VOLTAGE QUALITY AND REACTIVE POWER FLOW SOLUTION IN DISTRIBUTION NETWORKS WITH A HIGH SHARE OF RENEWABLE ENERGY SOURCES

Karel PROCHÁZKA
EGC CB – Czech. Rep.
kprochazka@egc-cb.cz

František KYSNAR
EGC CB – Czech. Rep.
fkysnar@egc-cb.cz

David MEZERA
E.ON - Czech. Rep.
david.mezera@eon.cz

Petr VACULÍK
E.ON - Czech. Rep
petr.vaculik@eon.cz

Josef NOVOTNY
E.ON - Czech. Rep.
josef2.novotny@eon.cz

ABSTRACT

Dispersed sources can cause significant voltage changes in the MV and LV distribution grids, which common voltage regulation of the grid by on-load tap changing of HV/MV power transformers can neither find nor respond to in an appropriate and effective way.
In the proposed solution, stabilization of the voltage is preferably achieved by power factor or reactive power regulation (PF / Q) of connected sources. Voltage regulation of the power transformer operates when changing the voltage on the MV busbar in a substation, mostly when changing voltage in the 110 kV network. We consider this approach as a logical and appropriate to the nature of the rapid changes in power of wind and photovoltaic power plants.

INTRODUCTION

The installation of a growing number and power of resources in distribution systems began to show their influence not only on power flow changes from the superior power systems and on grid losses, but also on voltage conditions, short-circuit power in networks and behaviour of protections. These technical problems have long been discussed by international professional meetings and publications, most recently e.g. [2] and [3].

Before introducing (copying) the measures which respond to these changes there is a need to take into account both the potential impact of the growing number and power of dispersed generation (DG) connected to our distribution networks (DN), their options / obligations to compensate negative impacts on the DN, as well as real characteristics of our networks, elements and their voltage conditions.

The paper informs on the work [1], dealing mainly with the impact analysis of possible regulation measures - the reactive power control on power flow and voltage conditions in the chosen example grid with MV and LV sources, both based on data supplied by the network operator, and on the use of data from monitoring of voltage conditions in DS networks of the CR - delivery points from transmission networks (TN), supply points of the 110 kV networks, transformer output voltage of 110 kV/MV, voltage on the primary and secondary side of the MV/LV transformers and voltage at the LV supply point and in the LV grid. 100% of measuring intervals were evaluated with duration of 10 minutes.

2. THE LEVEL OF VOLTAGE IN THE CZECH REPUBLIC NETWORKS

Measurement point	No.	Umin [%]	Umax [%]	ΔUMax [%]
TN/DN (110 kV) -	62	103,1	111,9	8,8
PCC 110 kV	107	96,1	110,7	14,6
TR 110kV/MV-MV	238	91,4	109,2	16,2
TR MV/LV-MV	20	95,8	107.4	11.6
TR MV/LV-LV	80	95,2	110,5	8,8
PCC in LV	149	80,3	113,5	25,7

Table 1 Voltage fluctuation in DN

If we compare these values with the regulation range of 110 kV / MV transformers - mostly Un ± 8x2%, it is obvious that the regulation range with a relatively large reserve complies in all cases. In some 110 kV networks, voltage is maintained within relatively narrow limits; however, these are grids with large connected sources using reactive power voltage control, tap changes on TN/DN transformers are used minimally. Conventional MV/LV transformers have taps ± 2x2, 5%, corresponding to a 22 kV grid of voltage limits 20.9 to 23.1 kV and can be switched only off-load. Voltage changes in the MV grids are thus fully transferred to the LV grids and significantly reduce allowable additional voltage changes in the LV grids.
For networks with major sources, the voltage at the connection point can be higher than the voltage busbar, from which transformer voltage controller derives its activity and could even lead to allowable voltage limits violations, without transformer voltage controller activation. The solution may be, for example:

- Dispatcher PF/Q control of individual sources according to the grid conditions
- Autonomous control of voltage of individual sources, i.e. the change-over of selected sources

on Q = f (U) control mode

- Autonomous PF control based on the supplied active power (PF = f (P))
- The system of voltage control (PF/Q) in the grid coordinated with on-load tap changer

Due to the frequency of changes in power output of photovoltaic power plants (PV) and wind power plants (WT) source types and due to the fact that the change of the transformer taps affects the voltage in the whole grid and not only feeders where dispersed sources cause the undesirable voltage variations, we prefer to respond to voltage changes in the places where they occur, at the devices that are causing them and which in conformity with Distribution Network Code are obliged to support maintaining voltage in the grid, i.e. to choose PF/Q control at the sources management with suitable time reserve prior to the intervention of the tap changer.

Only if, after full using of capacity Q controllable sources, voltage in some network nodes remains outside the desired limits, then we need to consider the change 110 kV/MV transformer taps, but after checking the voltage in other parts of the grid.

POTENTIAL EFEECT OF PF/Q CHANGES

The aim of this section is to show the range to which connected sources are capable of influencing voltage in the grid by their supplied or consumed reactive power whose changes are caused by the active power delivery to the grid. We expect in accordance with Article 9.3.2 of valid rules (Distribution Code) that in delivery point to the DN there will be available reactive power corresponding to the supplied power and power factor within 0.95 inductive to 0.95 capacitive limits, which are the thresholds for mandatory static support of voltage in the grid, currently for sources with power above 100 kVA.

To enable to assess the sources with different power in different types of grids and various locations of sources we have defined voltage coefficient expressing the sensitivity of voltage at the connection point to the change in reactive power.

$$k_{UMV} = \frac{\Delta Q_{MV}}{\Delta U_{MV}} \left[\frac{MVAr}{kV}\right]$$

$$k_{ULV} = \frac{\Delta Q_{LV}}{\Delta U_{LV}} \left[\frac{KVAr}{V}\right]$$

As an example for a selected grid in Fig. 1 there are in Tab. 2 presented reactive powers, which are available from the selected sources connected in V780 feeder, when supplying maximum simultaneous active power value determined on the basis of measured values of 0,8 Pinst and within the PF range from 0.95 inductive to 0.95 capacitive, corresponding change in voltage and voltage factor. In the table there are shown the parameters for these two sources of WT1 and PV2, connected to the LV grids behind MV/LV transformer.

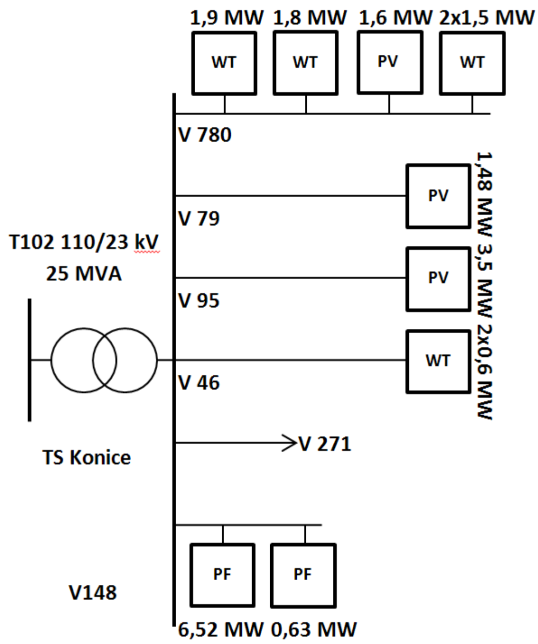

Figure 1 Example of a 22 kV grid with connected RES

WT 3, Zk=14,367 Ohm, 58,1°			k_{Uvn}
Pinst = 1900 kW	Q [MVAr]	U [kV]	[MVAr/kV]
extent	0,998	0,529	1,9
WT 2, Zk=11,428 Ohm, 59,6°			k_{Uvn}
Pinst =3000 kW	Q [MVAr]	U [kV]	[MVAr/kV]
extent	1,576	0,679	2,3
PV 1, Zk=16,248 Ohm, 51°			k_{Uvn}
Pinst =1600 kW	Q [MVAr]	U [kV]	MVAr/kV]
extent	0,842	0,461	1,8
Rest of MV DG, Zk= 2,42 Ohm, 80,77°			k_{Uvn}
Pinst=13336 kW	Q [MVAr]	U [kV]	[MVAr/kV]
extent	7,012	0,755	9,3
WT 1, Zk= 0,044 Ohm, 67,8°			k_{Unn}
Pinst =100 kW	Q [kVAr]	U [V]	[kVAr/V]
extent	52,6	5,0	10,5
PV 2, Zk= 0,031 Ohm, 68,4°			k_{Unn}
Pinst =164 kW	Q [kVAr]	U [V]	kVAr/V]
Variation	86,2	5,8	14,8

Table 2

PF in the range from 0.95 inductive to 0.95 capacitive conforms to current regulations in the Czech Republic. We assume that they will be in relation to the CENELEC

standards extended to 0.90 inductive to 0.90 capacitive and possible influence of PF / Q control on voltage will be higher.
The following Fig. 2 illustrates the theoretical course of voltage changes along the feeder and the possible stabilizing effect of the PF change. It is obvious that the PF/Q control can significantly reduce voltage increase caused by the supply of active power.

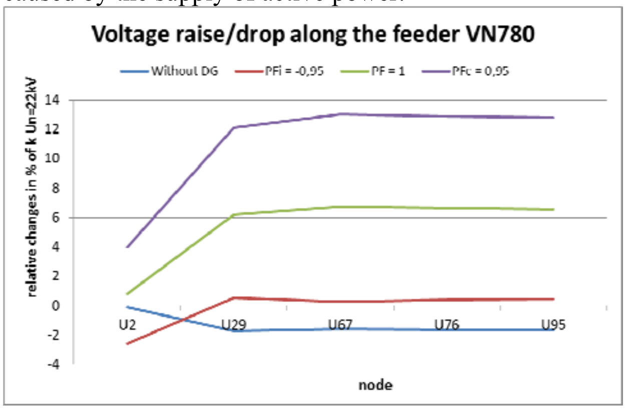

Figure 2

A PROPOSAL OF A CONTROL ALGORITHM OF VOLTAGE IN MV AND LV GRIDS WITH DISPERSED SOURCES

The proposed algorithm to stabilize voltage in MV and LV grids is based on the following assumptions and steps:
1) The monitoring of voltage on the output of 110kV/MV power transformer and in selected nodes of the MV and LV grids, monitoring of active and reactive power of individual sources in the MV grid.
2) Assessing whether the voltage change on the output of 110 kV / MV transformer exceeds specified limits and can be solved by automatic voltage regulation of the power transformer (criterion is long lasting deviation from the permitted voltage range, it is mainly the compensation of voltage changes on the 110 kV side, when voltage regulation at the sources in the grid could be useless)
3) When the voltage in some node (nodes) is outside the permitted limits, at first are determined the nearest controllable sources in the same voltage level (according to the impedance distance to the node with a non-standard voltage).
4) For controllable sources there is step by step identified a possible voltage change in the grid by using their reserve in PF/Q (it means reduction of the Q supply or consumption of the Q from the grid).
5) If the use of Q for achieving a needed voltage change is sufficient, the new values of PF/Q are specified and set. Afterwards is assessed, if the voltages returned back into a specified tolerance band.

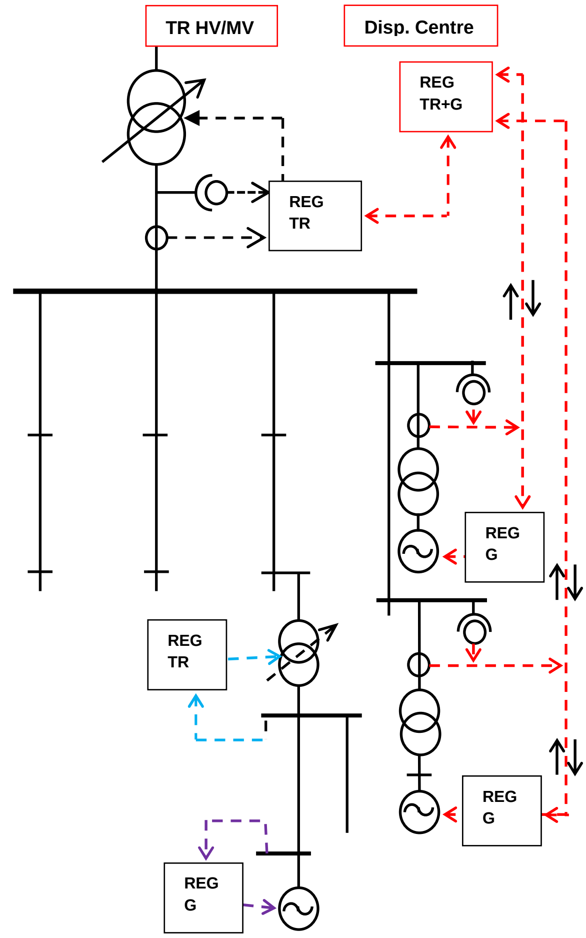

Figure 3 A principle of voltage control in the grids with dispersed RES

6) If using PF/Q control is not sufficient, there are set the new limit values of PF/Q and further there will be verified the possibility of the transformer tap change (with on-load switching), which supplies the particular voltage level in the grid and determined the needed new tap and the expected voltage in all monitored network nodes
7) If the change of 110 kV / MV transformer tap is permissible with respect to the voltage in other nodes of the grid, then a new value $U_{required}$ is set in the transformer voltage controller. If the change of the tap would cause voltage outside the allowable voltage range in some other nodes, then it will not be changed, and an error message will be sent about failure to achieve the desired allowable voltage range in all nodes of the grid and there will be recommended reduction of active power P of the nearest sources.
8) If the voltage of the MV grid is in permissible limits (or after completion of regulatory processes), there will be assessed the compliance with the required voltage limits in low voltage grids.
9) If there is a deviation of the voltage in the LV grids in some nodes from the allowable range, then it is verified

whether there are sources with PF/Q regulation in the LV grid and in a similar procedure there are set new values of Q / PF for them.
10) If the sources with PF/Q regulation are not in the LV grid and MV/LV power transformer has on-load tap changer, the new tap and the expected voltage in all the nodes of the LV network are defined.
11) If the change of the MV/LV transformer tap is acceptable with regard to voltage in other grid nodes, then changing to a new tap number is set . If the change of the tap would cause voltage outside the allowable voltage range in some other nodes, then it will not be changed, and an error message will be sent about failure to achieve the desired allowable voltage range in all nodes of the grid and there will be recommended reduction of active power P of the nearest sources.

CURRENT STATE OF ALGORITHM VERIFICATION

For chosen MV network with a schematic representation in Figure 1 there was developed and validated the basic algorithm according to the previous section.
Furthermore, for the preparation of the operational validation in the second half of 2013 for a grid with simplified diagram in Fig. 1 there was set the number of grid nodes from which the voltage will need to be transferred to the control centre to prevent the grid from unacceptable voltage variation in some nodes without activating of stabilization algorithm and without the appropriate response of PF/Q control or power transformer control. The control algorithm is extended also by the possibility of verification of voltage stabilization by switching selected feeders into parallel operation.
There is partially verified the dependence of active and reactive power of sources and loads on voltage changes in the grid, that is needed to verify the modelling of the expected state after the changes of PF/Q, also after output voltage changes of power transformer by tap changer operations.

CONCLUSIONS

The paper presents the results of monitoring of voltage in Czech distribution grids.
Further, on the example of the selected MV grid with RES whose installed capacity exceeds the consumption in the area, it gives details of the proposed approach to voltage stabilization in MV and LV network , by means of PF/Q control of sources causing voltage changes in the grid.
After voltage limits violation, using a network model it will be determined in which sources and what PF/Q values will stabilize network voltage and then these regulation parameters will be transferred to relevant sources.
Because embedded sources can cause much higher voltage changes in the grid than at the output of the supplying power transformer it is advantageous for the voltage stabilization to use possibilities of changes of reactive power of sources. The need for limitation of the sources active power can occur only when available change of PF/Q is not sufficient and the tap change of power transformer is not possible with respect to the voltages in other nodes of the network.
For sources in the LV grids and individual LV grids we do not expect central voltage monitoring and its control. If needed, then according to the kind and level of voltage changes, voltage stabilization can be achieved either by selecting the mode of operation Q = f (U), or by MV/LV transformer with on-load tap changer, and their autonomous control.
At present, the preparatory works to verify the control algorithms in real network are going on. As the next step we assume to make network model more precise using relations between P and Q on voltages and to add the optimization of network losses to the basic function of voltage stabilization.

REFERENCES

[1] K. Prochazka, "Řešení napěťových poměrů v sítích s velkým podílem OZE" (Solution of voltage problems in networks with a big share of RES) , *Proceedings, 16th Conference of the Czech Committee of CIRED 2012,* Electrical power engineering, ISBN 978-80-905014-1-6.
[2] D. Moneta, "*MV Networks with dispersed generation: Voltage regulation based on local controllers", Proceedings 21st CIRED conference on Electricity distribution, Frankfurt in 2011 Paper 0934.*
[3] I. Leisse, Coordinated voltage control in distribution systems with DG-Control algorithm and case study, *Proceedings CIRED Workshop, Lisbon 2012, paper 361*