CC_3.

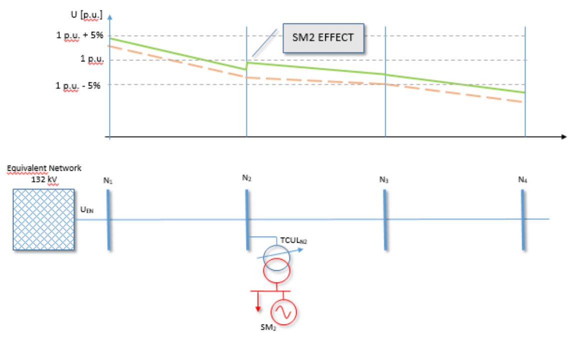

Figure 4: Effect of the insertion of DG.

A fundamental point to be determined from the simulations is the order in which conventional generators will be dispatch, considering the fact that their contributions have effect on the voltage profile of each node. In a radial topology, the generators located at the end of the system, will produce a greater increase in the voltages of the nodes relative to those located closer to the source node.

CONTROL OF THE HYBRID SYSTEM SYNCHRONOUS MACHINES + PV PLANT

With specific regard to the voltage control in the hybrid system SM4 + PV4, three variants for optimal reactive power supply are used. These alternatives are part of the management functions of the inverter.

a) The prescription of the fixed reactive power. This means that a reactive power value or between power factor cos (φ) = 0.90 inductive and cos (φ) = 0.90 capacitive is indicated.

b) Dynamic prescription of the reactive power. In this case, a dynamic power factor is set, as any value between cos (φ) = 0.90 inductive and cos (φ) = 0.90 capacitive.

c) Regulation of reactive power through a characteristic curve. Here, reactive power or power factor is regulated by a predefined characteristic, depending on the active power fed into the grid or the grid voltage.

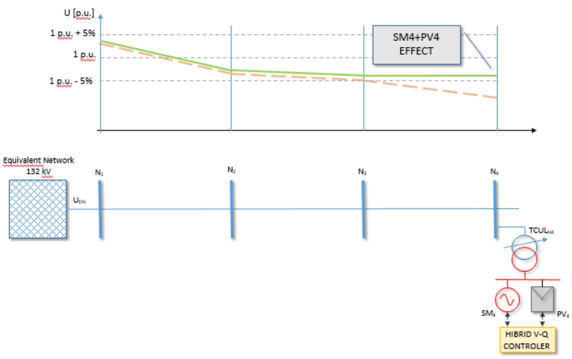

Figure 5: Effect of the insertion of the hybrid plant.

Figure 6 shows the combined effects of all actions of control.

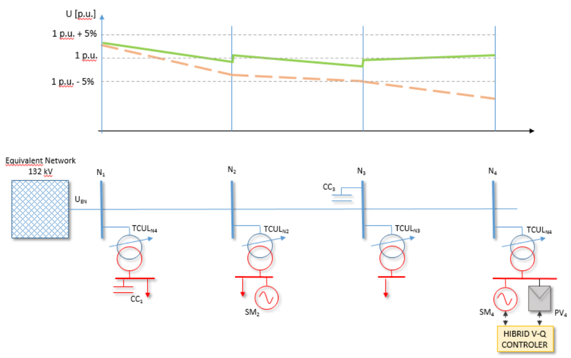

Figure 6: Effect aggregated to all network components.

DESCRIPTION OF THE ALGORITHM

Based on the hypothesis, that give frame to the control strategy formulation and simulation results, it is conceptually define an algorithm that optimizes technically and economically the process of voltage control in weak radial systems with hybrid generation. (See Figure 7).

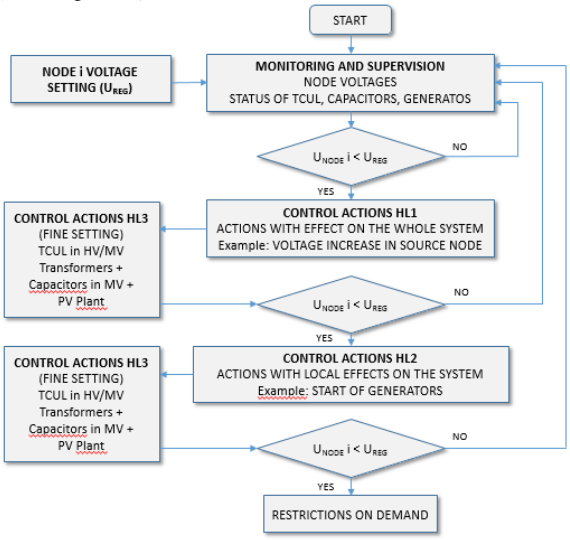

Figure 7: Conceptual Control Algorithm

APPLICATION CASE

Figure 8 shows the topological characteristics of the radial 132 kV grid that covers the center-west of the province of Santa Fe. In it, the voltage levels of each node are identified and all the elements that participate in the voltage control process.

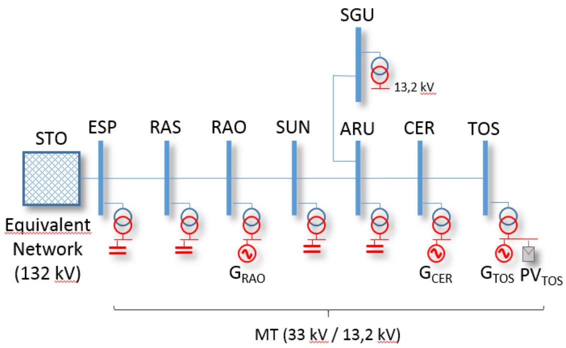

Figure 8: Network topology of study case

RESULTS OF THE IMPLEMENTATION

If the voltage level of 132 kV is maintained for all demand scenarios in the band of ± 5% regulation, the automatic voltage regulators transformers will maintain medium voltage profiles, also in operating margins.

The coordination algorithm monitors all voltages 132 kV. Being line end, the CER and TOS nodes will be the first to experience low voltages with increasing demand.

From the decrease in voltage 132 kV and in order to ensure medium voltage operating voltages, the monitoring algorithm will check if regulation taps exist at the STO source node (Figure 9).

If so, it will order an increase the voltage in that node. This action corresponds to the hierarchical level HL1 Control and it will repeat until only have two taps of regulation. (see Figure 3).

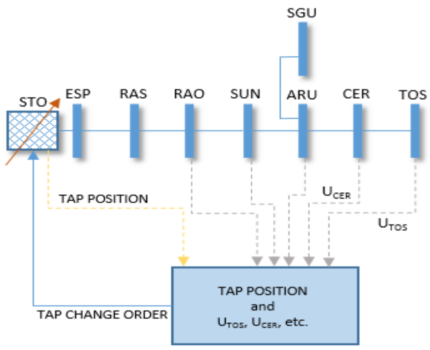

Figure 9: Hierarchical Level Control 1

In that situation, the next hierarchical level (HL2) is activated. First, the capacitive compensation bank of ARU with 7.5 MVAr at level 132 kV is connected . Complied with the above, starting of central motor generators Tostado (TOS) is ordered.

Thus, injection of these equipments and the PV plant will have on the bus of this transformer station. For controlling the hybrid plant, inverter function is adopted, which allows a fixed injection of reactive power to a power factor cos (φ) inductive = 0.95. This reduces the number of operations with inverter capacitors as well as the resulting voltage variations on MV.

TOS generating station has priority in the dispatch order because the load flow simulations performed with the software NEPLAN shows that injection of 1 MW at that node has the same effect on increasing the voltage that dispatching 2 MW in CER and 5 in RAO.

Both control actions HL1 and HL2 are accompanied by fine tuning which performed by HL3. Thus, it achieves to smooth voltage variations so that they are imperceptible to sensitive equipment (digital control).

CONTROL ACTIONS	VOLTAGE NODE (kV)								
	STO	ESP	RAS	RAO	SUN	ARU	SGU	CER	TOS
U_{STO} = 132 kV (NO CONTROL ACTIONS)	132	126,2	105,5	103,8	98,7	90,6	89,7	88,8	87,2
U_{STO} = 138,6 Kv (HL1+HL3)	138,6	133,6	116,1	114,7	110,6	104,3	103,5	102,8	101,6
ARU Compensation (HL2+HL3)	138,6	134	118,2	116,9	113,7	109,5	108,7	108,2	107
TOS Generation (HL2+HL3)	138,6	134,8	121,6	121	119,3	118,4	117,7	118,1	118,6
CER Generation (HL2+HL3)	138,6	135,4	125,2	124,4	123,4	123,8	123,1	124,3	124,9
RAO Generation (HL2+HL3)	138,6	135,9	128,3	127,7	126,9	127,5	126,9	128,1	128,6

Table 1: Effect of each control operation on the voltages

In Table 1 the effects of each control share, on the broker node voltages can be observed.

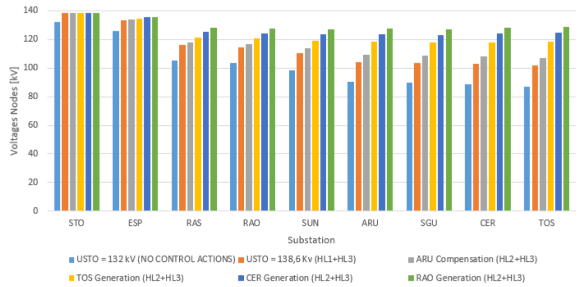

Figure 10: Result of each control operation

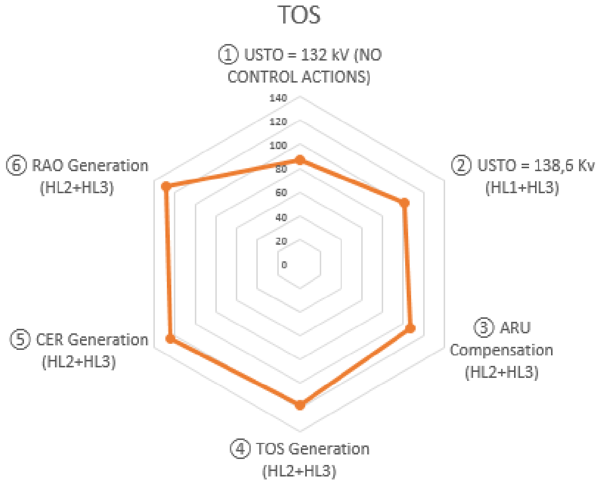

Figure 11: Result of each control operation in TOS node

As far as physical implementation regards (Figure 12), the algorithm is activated by events such as state changes on monitored switches, application Control Center, etc. or runs on a periodic base every 10 minutes for optimization purposes.

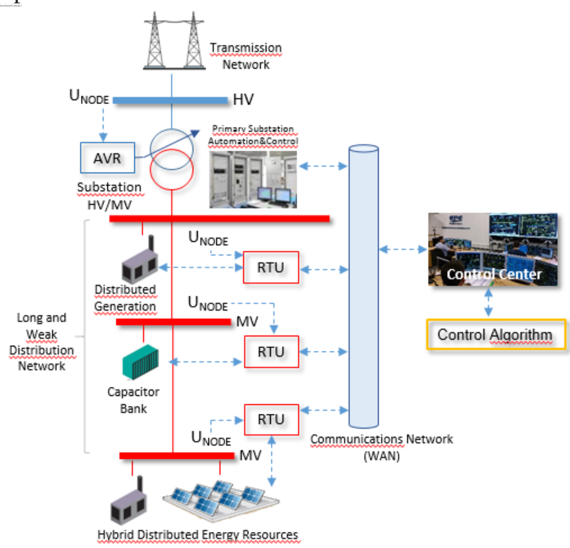

Figure 12: Physical scheme of the implementation

CONCLUSIONS

The tasks to be performed by operators in control centers are becoming increasingly complex. The integration of hybrid systems for generating electricity modifies the characteristics of traditional networks.

The implemented system provides an indispensable tool to control the tension in long radial systems where structural weakness becomes much more sensitive to voltage profiles.

Figure 10 shows the increased voltage node of the system after each of control action performed by de automatic coordination algorithm.

Figure 11 shows the effect of each control in the affected node (TOS) and validates the importance of injecting hybrid power generation system.

The proper performance of the functions of integrated network management belonging to the investor associated with the hybrid system is observed. The reactive power adjustment and limitation of active power according to the frequency of the network are checked.

The control actions implemented through the developed algorithm can reduce up to 50% operator tasks. Similarly, the time when the voltage of each node remains within the control band grew up to 70%. The number of drives on TCUL transformers has been reduced, very important fact to the life of transformers.

Finally, the quality of the energy required for demand is improved and integration of unmanaged resources such as photovoltaic systems through hybrid generation is achieved more efficiently.

LESSONS LEARNED

The programming language used by the SCADA system shows robustness and reliability. Staff support and power system operators rely on performance of the algorithm deployed and analyzed using the same tools to automate other operational tasks.

FUTURE WORK

Based on the developed algorithm, the integration to the network of energy storage systems will be analyzed, which collaborate with the process of voltage control on systems of radial T & D.

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