NEW APPROACH TO REGULATE LOW VOLTAGE DISTRIBUTION NETWORK

Yves CHOLLOT
SCHNEIDER ELECTRIC – France
yves.chollot@schneider-electric.com

Philippe DESCHAMPS
SCHNEIDER ELECTRIC – France
philippe.deschamps@schneider-electric.com

Arthur JOURDAN
SCHNEIDER ELECTRIC – France
Arthur.jourdan@schneider-electric.com

Sandeep MISHRA
ENSE3 INPG
Sandeep.Mishra@ense3.grenoble-inp.fr

ABSTRACT

This paper describes a new approach to regulate low voltage distribution network.
***The subject addressed is** how to control the Voltage at the level of the MV/LV substations for a better integration of distributed production using a Regulated Distribution Transformer with embedded intelligence.*
The paper will also describe how the solution has been extensively tested on several different network topologies with many different customer profiles installation.

INTRODUCTION

The multiplication of the PV generation and others distributed production needs to mitigate excessive voltages that occur when generation is high and demand is low while keeping a minimum voltage during peak demand.
In the past, such systems were traditionally located at the HV/MV substations, using On Load Tap Changers (OLTC) and capacitor banks and were designed usually to integrate a maximum MW rate of 20% of distributed production.
The proposed solutions allow integrating more distributed generation on the existing network.
How did we address the problem?
The approach consists on replacing the traditional MV/LV transformer by a new generation of OLTC transformer called regulated distribution transformer with similar foot print and life duration. This new generation of transformer is based on a booster system and powered by embedded intelligence to stabilize the whole LV network.
This paper describes the innovative technology of smart transformer and its application for voltage control besides different added values, listed below:
- Local regulation using the local voltage measurement to reduce the fluctuations coming from the MV
- Remote regulation using the DMS functions to have a consistent behaviour with the centralized VoltVAR regulation of DMS.
- Regulation using remote measurement located at some specific nodes of LV feeders to avoid unexpected disconnection of PV producers and to anticipate local voltage drop at the end of the feeders.
- Local regulation using sunlight sensors to compensate the PV (Photovoltaic) generation.
- Monitoring of imbalanced among phases on LV feeders for better compensation of over voltage
- Real time estimation of the distributed production using an innovative algorithm to know the remaining capacity of Photovoltaic injection
- In addition the solution allows the monitoring and optimization of the LV network using data processing via the cloud

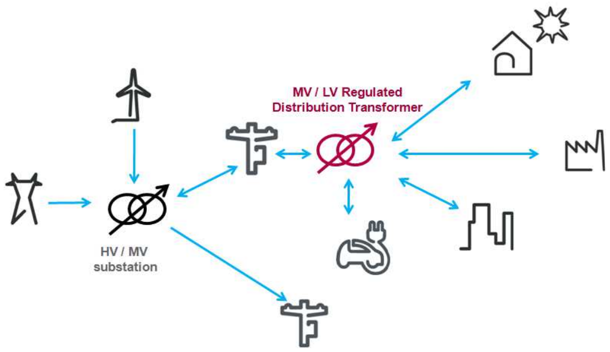


Fig 1-MV/LV Regulated Distribution Transformer

VOLTAGE REGULATION PRINCIPLES

Main general principles of VVO

VVO (Volt VAR optimization) can be formulated to minimize the weighted sum of energy loss, peak demand, voltage violation and current violation, while keeping engineering constraints like line overloads and tap change operation limits.
The control variables for optimization include:
- Switchable capacitor banks
- Controllable taps of transformer/voltage regulators
- Distributed generation
- Flexibility mechanisms like demand response

The first optimization level is centralized at the control center level by the advanced functions of the DMS or is managed in a reduce area level including some feeders like Integrated VoltVar (IVVC) systems.

At the LV distribution networks level the VVO consists mainly to adjust the output voltage (and reactive compensation) with either a reference fixed value (i.e. 410V) or a combination of - a remote set point sent by the centralized VVO, - a provisional timetables to deal with the peak periods and - local power measurement to compensate the drop due to the loads.

Needs for regulation

The main needs to regulate the LV network are:
1. To ensure Stabilization of the Grid affected by:
- Expansion of decentralized energy injecting power at various network points
- Extension of distribution network
- Poor quality of electrical network

2. To reduce the grid expansion cost:
- No need to reinforce the network
- Enable Grid operators to efficiently use the network capacity

3. To leverage the fast expansion of Green energy system, PV & Wind, into the lower parts of the network requesting grid reinforcement by the Operators

4. To contribute to efficiency policies through Voltage optimization:
- to drop the voltage during peak demands to reduce the active power.
- to increase the voltage in normal operation to compensate the downstream voltage drop.

THE REGULATED DISTRIBUTION TRANSFORMER

The regulated MV/LV transformer is dedicated for utilities, up to 1000kVA, to improve the voltage stability. It fits in existing substations with an easy replacement of the existing transformer.

Fig 2-Minera SGrid Booster – Schneider Electric

An innovative design combines a conventional transformer with a booster transformer in series on the same tank. This configuration allows ultra-low maintenance with several millions of operations because using proven LV contactors, with no mechanical parts inside the tank and no power electronics.

The on load regulation controls 5 taps of 2% of the voltage (or 9 taps with up to +/-10%) and is completed with a de-energized tappings to adjust the nominal voltage.

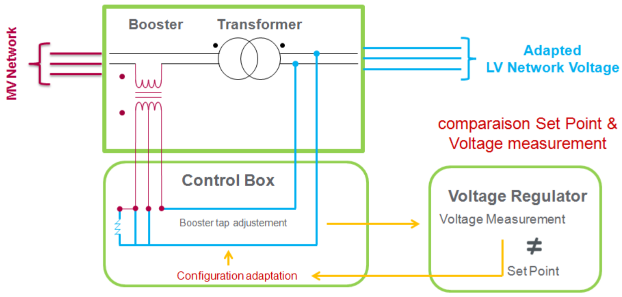


Fig 3-Regulation principle

The transformer embedded the regulation controller allowing local automatic voltage regulations.
Thanks to its remote supervision capabilities the transformer can be connected to DMS supervision allowing customers to reduce intervention costs and having full control over their assets.

The VoltVar Optimisation (VVO) of the DMS or an Integrated Volt Var Control (IVVC) system sends a remote set point to adjust the local voltage regulation.

EXPERIMENTATION OF A REGULATION TO MAXIMIZE THE PV PENETRATION

The basic regulation is traditionally done by measuring and comparing the voltage of the transformer with the reference voltage (set point usually 410V) in case of difference the taps are changed with an optimized algorithm to adjust the output.
This basic regulation doesn't fit well when the decentralized energy production increases and may locally raise the voltage. It is the reason why a remote measurement point is added in some LV feeder at an intermediate position or at the end position of the circuit.
It has been demonstrated that less than 5 appropriate locations of measurement points are enough to dramatically improve the regulation. Each measurement point, thanks to a short range radio (or CPL modem) transfers the voltage measurements to the controller.

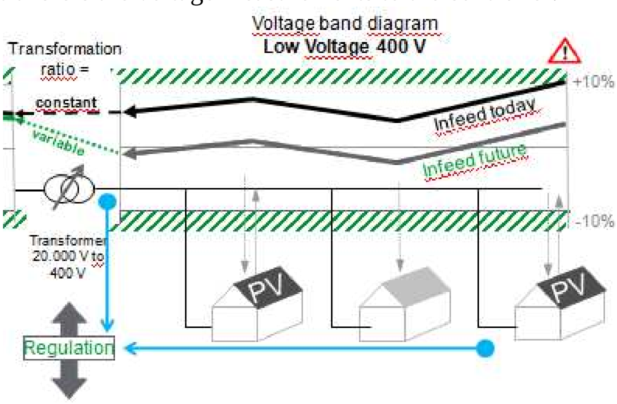


Fig 4-Remote Point Regulation

The algorithm, called Remote Point Regulation, consists on anticipate the voltage violation and adjusts the voltage in case of risk while optimizing the maximum of customers with the reference voltage.

A first proof of concept has been done in Belgium, TECTEO utility, on a residential area with 100 houses including 34 photovoltaic producers of 5.5kW.
The previous situation was critical has some PV productions been frequently disconnected during sunny days because some points raised 250V.
After installation, the result was positive:

- no more disconnection of PV detected,
- an average reduction of 8V is established,
- the voltage is stabilized

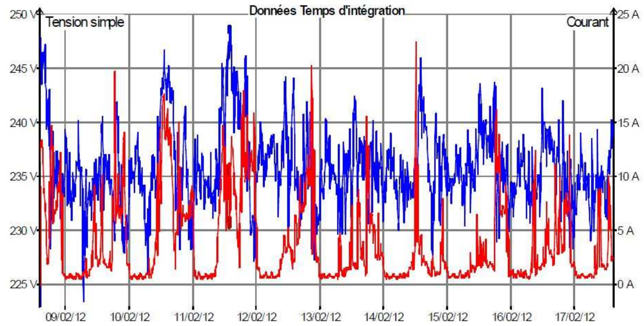


Fig 5-One week U (blue) and I(red) measurement at a customer point without regulated transformer.

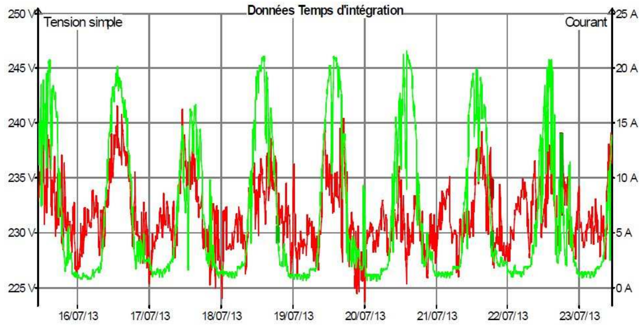


Fig 6- One week U (red) and I(green) measurement at a customer point using RPMM algorithm

To conclude, the benefit of this regulation is a global voltage reduction of 8V which improves the capacity of production of the LV network while optimizing the efficiency of customer loads. For the utility, it has been a positive investment avoiding reinforcing the LV network.

However, this regulation strategy requires the use of additional remote measurement equipments on the field and UHF radios for remote communication between measurements points and regulation equipment. It can be a drawback because it needs engineering and maintenance and unfortunately most of the smart meters cannot be used easily for that regulation. It's why an alternative offer is proposed using sunlight sensors as explained hereafter.

VOLTAGE REGULATION USING SUNLIGHT SENSOR

Another way of regulation using sunlight sensor has been installed in ERDF network located in the south of France, in a residential area, within the NiceGrid demonstrator.

For ERDF, the total cost to reinforce the LV networks due to solar production will probably reach 500M€ in 2020 [2]. One of the objectives of the project is to evaluate how the regulated transformer can sometime be an alternative to reinforce the lines when an exponential increase of photovoltaic connections' requests is located on the same area.

The hypothesis was to be able to connect on the same transformer an additional 100kW photovoltaic producer located at 300m of the transformer (which may raise the voltage of 8%) while traditional loads connected on others LV feeders drop the voltage of 10%, keeping all the customers on the legal limits of 400V +/- 10%.

For that, a regulation calibrated with a medium voltage reference of 404V at the secondary is enough and relevant during sunny days but it won't be optimal in winter or during the night, while there is no risk of overvoltage on LV feeders.

A light sensitive switch, located at the roof of the substation, gives an estimation of the PV production downstream the substation. Then it automatically modifies the voltage reference used for the regulation.
- In the sunlight, the regulation is done with a low voltage reference (404V) to increase the possibility of PV deployment without risk of overvoltage.
- When the light drops, the regulation is progressively set to a higher reference, up to + 4% (420V), to reduce losses and provide a higher voltage to satisfy end-users during peak periods.

In addition, at the regional level, the DSO can forecast an optimum Voltage reference for each next 24, 12 or 2 hours to better optimize the local small generation and storage systems. In case of a new remote voltage reference, the algorithm adjusts the voltage using this new set point as explained in the fig. 7

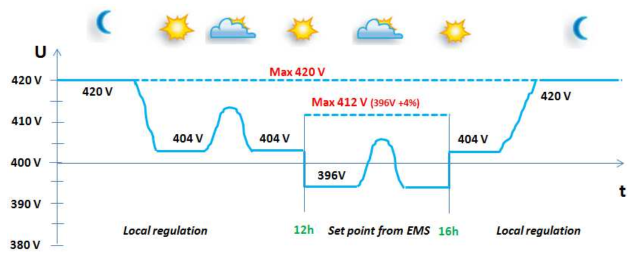


Fig. 7 – Output voltage of the regulated transformer

This innovative regulated transformer with light sensor has been installed in October 2014 in Carros with successful results of tap changes according to light measurement [1].

LINE DROP COMPENSATION

The exact load flow of the LV network is almost impossible to calculate from the MV/LV substation because too many parameters should be set up to know the profile of each customers and producers, besides large computation time and difficulty of using old deterministic algorithm.

In order to take into account the impedance of the lines, a simple and basic compensation, called Line Drop Compensation (LDC) is proposed using only 3 set points depending on transformer load.

The compensation is depending on line characteristics - Regulation based on line impedance - Voltage drop compensation at the end of the line as per customer predefined rules.

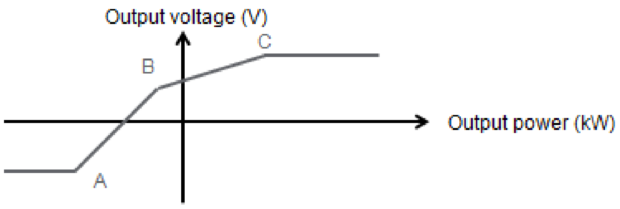


Fig 8- The set points A, B, C depending on its load characteristics.

This regulation is used in most general configurations and can be associated with the light sensor to flat the voltage variations. However this strategy doesn't fit well with non homogeneous feeders and can be improved with the following options.

INOVATIVE SOLUTION OF MONITORING TO OPTIMIZE THE VOLTAGE

A good way to improve significantly the efficiency of the voltage regulation consists in adding current or energy sensors on the secondary side of the MV/LV transformer.

Such improvement brings two advantages:

First, it allows to obtain information on the total imbalance of the transformer load. The imbalance has a major influence on the voltage drop. Theoretically speaking, a given load connected on a single phase of a three phase network produces 9 times the voltage drop compare to the same load well balanced on the three phases (assuming the neutral wire has a half section compare to phase wires). Even if the real life is not so contrasting, looking for the best balancing remains an efficient way to limit voltage drops.

Second, a regulation law taken into account the real load of the transformer can be implemented. A heavy transformer load will globally increase the voltage drop. Such additional sensors are easier to install compare to remote voltage measurements, because they're located in the substation, without need for expensive additional communication mean.

A step forward can be done if the transformer supplies several feeders with very different loads and/or line characteristics. In this case the global measurement made at the transformer secondary can hide very inhomogeneous situations feeder per feeder and can lead to inappropriate correction action.

Then second improvement consists in adding measurement on each feeder. Of course, since additional sensors have to be implemented, the decision to go in this way has to be made based on cost benefits analysis, which depends on the characteristics of the LV network and its connected loads. But it has to be noted that last available technology allows now to reduce significantly the total cost of such equipment. New energy sensors exist now on the market perfectly designed for such application. They are equipped with short range radio and are self powered, avoiding by this way any cabling operation, and their size has been chosen to allow an installation on live switchboard, even in tight and harsh environment.

Fig 9- Loads measurement of feeders thanks to ZigBee sensors

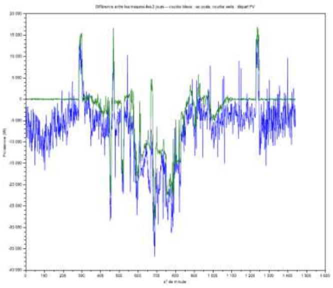
REAL TIME ESTIMATION OF THE DISTRIBUTED PRODUCTION

The goal of this regulation is to detect and quantify one or several Photovoltaic production units among several loads on a given electrical network.

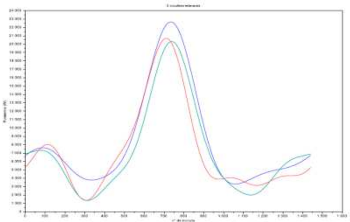
The principle of the algorithm is to analyse several daily load curves on each LV feeders downstream the substation during a period where solar production capacity is supposed to be constant (2 or 3 weeks).

Each curves will be compared with the other ones, the objective is to find curves couples where the loads are similar during non production hours and different during sunny hours.

The difference between these two curves is a rough image of a Photo-voltaic production.



The results will then be filtered to eliminate fast variations and selected with several criteria like time synchronisation with sunshine.



The process is iterated and the results are corrected with a seasonally factor.
We measure on real time the peak power installed downstream the meter. It integrates the real efficiency levels of PV installations, new installations and over sizing installation by customers.
Field tests show accuracy of estimation better than 10% for PV installed power.

Monitoring each feeder allows DSO:
- To better estimate the DER and then to improve the algorithm of line drop compensation within non homogeneous networks
- To proceed phase rebalancing for more integration of PV

CONCLUSION

Utilities in many regions are being driven by new environmental regulations to gradually close their central fossil-fired generating plants
Those plants will be partly replaced by renewable energy production means, such as hydraulic, wind and solar, which continue to grow at a rapid pace. For example, in Germany more than 35 per cent of energy consumption is targeted to come from renewable by 2020, and 80 per cent by 2050.
In response to these continuing challenge, grid operators have to improve more efficiently the VVO over an increasingly complex network, while also improving response to critical events.

The experimentations of MV/LV regulated transformer and others electronic devices [3] is a way to answer to different needs with some simple algorithms. Here are the main benefits of each solution described in this paper:

Benefits: / Solutions	System simplicity	Optimize cost	Upstream fluctuation (wind farms)	Downstream fluctuation (PV)	Inhomogeneous LV network
Traditional local regulation	***	***	**	*	*
Centralized regulation (DMS)	*	**	***	*	*
Remote point regulation	*	*	**	***	**
Solar sensor regulation	***	***	**	***	*
Line drop compensation	***	***	**	***	*
Monitoring of LV feeders	**	**	**	***	***

Technology is now available to cover a wide range of requirements for optimization of LV networks.

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