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EXTENDED VOLTAGE CAPABILITY OF DECENTRALIZED GENERATION

SAŽETAK

Mrežna pravila su općenita pravila koja OPS, ODS i ostali korisnici elektroenergetske mreže moraju poštivati kako bi se osigurala stabilnost sustava. Dodatna pravila se primjenjuju na proizvođačke jedinice. U Njemačkoj postrojenja distribuirane proizvodnje moraju zadovoljiti velike zahtjeve po pitanju dinamičke potpore mreži. Npr. elektrana se ne smije odspojiti od mrežnog napajanja u slučaju trajnog prenapona i do 130 % Un.

S obzirom da su takvi zahtjevi u sukobu s funkcijom uređaja relejne zaštite elemenata distribuirane proizvodnje, A.Eberle je razvio uzdužni sustav regulacije napona koji omogućuje da oba zahtjeva budu ispunjena.

Takvi regulatori se također mogu koristiti i u nn mrežama u kojima postoje naponske oscilacije, jer on stabilizira napon unutar predefiniranih granica i kao takav zadovoljava zahtjeve na kvalitetu napona.fluctuation problems, as it stabilizes voltage within preset limits and as such meets demands for power quality.

Ključne riječi: mežna pravila, distribuirana proizvodnja, regulacija napona

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SUMMARY

Grid codes are global rules that TSOs, DSOs and other participants in electrical network must obey in order to ensure system stability. Additional rules are applied on energy generating systems. In Germany distributed generation units must meet high demands concerning dynamic network support. For example, DGU must not be disconnected from the mains supply in the event of continuous overvolatge of up to 130 % Un.

Since such demands are in collision with generation unit's protection devices, A. Eberle developed longitudinal voltage regulator system which enables both conditions to be fullfilled.

Such regulators can also be used in low voltage networks with voltage fluctuation problems, as it stabilizes voltage within preset limits and as such meets demands for power quality.

Key words: grid code, distributed generation, voltage regulation

1. INTRODUCTION

Guaranteeing the voltage and quality of power is a significant challenge for distribution grid operators (DSOs) due to a change in power flows associated with a continuous increase in feeds resulting from added distributed generation. In the topology of current low voltage grids the loads are supplied mainly from a system of central power stations, which means that distributed renewable generation can increase the voltage to unacceptable levels.

In Germany, a country with one of the largest renewables install base in the world, where just photovoltaics exceed 38.5 GW installed power, the grid operators, especially in rural and suburban areas, have already a great difficulty meeting the voltage ranges prescribed by the VDE-AR-N 4105 the German low-voltage guideline [4], which state that decentralized generators may not increase the voltage by more than 3 %. At same time, the regulators/legislators are pushing energy companies to implement technical systems that help guarantee the quality of power in situations of maximum feed.

In most countries this is also a real issue for the low voltage grids, which are already operating at the limit of their voltage range, restricting the acceptance of deeply needed low carbon foot print new renewable generation capabilities. In general this phenomenon is ignored due to the perceived rise in costs when attempting to solve such issues via line reinforcement.

Voltage controllers along the supply route can be a cost-effective alternative to the expansion of the grid if the short-circuit capacity and the thermal transfer capacity of the system is sufficient. Depending on demand, voltage controllers can be adjusted by selecting the right set point value. The voltage range needed to feed the controller can increase considerably.

To respond to this reality, a smart Low Voltage Regulation System (LVRSysTM) has been developed at A. Eberle GmbH & Co. KG in Nuremberg, Germany. This system can be installed directly on selected feeders located after the distribution transformer, with the aim of handling over and under voltages. A number of grid operators have taken the leap of implementing such low voltage regulation systems mainly because of their ability to retrofit individual feeders and decouple phases, resolving the regulation problem without affecting the entire grid situated behind distribution grid transformers.

This paper is introducing the general regulatory aspects related to the low voltage distribution grids highlighting the challenges for the DSOs in the low voltage level. The discussion continues by outlining the planning required for installing such systems and it is followed by a description of the LVRSysTM modus operandi. Essential aspects related to a pilot install of a Low Voltage Regulator system are provided next. After that the issue of the low voltage grids and the issue of the integration of renewable energy sources into the high voltage level will be linked, followed by conclusions and upcoming steps.

2. DISTRIBUTION GRID OPERATORS (DSOs) CHALLENGES [7]

The European distribution system has a three-phase character all the way to the connection point of various loads (e.g. households). At this point the typical connectivity is a TN-C-S system providing a separate three-phase supply with separated neutral and earth.

The DSO EU distribution system (see Figure1.) spans usually between the Medium / Low Voltage transformer substation and the connection point with maximum connector lengths of 200m in urban areas and 400m in rural areas (due to reduced end of line loads).

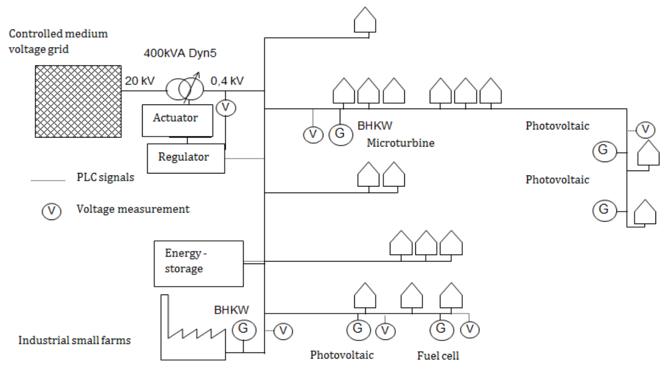

FIGURE 1. European Medium/Low Voltage grids

The tri-phase system is designed symmetrical, with the nominal voltage Line-to-Neutral of 230Vac and Line-to-Line of 400 Vac. The angle between each phase voltage vectors is usually set at 120°.

The usual constant loading of the distribution wires should not exceed 60-70%, therefore a higher wire loading will force the DSOs to expand the grid.

Since the DSOs are responsible for a secure and reliable power distribution across their networks requirements and restrictions are implemented when connecting loads or distributed generation across.

As such two key metrics (see Figure 2.) are to be considered in distribution networks:

- ±10 % tolerance for voltage excursions measured at the point of connection in most EU countries (± 6 % in UK) based on DIN EN 50160 [3].
- Maximum of 3 % voltage increases in rural and suburban areas by distributed generators as prescribed for instance in Germany by the VDE-AR-N 4105 low-voltage guideline [4].

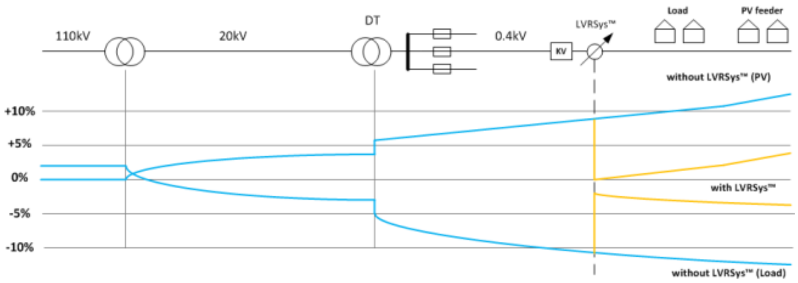

FIGURE 2. Distribution grids with Medium/Low Voltage Regulation

Guaranteeing the quality of power represents a challenge for grid operators due to a dramatic change in load flows associated with the significant increase in volatile in feeds resulting from the energy transition due to accommodating of ever increasing low voltage generation. Low voltage grids that are already operating at the limit of their voltage range are affected the most.

In addition to this technical reality, legislators are pushing DSOs to implement electronic systems that help guarantee the quality of power in situations of maximum feed.

DSOs are discussing different approaches to keep the voltage stability and the grid quality under control: expand the grid, use inverters with reactive power capability, use smart low-voltage regulation devices or install controllable local grid transformers.

The low-voltage grids that do not have enough short-circuit capacity to integrate additional decentralized supply units need to be expanded. However, expanding the cables to solve the voltage problem is inefficient and expensive, as can be seen from the following calculation: a 3 % increase in voltage is achieved by connecting a low-voltage cable (150 mm2 width, 500 m length) to a decentralized generation plant with a capacity of 45 kW, in this case only 25 % of the cable‘s capacity is used.

Even though expanding the cable network at first glance appears to be a good way of increasing the short-circuit capacity, it is far too expensive as a solution for just cancelling out short lived local over and under voltages.

If the grid‘s short-circuit capacity is sized properly, DSOs can attenuate almost to zero the over and under voltages in more cost effective ways (e.g. by feeding-in reactive power, which under normal circumstances can reduce voltage peaks).

Inverters, part of photovoltaic systems that feed-in reactive power, can become suitable for grids with a small R/X ratio, in particular at the medium-voltage level.

In Germany according to the same low-voltage guideline VDE-AR-N 4105, systems installed after January 2012 must be able to feed-in reactive power to prevent voltage peaks so they are available to a large extent in the grid. But at low-voltage levels, a lot of reactive power would have to be fed-in in order to achieve a noticeable decrease in voltage. The reactive power feeding is an interesting approach in terms of costs, but for the reasons stated above, does not make much sense for low-voltage grids (where cables have a high R/X ratio). In addition, one should not forget that feeding reactive power puts an additional stress on the entire grid and shifts the problems to upstream (MV) voltage levels.

As an alternative approach, using controllable local grid transformers, at first glance, seems to be an effective way of guaranteeing grid quality. Such units increase the grid's capacity because they can reduce the voltage centrally, meaning that the grid operators do not have to undertake extensive cable expansions. Controllable local grid transformers are part of the three-phase equipment, meaning that they are unable to control asymmetrical states. Controllable local grid transformers are technically meaningful if the grid operator can accurately predict that the voltage stability will remain within prescribed bounds in the next 20 years.

Due to such challenges DSOs are having an increased interest in low voltage regulation systems, which can complement local grid transformers by retrofit. Such systems comply with the added requirement that the low voltage grid should continue to operate in the event of such a system failure or maintenance outage.

3. ENHANCING DSOs CAPACITY BY LOW VOLTAGE REGULATOR [1]

Grid improvements, either by line extension or low voltage regulation, are essential since power flow reversals could spike the voltage over allowable limits.

This can happen for short or long periods of time due to new customers attempting to add their own distributed generation capabilities onto an already stretched grid.

The first steps in quantifying the need for such low voltage regulation systems is to implement and evaluate the line expansion versus regulation solutions into simulation systems available enabling planning with foresight.

The objective of such an analysis is to ensure that the DSOs can significantly improve the quality of the grid by an efficient infrastructure costs.

Typical steps taken in assessing the opportunity for installing a low voltage regulator are:

- Measurements of voltages in the grid „hotspots“
- Finding the voltage stability problems in the grid
- Calculation and comparison of solving over voltages with line expansion vs. active voltage controls
- Simulation of the controller placed online (e.g. LVRSys™)
- Decision to build up a low voltage controller
- Decision on where controller is most useful
- Establish the most appropriate controller power rating

4. LVRSYSTM – BIDERECTIONAL STEPPED VOLTAGE REGULATION [8]

Using an innovative control system researched and developed at A. Eberle GmbH & Co. KG a Low-Voltage Regulation System (LVRSysTM) has been designed and produced to address the above listed challenges and allow for a hassle free integration into the DSOs grid.

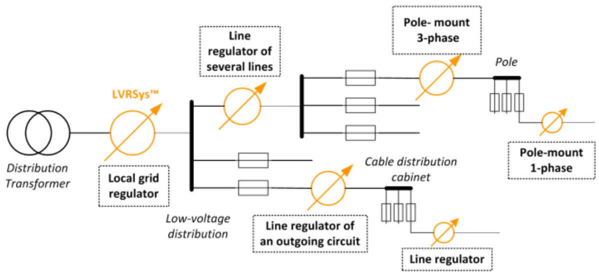

FIGURE.4. LVRSysTM typical deployments

Such systems can be seamlessly attached to the uncontrolled local grid transformers feeders or bus bars, considerably boosting their functionality (see Figure 4. examples). In addition, the regulator is not linked to the local grid transformer.

The LVRSysTM simple and cost effective design enables all three phases to be controlled independently of each other and hence to compensate phase asymmetries.

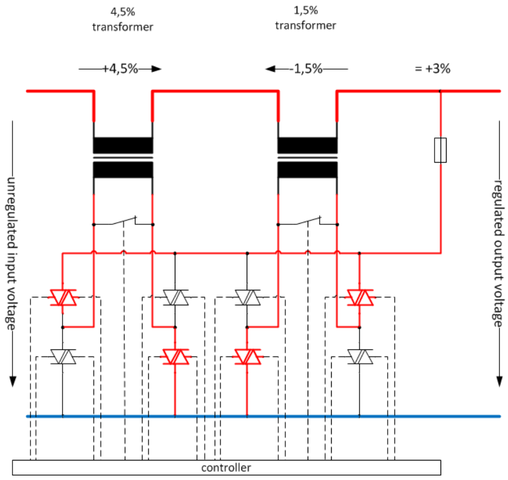

FIGURE 5. LVRSysTM typical construction

As also shown in Figure 5, this equipment relies on feeding an additional voltage (e.g. 1.5 % and 4.5 % of the nominal voltage) through auto transformers, which, based on the demand, have an increasing (in phase) or decreasing (out of phase) effect of ± 6 %. This value can be modified by an appropriate selection of the autotransformers ratios up to 10 % (obtained via 2.5 % and 7.5 % of the nominal voltage). A finer step size can be obtained by adding flexibility by third 0.5 % transformer.

The direction (summation or subtraction of % values) is determined by connecting the auto transformers primary winding through a thyristor bank, driven by a REG-LVR electronic controller. The bank switches the primary side of the additional transformer so compared to the current phase, the current through the semiconductors is very small leading to a very small power loss of the system (below 1 %).

Galvanically isolated signals are logically split from the switching stage, which is determined by the low-voltage regulator. Robust and maintenance-free power semiconductors function as actuators. If an error occurs or the secondary electronics need maintenance, a contactor is activated and bypasses the unit. The local grid keeps working without the regulation unit. The service switch is also active during maintenance work on the transformer, enabling the local grid to keep working without the regulation unit. The operator keeps the grid up and saves costs at the same time.

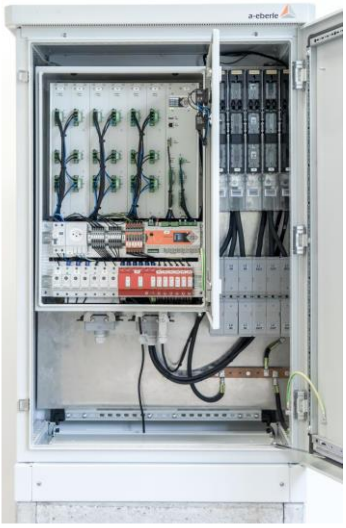

FIGURE 6. Low Voltage Regulator System (LVRSys™) components (70 kVA rating)

To avoid dynamic processes as much as possible, customers can define and set a dead band (tolerance range). If the voltage is within the predefined range, the regulator is in automatic standby mode. If the voltage is outside the predefined range, automatic regulation is active. For example, if the dead band is set to ± 5 %, the control range increases by ± 6 % to ± 11 % of the nominal voltage. If needed, the regulator can also take voltages measured on the critical nodes into account. This guarantees that no voltage point in the grid is outside of the predefined limits.

5. PILOT INSTALLATIONS PERFORMANCE CHARACTERISTICS [2]

More than 300 systems have been installed in various utilities to address:

- Voltage instability caused by renewable energy
- Voltage instability caused by changed loads (e.g. heat pump or electro mobility)
- Unbalance caused by one phase loads/feeders
- Energy savings in the industry sector

The use of LVRSysTM did not cause any rapid voltage changes or have any impact on the power quality measurements (e.g. harmonics or flicker).

The asymmetry of the phased voltages can increase slightly, an expected behavior, but with one pair of auto-transformers per phase the LVRSysTM can regulate all three phases independently.

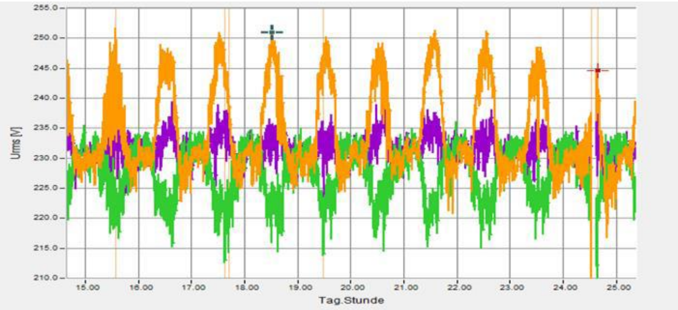

FIGURE 7. Low Voltage when the grid is NOT CONTROLLED

In Figure 7. the behavior of a three-phase power network in an Austrian village of Eberstalzell, over a 10 days period can be observed. For this particular example distributed generation was applied to a specific phase (orange curve) similarly with loads serviced by a different phase (green curve). This situation was envisaged by the power utility due to the feeder and DG generation available. Unwanted excursions voltage swells violating standards were common.

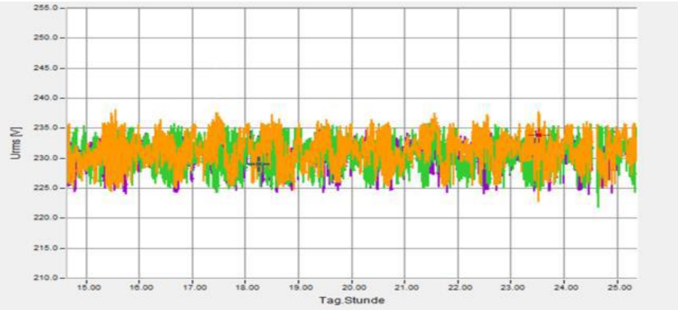

FIGURE.8. Low Voltage when the grid is CONTROLLED with LVRSys™

In Figure 8. it can be examined the voltage at the LVRSysTM controller output can be viewed that which has been carefully being brought within the range and tolerance band required.

It can also be seen thathow the phases were independently controlled. ButBy choice the output voltage dispersion was kept to a certain level to minimize the number of step changes ensured by the controller.

6. LOW-VOLTAGE-REGULATION FOR THE INTEGRATION OF POWER GENERATION PLANTS INTO THE HIGH-VOLTAGE-GRID

6.1. Grid code

The grid and the operating system rules of the transmission system operator, also called grid codes or transmission codes, are considered the mandatory requirements for generating plants on the high- and extra-high voltage grid. In Germany the regulation VDE-AR-N 4120 [5] is used. When grid codes are applied, and they are applied globally, the system stability is at the forefront of the operating strategy for all grids.

6.2. VDE-AR-N 4120 [5]

The VDE-AR-N 4120 describes the technical conditions for the connection and operation of customer systems to the high-voltage grid (technical connection conditions). The application rules apply to the mains connection such as flicker, harmonics levels or reactive power behavior.

Specifically for generating plants there are rules which provide grid services. To fulfill these requirements the manufactures are allowed to use additional devices. This must be taken into account when the certificates of the power plant are prepared.

Figure 9. WIND TURBINES with LVRSys™ installation

6.3. Essential requirement for voltage stability of the Quasi-steady operation mode (47.5 Hz to 51.5 Hz)

Generating plants must not be separated from the mains of the grid when the voltage is in the range of 96 kV to 123 kV. This corresponds to an extended voltage range from UN -13 % to UN +12 %. Stress gradients < 5 % UN / min are regarded as quasi-stationary.

In the case of a 10 % voltage deviation, the generating unit must not disconnect from the grid, if the generating system was previously in a steady state.

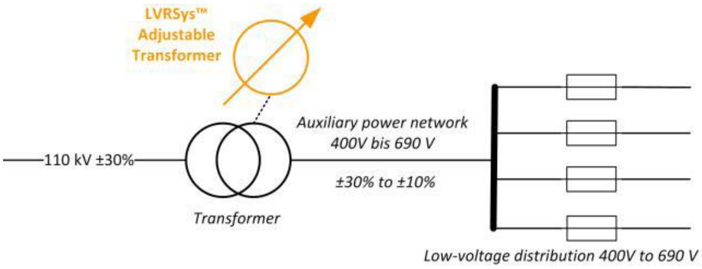

Figure 10. Adjustable transformer for the auxiliary power network

6.4. Dynamic grid services

The dynamic grid services should prevent unwanted disconnections of generation power and thus a threat to grid stability. A generating plant shall not disconnect from the mains of the grid at:

- 1.30 UN for 100ms

- 1.25 UN for 20s
- 1.15 UN for 60s
- 0.80 UN for 60s

Many components in the generation plant are not designed for long-term over-voltages.

6.5. Low-Voltage-Regulation-System LVRSysTM

The LVRSys™ mitigates overvoltages within 15-25 ms and improves static voltage stability within the generating plant. The longitudinal regulator system helps to attain the requirements and hence obtain certificates according to VDE-AR-N 4120. The system can be used in three phase 400 Vac as well as in 690 Vac grids. Because of the compact design, it can be easily integrated into customer-control cabinets.

The system can be understood as a backpack for distribution transformers. The control takes place directly at the transformer (controllable local distribution transformer). However, the control speed through the thyristor technology is significantly faster.

Important points:

- Integration into customer-specific control cabinets
- Response time <25 ms
- Grid voltage level 400 V and 690 V
- Version as longitudinal controller without distribution transformer
- Version as a controllable transformer with thyristor technology The dynamic grid services.

7. SPECIAL CONTROLLER BEHAVIOR FOR THE HVRT CAPABILITY

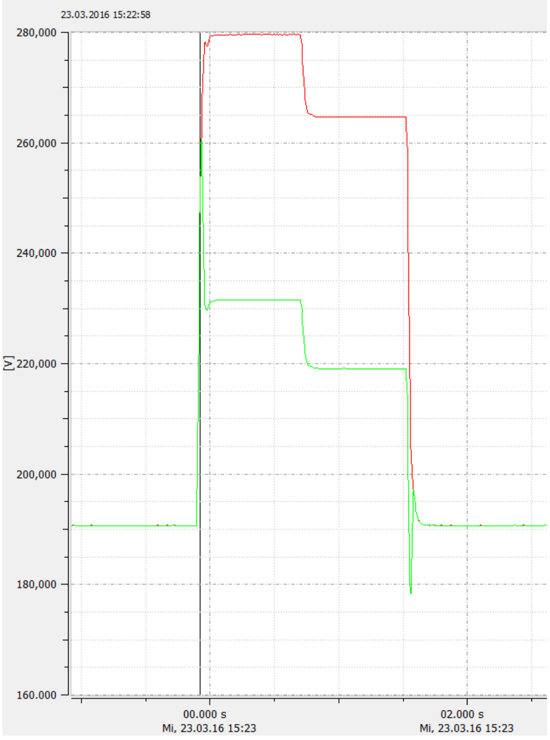

Figure 11. Time reaction of the controller (red: input voltage / gren: output voltage)

The controller permanently measures the output voltage of the LVR-System. The measurement period is based on a 10ms trms value. If one voltage exceed the limit of +10% of the rated voltage, the controller lowers the output voltage with the maximum speed of the thyristor power stage. The reaction time of the measured voltage deviation and the voltage reduction is 15 ms. Figure 11 shows the input compared to the output voltage while overvoltage occurs.

8. CONCLUSIONS AND FUTURE WORK

In determining the desired value, the associated voltage regulator can consider the voltage at the distribution transformer and the critical nodes in the depth of the energy network and enables decentralized power generators to fulfill the connection conditions to the high voltage grid. This control strategy allows voltage optimization across the entire low voltage grid based on measurements at critical nodes, which are points with over-voltage and under-voltage equipped with remote voltage measuring devices.

The installation of an LVRSysTM, sometimes in combination with a SCADA system or a RONT (regulated distributor transformer), is among typical application scenarios. The respective grid configuration defines whether it makes more sense to use the controller on the bus bar or in conjunction with the RONT.

Various DSOs experienced that LVRSysTM can be brought into the grid interactively allowing for flexibly when to install and service the system. It also allows for the low voltage grid to continuously operate in the event of a failure or maintenance outage. The different versions of this system can be easily mapped into simulation network elements enabling planning.

Several appropriately sized systems were installed in several power networks providing a stable control of output voltage levels in the 230 Vac range as per the specifications.

The main benefit of these applications is that the system is able to adjust individual voltages and reduce asymmetries when installed in local grid sections maximizing the ability to absorb new renewable generation sources installed in the low voltage grids.

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