INTELLIGENT VOLTAGE CONTROL IN DISTRIBUTION NETWORK WITH DISTRIBUTED GENERATION

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ABSTRACT

This paper presents a new approach for Volt/Var control in distribution networks with presence of Distributed Generators (DGs). Due to the lack of measurement and communication on these networks, the method proposes the use of a local, intelligent and auto-adaptive voltage regulator for DGs. This regulator is able to coordinate in real time the control of several DGs, connected to the same HV/MV substation, without communication system. A patent has been filed concerning this regulator in November 2005.

INTRODUCTION

The penetration of distributed generators (DGs) e.g, according to CIGRE definition, generation not centrally dispatched, equal or less than 100 MW and usually (but not only) connected to distribution networks is increasing. The connection of DGs to the grids induces local voltage constraints.

So this paper focuses on voltage control in distribution networks with a local innovative regulator developed for DGs. First, it presents the French Distribution Network Operator (DNO) requirements and the equipments used to control voltage inside its contractual values. Then, the DGs impact on actual control is reminded. Finally, the paper describes the voltage regulator developed by the GIE IDEA[1] in Grenoble [1] and it focuses on various simulation results.

CONTEXT

Today, voltage constraints in distribution networks are solved during the connection studies. Before the connection to the grid the DNO checks and verifies with a determinist approach, that the voltage values can be maintained in the contractual limits everywhere on the network whatever the operating conditions. Thus the DNO defines the kind of control for DG (constant reactive power (Q), Q control or V control). However in the future, with a continuously increasing penetration of DGs in the network, DGs will have a more active contribution to voltage control. This paper presents a local, intelligent and auto-adaptive voltage regulator.

Grid requirements

The voltage supplies to MV and LV customers must conform contractual laws. DNO controls the root mean square voltage and its contractual rule concerns the average value on ten minutes points. In France for example, contractual obligations on MV networks consist to maintain voltage in the range 20 kV ± 5% and between 230V [+6%, -10%] on LV networks.

DGs requirements

Today in France, the voltage level for the grid connection of a generating plant depends on its size. Concerning DG contribution to voltage control and reactive power, the requirements are defined in the French ministerial order [2] and in paper [3]. At the present time a voltage control system is required only for DGs bigger than 10MW.

Facilities of control

DNO equipments

Today, the DNO controls the network voltage with two main voltage setting devices.

- The HV/MV transformer On-Load Tap-Changer (OLTC) which changes the transformation ratio according to a voltage set point
- The MV/LV transformer off-load tap-changers are equipped with three tapping steps of 2.5% around the nominal ratio.

Capacitor banks are also installed on HV/MV bus to compensate reactive power demand.

DG impact on voltage control

The connection of a DG unit modifies the voltage profile on the grid due to the change in the active and reactive power flows in the network impedances. Usually, the voltage increases at the connection point and on the feeder. DGs connection effects are presented in paper [3]. The main one is reminded below:

- DG connection creates overvoltage during minimum load times.
- Undervoltages could also occurred during peak load times when generation is not connected.
- Usually, DGs un-optimise voltage settings at the HV/MV substation, particularly when the allocation of generation is not homogeneous between the different feeders.

As we have seen, DGs disturbances on voltage profile are numerous. Next paragraphs present a new local voltage regulator for DGs. This regulator is able to control voltage not only at the connection point but also everywhere on the grid. It coordinates the action of the various DGs without communication system. In November 2005, a patent has been filed concerning this auto-adaptive regulator.

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[1] Groupement d'Intérêt Economique Inventer la Distribution Electrique de l'Avenir

PRINCIPE OF AUTO-ADAPTIVE REGULATOR

DGs connected in the network can participate to voltage control, however, a few questions arise:

- who decides to change DGs voltage set points?
- how much? (set point value appropriate to bring back the voltage within the acceptable limits)
- when and how long? (Moment of change)
- Where? (Which DG?)

The developed auto-adaptive regulator answer partly to these questions with technical but also economical advantages: local decisions based only on local measures. This avoids investments on communication systems for DNOs.

The paragraph below describes the working principle of auto-adaptive voltage regulator.

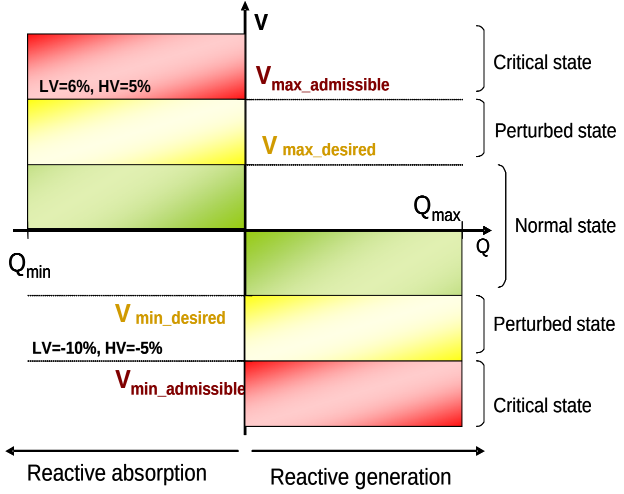

Fig.1a: Principe of auto-adaptive regulator

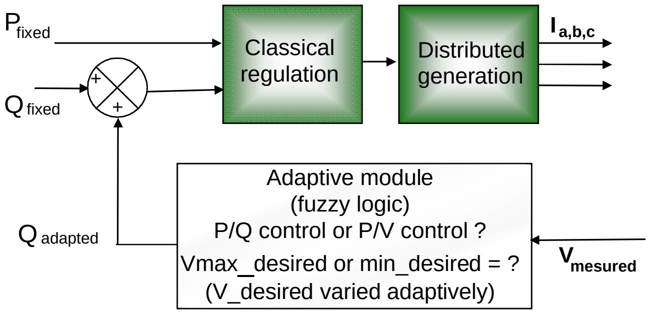

Fig.1b: Functionality of auto-adaptive regulator

Three operating modes of the regulator are possible. They correspond to three possible states (Fig.1a):

- ***Normal state***: where the voltage is located inside a window of "desired" voltage ($V_{min\_desired} \leq V \leq V_{max\_desired}$). In this state, DG is in P/Q control (PF/VAR control).
- ***Disturbed state***: where voltage leaves the desired limits ($V > V_{max\_desired}$ or $V < V_{min\_desired}$). The goal of the adaptive regulator is to maintain, within the limits of the system, the voltage between these fixed values. Thus under disturbed conditions, DG commutates in voltage regulation mode (AVR for the synchronous machines and P/V mode for sources using an inverter). Here, only reactive power is used to control voltage at the DG connection point. The voltage set point is set at $V_{min\_desired}$ or $V_{max\_desired}$ according to whether the network voltage profile is too low or too high. If DG is in reactive power limitation (Q=Qmin or Q=Qmax), it cannot ensure any more the control in the desired voltage. The voltage moves and reaches critical state when voltage admissible limits are crossed.
- ***Critical state:*** where the voltage is out of the admissible limits ($V > V_{max\_admissible}$ or $V < V_{min\_admissible}$) and, as previously explained, DG cannot act any more by compensation of reactive power. In the critical state regulation of active power becomes necessary. So DG commutates in active power regulation mode (Mode P). It means that DG changes active power generation in order to bring back the voltage in the admissible values.

The change of regulator operating mode is automatic and auto-adaptive. Moreover, the regulator only uses voltage or current measurements at the connection point and does not need any communication link with DNO or other DGs Automatic Voltage Regulator (AVR).

In addition automatic adjustment of desired limits allows several strategies of control.

First, it is possible to use this regulator for maintaining voltage at DG connection point only. Indeed, by setting desired limits such as $V_{max\_desired} = V_{max\_admissible}$ and $V_{min\_desired} = V_{min\_admissible}$ the regulator operates to maintain in priority the voltage at the connection point in the admissible values. Nevertheless, with this strategy of control, the regulator acts slightly for keeping the voltage in the adjacent buses.

Secondly, it is possible to set constraining values for the desired limits ($V_{max\_desired} < V_{max\_admissible}$ and $V_{min\_desired} > V_{min\_admissible}$). With this strategy the regulator controls first the voltage at DG connection point. Moreover, the conservation of voltage in a narrower window at the connection point ($V_{min\_desired} < V < V_{max\_desired}$), also regulates the voltage on the adjacent buses. But careful, for small DGs this choice is very sensitive to reactive power limitation. Indeed, if one sets a rather low value for $V_{max\_desired}$, DG often reaches the limit of reactive power absorption. On the contrary, if the $V_{min\_desired}$ value is high DG often reaches the limit of reactive power supply. Three strategies of control are possible for these values.

Fixed desired window

The user can set these values, ex: $V_{max\_desired} = 1.04$ pu and $V_{min\_desired} = 0.98$ pu. This choice is available for every networks. The $V_{min\_desired}$ value specified at 0.98pu maintains a rather high voltage profile. This contributes to decrease the losses on the network. The $V_{max\_desired}$ value specified at 1.04 pu enables to maintain the network voltage profile not too high.

Controlled desired window

After an Optimal Power Flow (OPF) calculation, grid operator can impose these values for each DGs. OPF calculation is at least necessary for two extreme scenarios (low load scenario associated with the maximal generation plan; and full load scenario cumulated with the minimal generation plan) to determine these values. They can be modified in real time by the grid operator when a change of topology occurred on the grid for example.

Adaptive desired window

The regulator changes in an adaptive way the desired voltage values, correlatively with the operation, by respecting reactive power limits of each DG. Indeed, according to the voltage value on the connection feeder and the quantity of reactive power produced or absorbed, the $V_{min\_desired}$ and $V_{max\_desired}$ will be variable. Adaptive limits allow all DGs to contribute to voltage profile without communication system, even DGs located on not critical voltage feeders. In fact, the more the voltage measured is closed to 1pu the more the voltage desired window will be narrow. This window moves according to the quantity of reactive power provided or absorbed compared with the physical limits of the DG considered. More the contribution of reactive power is important more the window of voltage will increase by respecting the limits ($V_{min\_admissible} \leq V_{min\_desired} \leq V_{max\_desired} \leq V_{max\_admissible}$).

This adaptation is realised with the use of an adaptive module based on fuzzy logic (Fig. 1b).

Fuzzy logic is chosen for its capacities of interpolation. Indeed this logic is more precise than Boolean logic to adapt desired voltage window according to each voltage and reactive power measured at connection point.

STUDIED NETWORK

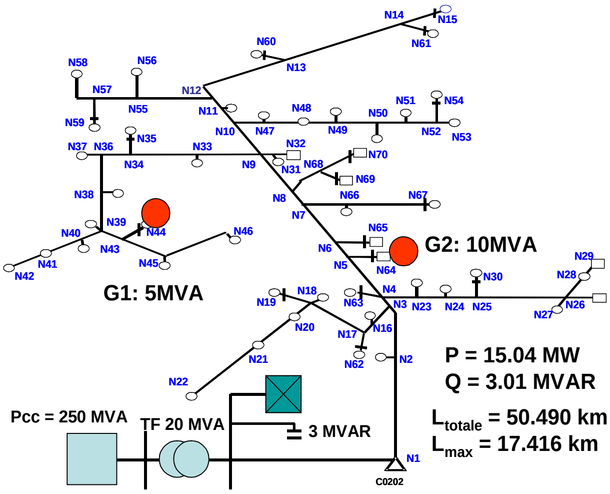

Fig. 2: Studied HV network

This typical urban network comprises the transformer 63kV/20kV, five MV feeders. In the Fig. 2, only the feeder where DGs are connected is drawn. The four other feeders are presented by an equivalent load. For the considered part of the network, the maximal power demand is 15 MW and 3 MVAR (Table I).

Two DGs are connected at node N44 (DG1: 5MVA, 4MW) and N64 (DG2: 10 MVA, 8 MW).

TABLE I: DATA FOR STUDIED NETWORK

	Load (MW)	Load (MVAR)	Total length (km)	Max. length (km)
Urban network (20 kV)	15	3	50	17

SIMULATION RESULTS

In order to show the performance of the regulator, four configurations of voltage control are used:

- Power factor (PF) regulation for DG1 and DG2 (Cf. 1)
- Auto-adaptive regulation for DG1 and DG2 (Cf. 2)
- PF regulation for DG1 and DG2 with OLTC transformer (Cf. 3)
- Auto-adaptive regulation for DG1 and DG2 with OLTC transformer (Cf. 4)

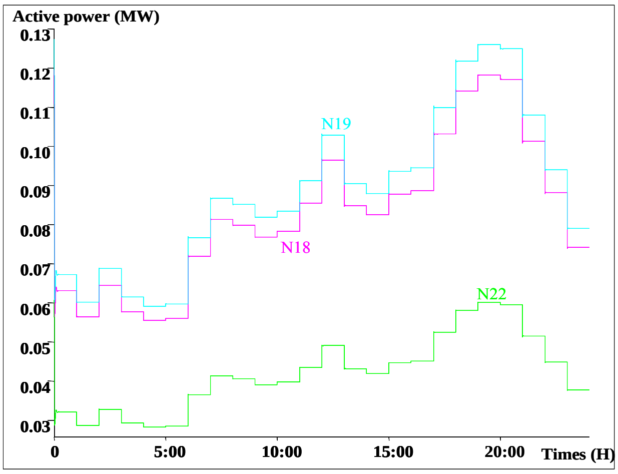

Fig. 3: Load variation for 24h

Scenario 1

In this scenario, loads vary during the day as shown in Fig. 3. Two critical states are considered: low load scenario (22-6H) and full load scenario (18-22H). Supposed that active power provided by DG1 and DG2 are constant (4 and 8 MW, respectively).

The voltage constraints occurred on node N44 where DG1 is connected between 0 and 6 hour (Fig.4). So the performance of each regulation will be compared on this bus (Fig.5).

For Cf. 1, without a voltage control, in the low load period an overvoltage occurred on bus N44 where DG1 is connected. The voltage reaches 1.059 pu (>1.05pu).

For Cf 2, with the developed auto-adaptive regulator, all nodes are maintained in admissible voltage limits (Fig. 5).

For Cf. 3, the OLTC transformer regulation induces an overvoltage at bus N44. Indeed, during (20-22H) the OLTC maintains the HV/MV voltage set-point at a high value. The objective is to avoid under voltage on feeders without generation when the load is high. This induces over-voltage on the feeders where DG1 and 2 are connected.

For Cf. 4, just as the Cf.2, all voltages are maintained in admissible limits.

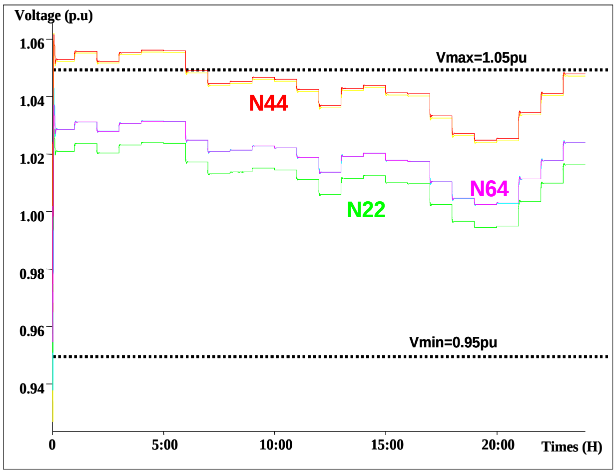

Fig. 4: Voltages at N22, N44 and N64 obtained by PF regulation

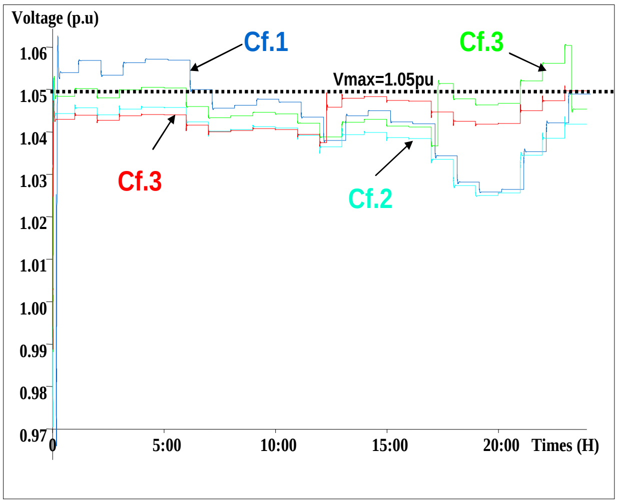

Fig. 5: Voltages at N44 for four voltage control strategies.

Scenario 2

Equivalent to the first scenario, but at t=18h30, an incident occurs in the HV network (63kV). The voltage on HV network decreases to 0.925 pu. This event can provide a low voltage in the 20kV network.

For Cf. 1 the voltage at bus N1 can reach to 0.92 pu during 19 to 21H (Fig. 6).

For Cf. 2, voltage profile is improved with the help of the developed voltage regulator of DG1 and DG2. DG1 and DG2 provide reactive power in order to increase the voltage at connection points. These actions allow to maintain all nodal voltages in admissible limits.

For Cf. 3, the same as the first scenario, without a coordination of OLTC transformer with others controls, there is an overvoltage on several buses caused by the action of OLTC transformer (Fig.6).

For Cf.4, as the same as the Cf.2, all voltages are maintained in admissible limits.

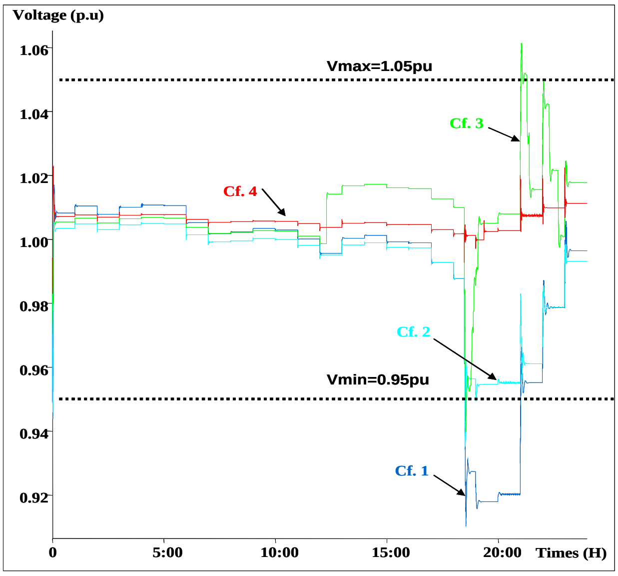

Fig. 6: Voltages at N1 for four voltage control strategies.

CONCLUSION

The results obtained show that auto-adaptive voltage regulator is able to maintain voltage plan on distribution network on normal and emergency conditions. This regulator is adaptable in configuration with and without OLTC transformer.

This regulator permits to improve the performances of the DG and to maintain a good voltage profile in both steady-state and transient state by maintaining the active and reactive power of the DG within its own limits.

Scientific works must be led to coordinate local regulators and DNO equipments (OLTC) in order to optimize voltage profile, particularly when there is big unbalance of generation between MV feeders.

Moreover, the use of such regulator requires a change of regulatory frameworks and of contractual rules. Particularly, the producer remuneration for voltage control should be defined.

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