INTERACTION OF MV- AND LV- AUTOMATION SYSTEMS FOR A SMART DISTRIBUTION GRID

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ABSTRACT

The electrical energy sector is in a fundamental changing process. The integration of decentral renewable power plant and new electrical devices, like electrical vehicles, cause critical situations in the distribution grid. Smart grid systems can solve these situations. Nowadays there are smart grid solutions for the medium or the low voltage level. These systems work decentral (semi-) autarkic and consider only one single voltage level although there are huge interdependencies between the different levels. For this reason this paper starts with the approach to build up a holistic smart grid system for the complete distribution grid. Such a system can provide a reliable energy system in a more efficient way. As a first step, the interactions between medium and low voltage smart grid systems are shown in this paper. Especially the ability of the low voltage system to be an aggregated medium voltage actuator is presented. The low voltage smart grid system aggregates all actuators for the medium voltage and provides reliable actuator flexibility. Possible aggregation modes and control strategies are shown and it is evaluated how low voltage grids can be used as a medium voltage actuator. Especially the assessment of the actuator flexibility is in the focus of the paper. For this reason, different simulations have been carried out. It will be shown, that the combination of both LV- and MV-systems in a holistic smart distribution grid will open up huge synergy effects.

INTRODUCTION

During the last decade the energy revolution has been changing the electrical energy sector dramatically. Especially the modification of the energy supply and the energy consumption are challenging the distribution grid, because the earlier top down principle isn't applicable anymore. The integration of renewable decentral power plants and the new load situation, caused e.g. by electrical vehicles in the low voltage grid, turn the system to the bottom up principle. These changes induce critical grid situations like violations of voltage boundaries or overloads of assets. [1]

One solution to avoid critical situations and to operate the distribution grid sustainable, affordable and reliable is the use of smart grid systems. These solutions provide a grid state analysis and a control action in critical situations. Different systems (like iNES – intelligent distribution grid management system [2],) with a variation of functions are available or under development. Nowadays, these solutions are designed either for the low or the medium voltage level (LV or MV), but a solution for both voltage levels has not been developed yet. [3]

The combination of both LV- and MV-automation systems present a cost efficient way to automate the distribution grid, because an integrated approach can reach various synergy effects. [4] [5] Besides the main function of monitoring and controlling the low voltage grid, every LV automation system can be used as a measurement and an actuator for the MV system. [6] A possible automation system structure is shown in Fig. 1. This structure presents a holistic automation system, which can be realized with different control strategies presented in [7].

Depending on the chosen control strategy, the LV automation system has to realize the defined functions of the holistic system. Nevertheless, the main function of the low voltage system (monitoring and controlling of the LV grid) has to be satisfied before other functions can be provided. This causes a lot of restrictions, which have to be considered by the implementation of the holistic system. If the grid conditions is very critical and a blackout can be avoided by violation of the LV restriction exception can be implemented and considered.

This paper assess the ability of LV-grids to be a part of a holistic smart distribution grid.

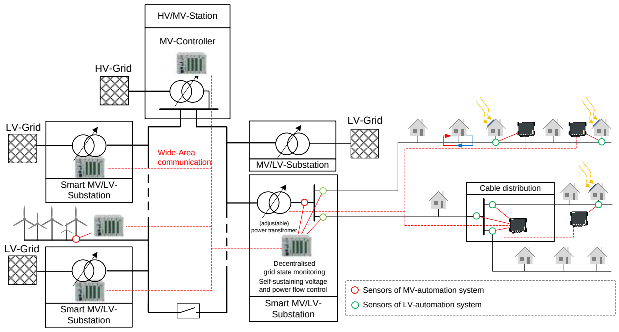

Fig. 1: Possible structure of a holistic automation system for low and medium voltage grids

SMART GRID SYSTEM FOR THE LV

The primary objective of a LV smart grid system is to provide a reliable and secure grid state in the LV grid. This is possible by monitoring and controlling the system with a smart grid system like iNES. Such a system can estimate the grid state by using a small number of measurements and solve critical situations by using available actuators. [2]

The system is installed in a single LV grid and runs decentral (semi-) autarkic. To solve critical situations in the grid different actuators are needed. On the one hand, there are grid actuators like on-load tap changers (OLTC) in the MV / LV substation and cross regulators as well as different user devices like photovoltaic power plants or electrical vehicles providing actuator flexibility and acting as a power actuator. Further information about the LV-smart grid function can be seen in [2] and [8].

At closer examination, it turns out that the LV smart grid system is installed for a small number of interventions a year. For example in a grid with huge photovoltaic penetration, the smart grid system has to intervene at situations with high infeed and low power demand like some sunny Sundays in the summer. [4] For the rest of the time the system observe the grid and doesn't intervene but the infrastructure is available and prepared the whole time. This availability time can be used for the MV grid and synergy effects can be achieved.

The installed actuators can provide flexibility for the MV grid but especially the user device actuators, which can directly control the power are relevant for the MV controller. Also the grid actuators can be used to increase the LV grid flexibility.

AGGREGATION OF THE FLEXIBILITY

The interaction between MV and LV smart grid system is referenced to the substation because this point of coupling is the border between MV and LV. The MV controller is responsible for the MV grid and the LV controller for the LV grid. For this reason the substation is the aggregation point for the holistic system. The LV controller has to aggregate the actuator flexibility to this point. This aggregation is also decentral autarkic because the internal behaviour in the LV grid isn't relevant for the MV controller. The following actuators are applicable for the MV smart grid system.

Applicable Actuators of the LV for the MV

The integration of the LV controller into the MV controller as an aggregated actuator has to consider which controllability is needed for the MV system. To keep critical situations under control the MV controller can use different MV actuators like grid- and power actuators. It has to be considered that the LV grid actuators haven't a direct influence on the MV grid.

For this reason only the LV power actuators are relevant for the MV controller.

At the substation occurs a power flow dependent on the power demand and supply. This power flow fluctuates and influences the MV grid. A typical power fluctuation of LV grids is shown in Fig. 2. The control intervention of the LV controller for the MV system has to superimpose this course for an effective influence. Especially sharp variation of the course influences the MV grid state, these variation can be controlled by the LV actuators.

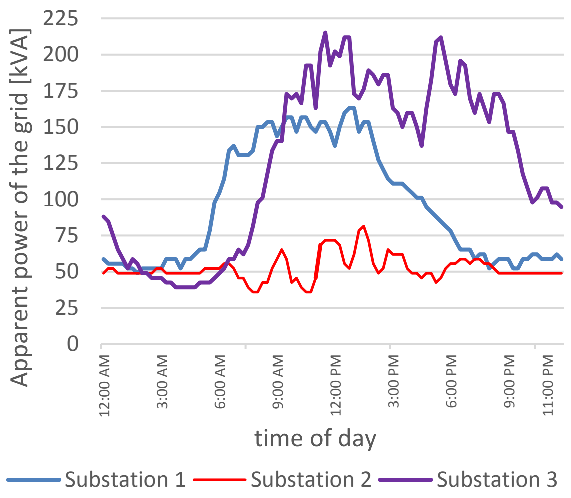

Fig. 2: Intraday power flow course of LV grids

The maximum variations of active and reactive power at the substations are presented in Tab. 1. This variation is the maximum change of two consecutive measured values in the observation period.

By the development of a holistic system these fluctuations and the fluctuation of actuator flexibility have to be considered because the fluctuation needs enough compensation flexibility. This can be solved by using a lot of MV- and LV actuators. A huge number of actuators provide a reliable flexibility, so that the MV smart system can solve every critical situation.

Tab. 1: Fluctuation of the power at the MV/LV substation

Grid	maximum ΔP [kW]	maximum ΔQ [kvar]
1	11	3.6
2	18	6.6
3	8.4	4.2
4	6.8	4.1
5	26	20
Grid	**average ΔP [kW]**	**average ΔQ [kvar]**
1	1.6	0.6
2	4.2	0.9
3	1.7	0.7
4	1.4	0.6
5	3.8	2.2

Aggregation Process of the Flexibility

The LV flexibility provided for the MV system can be categorized into two influence classes. Each class is divided into active and the reactive power.

1. Reduction of the power supply;
   Respectively, increasing power demand
2. Reduction of power demand;
   Respectively, increasing of power supply

This two classes define the flexibility of the LV grid at the substation. The aggregation of all LV actuators could be done in different ways. The following three modes are under development and for both classes equal. For this reason each actuator flexibility is considered in the associated factor.

$$Flex_{Mode1} = \sum_{n=1}^{n} ActuatorFlex(n) \quad (1)$$

$$Flex_{Mode2} = \sum_{n=1}^{n} ActuatorFlex(n) - GridRest(n) \quad (2)$$

$$Flex_{Mode3} = \sum_{n=1}^{n} ActuatorFlex(n) - GridRest(n) - Pred(n) \quad (3)$$

The result ($Flex_{Mode}$) is the aggregated sum of the available actuator flexibility. For example the sum of reducible active infeed power (class 1 active power). The total flexibility considers all actuators with the control variable n.

In mode 1 the total available actuator flexibility will be considered. Each actuator provides the full or maximum control degree of freedom. The aggregation is very simple and provides a maximum of flexibility but LV grid restrictions aren't considered. In some cases the LV grid state limit the flexibility because otherwise the full use of LV flexibility for the MV causes problems in the LV grid. For this reason mode 2 considers grid restrictions. The grid restriction (GridRest) is subtracted from the total actuator flexibility. This is implemented by using the sensitivity matrix. [9] The aggregation process tests for each actuator flexibility, if the control intervention causes a critical situation for the LV grid. These test provides the maximum actuator flexibility which is possible with the installed actuators and the available LV utilities.

The mode 3 aggregation subtracted another part of the flexibility. The MV controller needs reliable actuators, which are available for the most time with the announced flexibility. Therefore a prediction of the actuator flexibility is integrated, which considers how long the announced flexibility is available. If the actuator provides the flexibility for the next for example ten minutes the flexibility is short term reliable and can be announced. By these aggregation it has to be considered that the prediction is an estimation with different confidence interval.

All these aggregation modes consider different types of actuators and provides a different quantity of flexibility. It must be pointed out, that the aggregation of active and reactive power is carried out independently of each other. These provides the maximum announcement of flexibility but these maximum isn't available at once. For this reason the use of the active and reactive flexibility has to be successive and the flexibility potential has to consider the influence of the previous control command. This difficulty has to be implemented in the control strategy of the MV controller, because this controller has to decide which flexibility is needed.

Exemplary assessment of the LV Flexibility

To assess the LV flexibility the aggregation modes 1 and 2 are tested at a rural LV grid. The grid includes a total number of sixteen actuators see Tab. 2.

Tab. 2: Available actuators in the assessed LV grid

Actuator	Number	Flexibility
On load tap changer	1	± 7.5% of voltage
Photovoltaic plants	7	Total 285 kW
Electrical vehicles	5	Each 44 kW
Electrical vehicles	3	Each 23 kW

This rural LV grid is simulated for different purposes. (Reliability of the actuator flexibility, influence of a OLTC and the difference between mode 1 and 2)

Fig. 3 shows the actuator flexibility for one week. It is a constant intraday apparent for the reducible active power supply. This is caused by the dynamic infeed of the photovoltaic plants. The reducible active power demand applied by the electrical vehicles is randomly and unpredictable. Therefore fig. 3 shows that the LV grid is a volatile actuator with some sudden flexibility changes. To build up a more reliable system mode 3 has to be developed and implemented. Especially supply and demand prediction can help to provide reliably flexibility.

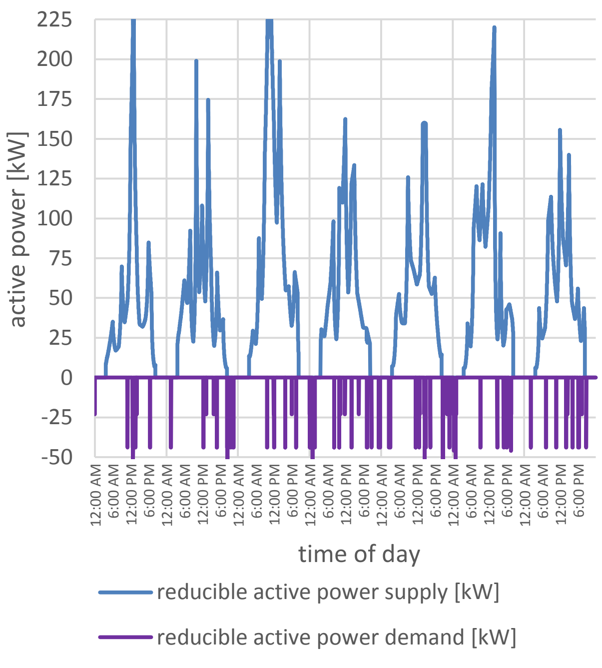

Fig. 3: Weekly curve of active power flexibility

In fig. 4 mode 1 and 2 are compared for one day. It can be seen, that mode 1 and 2 aren't so different. Only at three times mode 2 has to limit the actuator flexibility because of the grid restriction. These restriction is only at the reducible active power supply because in this moments a reduction of the infeed caused an under voltage fault.

These result is very grid dependent because the position of the actuator and the critical situation is essential for the situation. Especially the sensitivity matrix has to be considered, because each branch and the included actuators have a different influence on the LV grid.

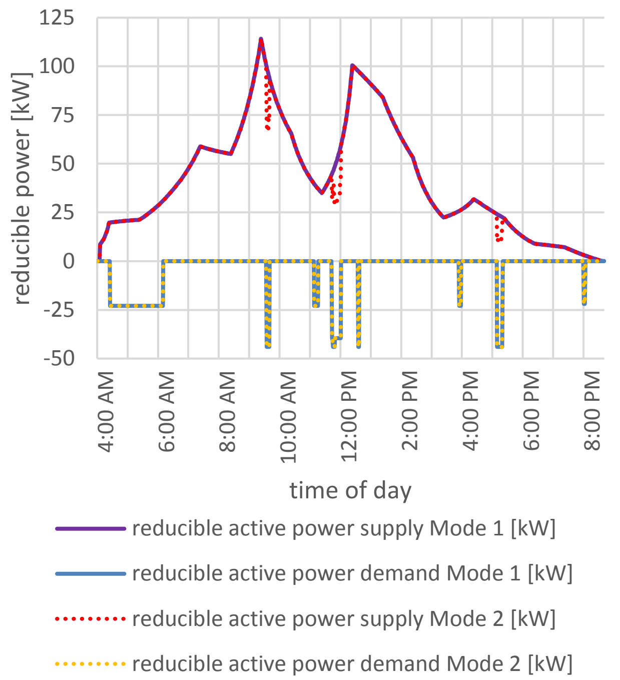

Fig. 4: Comparison of mode 1 and 2 for one day

The last investigation assess the influence of an OLTC to the LV flexibility. Fig. 5 shows the active power supply flexibility of the grid for three days. It can be seen, that the OLTC increase the available flexibility. The OLTC helps to hold the voltage in the allowed range. By using the actuator flexibility the OLTC stabilises the voltage and the maximum actuator flexibility is available for the aggregation without causing a critical situation in the LV grid. For this reason also the grid actuators helps the LV system to provide flexibility. The use of the grid actuator for the LV aggregation causes abrasion. These increased wear has to be considered so that maybe the grid operator restrict the use of grid actuators for the MV controller.

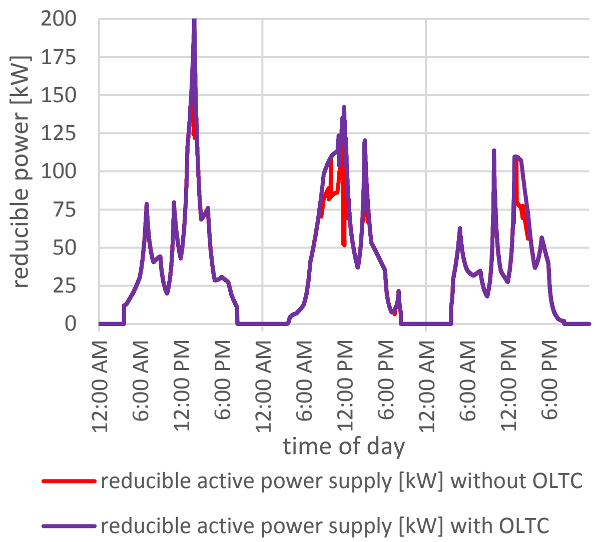

Fig. 5: Assessment of the OLTC influence

UTILISATION OF THE LV FLEXIBILITY

To build up a holistic smart grid system for MV and LV both controller have to interact with each other. By implementing an interface in every controller the systems can work together. Especially by changing the counterpart a universal interface is helpful. A possible interaction can be done step by step. The substation measurement can be used for the MV grid state identification all the time and the LV smart grid system works as an MV measurement. The effective control process is independent of the measurement. The use of the flexibility starts with the aggregation of all LV actuators. The aggregated flexibility will be announced to the MV controller. When the MV controller detects a critical situation, it will consider the LV flexibility and send an effective control command. The LV controller gets the control demand and realizes the intervention. These realisation can be done on different ways because the LV controller has a lot of possible opportunities to implement the control command. For this reason the LV controller has to consider a LV optimisation and control the chosen LV actuators for the MV system. The following LV optimisations are possible.

1. Minimize the LV influence
2. Reduction of the LV grid losses
3. Reduction of compensation payment
4. Equate the utilization time of actuators
5. Considering predicted critical LV situations

When the critical situation is over the MV controller has to reset the LV controller so that the intervention can be stopped and all actuators can work autarkic again. Without a reset the reduction of infeed or demand doesn't stop and energy losses or compensation payment increase unnecessary.

CONCLUSION

The presented results demonstrate that a LV smart grid system can be a useful and reliable MV actuator. The possible actuator flexibility of the LV system can be easily implemented into a MV control strategy. Especially the different aggregation modes provide a reliable announcement of flexibility. These implementation will create synergy effects and increase the cost efficiency of smart distribution grids.

With an increasing number of actuators the reliability of the flexibility increases too. Especially by implementing a lot of different kinds of actuators the reliability of the flexibility increases, too. Also the usefulness of a prediction systems is shown. With a flexibility prediction the MV controller can use the actuators more effective and future critical situations can be solved before they occur.

The LV flexibility and reliability is grid and utilisation depended, for this reason an individual review of each grid is necessary. In order to derive general findings more simulation investigations and a field test will be done in future.

Also the efficient use of the LV flexibility in the MV controller needs further investigation, because the behaviour and properties of aggregated LV actuators are not invariant. The amount of flexibility is smaller than the common MV actuators but with an increasing number of LV smart grid systems the MV controller can use numerous small efficient units at the critical node. Especially the interaction between MV and LV controller has to be implemented with a general interface that different applications can work together. Also incidental activities are needed for a secure communication and a reliable system.

The approach to build up a holistic smart distribution grid is the next step to provide a reliable, save and environmentally friendly electrical energy system. The low voltage grids and the installed actuators can be a decisive factor in the holistic smart grid. The aggregation of LV actuators provides a significant flexibility potential for the MV grid which can be used to solve critical situations efficiently.

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