THE CONCEPT OF GRADUAL IMPLEMENTATION OF SMART GRID THROUGH THE DISTRIBUTED GENERATION INTEGRATION

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ABSTRACT

The emergence of distributed generation (DG) introduces a new level of dynamism in the distribution network. Network becomes the most dynamic part of power system altering frequently its status from consumer to the source. The existing remote control system isn't able to track those changes, nor reliably control the system. Permanent solution is the smart grid. However, significant resources (and time) required for the systematic introduction of smart grid delay the implementation of these ideas.

The paper is based on the principle that one should take advantage of any equipment already available in the network (e.g. smart meters). The lack of equipment, especially in initial stages, should be compensated by calculations and advanced engineer reasoning. The idea is to monitor the points of energy injection into the local network and to monitor one control point (the „weakest" point) in line, which is the indicator of voltage problems, and based on this information, to define the mode of DG control, and, by that way predefined autonomous control of each DG, to control the situation in local network.

INTRODUCTION

DG integration changes the basic concept of distribution network. The distribution network is no longer radial. Power flows are no longer defined by the energy from the parent network, which flows to the end user. DG brings the new level of uncertainty in the development, planning and management of the distribution network. Uncertainty is more significant at lower voltage levels. A low voltage network is more branched, "weaker", but at the same time it is less integrated into the remote control system.

The concept of gradual introducing smart grid through the integration of DG in network includes three levels:

1. The grid of smart points,
2. The grid of local smart zones,
3. The smart grid - smart distribution system.

APPROACH TO DG INTEGRATION INTO THE DISTRIBUTION NETWORK

There are two approaches: conservative and advanced.

Conservative approach

Conservative approach is based on the assumption that network must be capable (reinforced, reconfigured or built if necessary) to evacuate all the energy produced (within the allowed connected power of DG) while providing current-voltage conditions in the network within permitted limits in each extreme situation of normal system operation [1], [2]. Conservative approach is now in force in Croatia.

This implies reinforcing the network to accommodate extreme network conditions: maximum production in minimum consumption and maximum consumption without the production. Consequently, many investments in the network have to be made, although those investments have the purpose only in the marginal network conditions, whose incidence and duration are highly questionable.

Profitability of such network reinforcement investments is questionable at several levels: primary investment, subsequent network maintenance, and also because of the delays of DG connection due to the time necessary to implement reinforcements in the network, which must precede the connection of DG. There is also a problem of loss of usefulness of these projects in the event of termination of the DG operation, especially if its operation is feasible only due to the help of substantial incentives (electricity price) [3], which are subject to constant change (especially in context of global trend to reduce incentives).

Advanced approach

Advanced approach is a courageous step and offers the opportunity to the DG itself to decide whether to delay the connection to the network and wait / pay for the reinforcement of network or to choose advanced approach: DG will adjust to the inherited network conditions.

Pros and Cons for DG: The DG does not have to wait for network reinforcements prior to its network connection, and has no obligation to pay the costs of network reinforcements, while losing the ability to deliver (sell) to network a negligible portion of energy produced in rare extreme situations (due to adjusting to inherited network).

Pros and Cons for distribution system operator (DSO): DSO is not forced to create and maintain the network to the extent that the majority of it is not utilized in normal operation, but only in extreme situations in the network (such network is unprofitable in long-term, and undertaken reinforcements lose its purpose).

Advanced approach enables maximizing the utilization of available resources in the network. In this case the operation of the system within the permissible limits depends not only on the DSO; it also depends on the operation and control of each DG. Therefore it is necessary to develop a method for recognizing allowed limit values (of voltage) for each DG, in order to minimise restrictions of DG operation, without risking the integrity of network and endangering acquired rights of other network users.

The flexibility provided by the advanced approach, compared with the rigidity of the conventional approach, gives the DSO a time needed to adjust the distribution system to new conditions influenced by DG integration.

IDENTIFYING THE PROBLEM

In network with DG, power flows are determined by the relative relations between actual production and consumption in the local network. Consequently, the voltage conditions in the network are constantly changing, creating a problem of low voltage (allowable voltage drop), but also creating a new problem of a high voltage (introducing the concept of permissible voltage rise).

The most important problem in radial distribution network without the automatic voltage regulation is daily fluctuation of voltage in remote parts of the network due to the relative change in relations between local production and consumption during the day. The voltage profile of the feeder fluctuates daily both in the overvoltage and in undervoltage domain; therefore manual voltage regulation in substation is not applicable.

The voltage profile of the feeder with DG behaves differently than of the feeder without DG. A special problem occurs in case of substation supplying the feeder with the DG and the feeders without the DG, or the feeders with the different types of DG.

If there is an automatic voltage regulation in the substation, there is still a problem how to regulate the voltage in the substation while the voltage profiles in belonging feeders are significantly different, despite the fact that the feeders are connected to the same substation.

Local impact of the DG often does not reach a point in the network that is remotely controlled. In such cases the impact of DG integrated deep in the network can't be detected by the remote control centre, no matter how important (or damaging) the impact may be to the nearby network users.

The usual control of the distribution network operation is based on measurements of the current and voltage values in substation, at the beginning of line (feeder). In the case of radial network without DGs, based on these measurements, current and voltage conditions on the entire line can be assumed with high accuracy, if the model of the line and the character of the consumers are available (Figure 1).

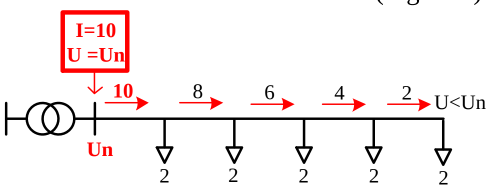

Figure 1: Measured values at beginning of line without DG are competent indicator of conditions along the line

However, in the network with DG, these measurements are no longer a relevant indicator of the current and voltage conditions along the line. While measuring the same values of current and voltage at the beginning of line, power flows (current) and voltage profile of line might vary significantly along the line (Fig. 2) influenced by the actual relative ratio of local production and consumption in the line [4].

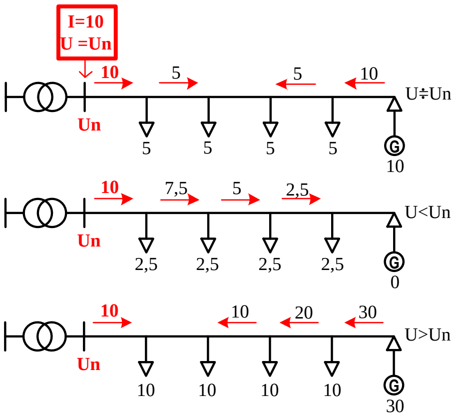

Figure 2: Measured values at beginning of line with DG aren't competent indicator of conditions along the line

RESOURCES AVAILABLE FOR SOLVING THE PROBLEM

Once the problem is identified, and it was established that the comprehensive integration of smart grid is still far away, it is necessary to find a transitional solution relying on the already available resources in the distribution network.

At the moment available resources in Croatia are:

- smart meters are installed for each DG;
- power quality (PQ) is monitored for each DG (both on LV and MV level) during commissioning;
- permanent PQ monitors are installed for each DG in MV network;
- MV connection facilities are remote controlled by DSO;
- connection facilities (owned by the DSO) have a disconnecting switch with the overvoltage protection (for disconnecting each DG over 30 kW);
- it is feasible to demand DG to perform voltage regulation;
- it is feasible to install smart meters at the metering point of the consumer or at targeted point in the network;
- each smart meter is remotely accessible (GPS/GPRS);
- DSO is conducting comprehensive analysis of network with DG – it is a routine in DSO; it daily upgrades knowledge and gives a solid foundation for the continuous improvements of DG integration into the DSO's network;
- DSO has a critical mass of experts to implement the necessary network analysis.

THE GRID OF SMART POINTS

The former approach in the radial network was to monitor the current and voltage in feeding point (in the substation, on the beginning of the line). This has been proven an excellent approach, and it should be used also in a network with DGs. One only needs to make a shift in thinking and accept that each DG is also a feeding point.

In this context, one should accept that the "monitoring

conditions at the beginning of line" now includes monitoring conditions not only in feeding point in the parent substation at the beginning of line, but also monitoring all points of energy injection from DGs connected to a line.
Monitoring simultaneous measurements on all feeding points will provide information about the energy injected the line. By measuring the voltage at these points one can recognize the status of consumption of the line relative to production (the higher voltages, the consumption is lower).
The term "Smart point" is introduced. **Smart point** is the node in the network with the ability of remote monitoring and controlling the network conditions. Each DG should become the smart point (Figure 3).
The question is how to conclude, based on measurements at just a few smart points in line, if voltages in the line were outside the permitted range. This problem is present in initial stages of DG integration with only a few smart points in a line, and most of the lines not having any smart points.
The term "weak point" is introduced. **Weak point** is the most vulnerable node– node with the highest voltage fluctuations in the feeder. Weak point is the indicator of impact of the DGs and performance indicator of DG's voltage regulation. Weak point has ability of remote monitoring the network conditions (Figure 3). Generally, the weak point is smart meter installed at network user site.
DSO should compensate the lack of smart points in the network, especially in the initial stages, by comprehensive network analysis and advanced engineer's reasoning.
Analysis, based on the calculations and engineer's conclusions should identify the weak points in the network and provide optimal limits of measured (and controlled) values on site of DG. The goal of this network analysis is to enable network operation while preserving conditions in the network within the permitted limits.
DSO should be responsible for preserving conditions in the network within the permitted limits while DGs are not in operation. While the DGs are connected to the network and producing electricity, DGs are obliged to control the local network (feeder) conditions and to keep it within permitted limits, including at the local weak point.

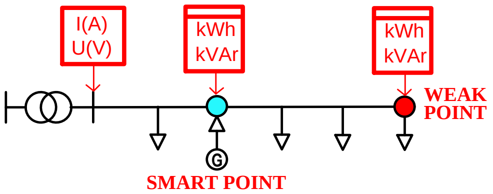

Figure 3: The weak point is an indicator of efficiency of local voltage regulation

Optimal boundaries of controlled voltage values (and possibly power factor) are the values measured at smart point while weak point reaches permitted limit values.
In case of more DGs in one line, situation becomes more complicated (Figure 4), but the same approach is applicable. By network analysis one determines the voltage value at the smart point(s) appearing in the moment of appearance of extreme voltage at weak point. Weak point indicates the lowest possible voltage in line - in the case of maximum consumption without DG production. It gives the criteria for the setting of manual voltage regulation in the substation (at power transformer). Further network analysis shall be conducted with already determined setting of voltage regulation in substation. Analysis should determine the level of simultaneous reduction of voltage (or active power) at each DG in order to keep the voltage in line under the upper limit in the worst case scenario: maximum DG production in the minimum of consumption.

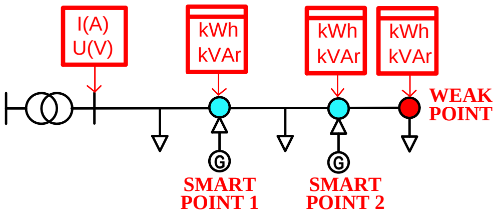

Figure 4: Line with two DGs (smart points)

Voltage reduction in each DG in the feeder is based on the principle of equality: reduction of the same percentage of connected power of DG. According to the applied principle of equality, tripping voltage value for activation the voltage reduction should be specified individually for each DG.

THE GRID OF LOCAL SMART ZONES

The increase of the number of integrated DGs will eventually result with sufficient smart points by which it will be possible to control the whole local network. In that moment local network becomes local smart zone (Figure 5).

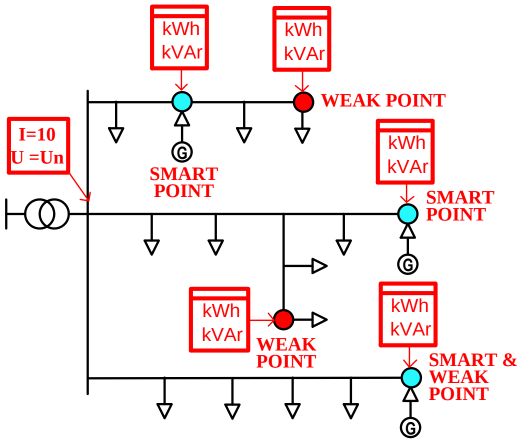

Figure 5: Local smart zone

Further increase of number of DGs will result with fewer weak points, because DGs will be integrated also at weak points, therefore weak points will become "smart & weak point". As network lives, changes will appear: connection of new DGs and consumers, as well as changes in the configuration of the feeder that have nothing to do with DGs, may lead to a change of the status of the weak point. It is possible that the repeated analysis of the network under new circumstances results with a new weak point, at different part of the feeder. Everything is subject to change and should be continuously reviewed.

SUPERVISION OF IMPLEMENTATION OF VOLTAGE CONTROL

DSO should supervise the implementation of voltage control performed by the DG. There are two levels of supervision performed as regular periodic (monthly) control of smart meter reading (all measurements in the period since the last measurement) at:

a) Smart meter at smart point (DG): control if the measured voltage (regulated value) was within the predefined boundaries of regulated value (U, cos φ) for each DG.

b) Smart meter at weak point: control if the measured voltage (controlled value) was within the permitted limits.

There are two possible negative findings by the supervision of measured values at weak point, compared with simultaneous readings on smart point:

- DG didn't implement the voltage regulation in a given range=> DG will be penalised and has to set the overvoltage protection to a predefined tripping values for voltage regulation, because the DG without regulating abilities has to be disconnected when exceeding the limit values.
- DG implemented voltage regulation in a given range, but the measured voltage values in the weak point were outside the permissible limits => the new network analysis has to be done. This analysis should determine new settings (tripping values) for the voltage regulation at smart point (DG), and new settings should be implemented immediately.

THE SMART GRID

Ultimately, by further increase in number of local smart zones, the whole network will be covered with smart zones, becoming the smart grid, creating smart distribution system. Detailed network analysis performed by engineers, will not be necessary any longer. Still, the regular, periodical control of smart-system's decision-making procedures, performed by engineers, will be of utmost importance, by the following criteria:

- Identifying the false decisions: an experienced engineer can detect inconsistency of a programmed smart conclusion.
- Maintaining the level of engineer's experience and knowledge: review of smart system's decisions and control of decision-making process, as well as insight into the magnitude of the simultaneously measured values in the entire network, results with insight in the actual functioning of the power system and of its components individually.
- Avoiding the helplessness: by letting smart system to control the distribution system configuration, humans (engineers) become helpless at the moment of malfunction of the smart system: being unable to identify the current system configuration and unable to take over the control of the system until re-establishing the smart system control.
- Improving logic of smart grid. Only continuous reviewing and expert criticism of performance of smart grid can make a competent evaluation of the system, and thus decision of any necessary modification of the smart grid logic.

CONCLUSION

Paper questions the sustainability of the network with the passive DGs. The DG is given an option: to remain passive network user (conservative approach), or to become responsible entity (advanced approach) contributing to voltage stability in the local network thus participating in network control. Distribution of responsibility (among DSO and DGs) for maintaining of voltage stability is inevitable and becomes fundamental precondition for the preservation of the integrity of the system and for ensuring adequate parallel operation of DG and the network.

Smart meter is no longer just the electricity metering point, it has important role in DG and network control. Smart meter becomes the indicator for setting the voltage regulation and protection.

Paper introduces voltage control in real time (performed by DG) based on decisions out of real time (based on the DSO's network analysis and measurements by the smart meters).

The idea of restoring the dignity and responsibility of the engineers, especially engineer's reasoning and the consequent conclusions, in long term will become the most important benefit of proposed concept. In the context of devaluation (often justified) of engineering status, it is important to improve the professional skills of engineers by exposing them to a decision-making process in which professional competence is immediately verified in practice. Instead of immediately generating self-learning programs for smart grids, the proposed concept encourages engineers to self-learn and to develop their own advanced thinking (smart) mechanisms.

Proposed concept allows and compels professionals to study the interaction of real DG within the real distribution network in real time, and to understand each deviation in network behaviour due to the DG integration, enabling the engineers to prepare for future challenges of controlling the decision-making process in on-line operation of self-learning software in future smart grids.

The paper gives a concept of simple and easily applicable gradual model of controlling the network conditions through the integration of DG, that might, if well developed and consistently applied, immediately be implemented and effective, not implying completeness, nor necessity of imminent transition to the next level.

REFERENCES

[1] 2006, "The general conditions of electricity supply", Croatia, *Official Gazette* no. 14

[2] 2006, "The grid code", Croatia, *Official Gazette* no.36

[3] 2012, "The tariff system for electricity production from RES", Croatia, *Official Gazette* no.63 and no.121

[4] M. Čavlović, 2011, „Challenges of Optimizing the Integration of DG into the Distribution Network“, *Proceedings, 8th International Conference on the European Energy Market*, Zagreb