INFLUENCE OF REACTIVE POWER COMPENSATION IN TRANSFORMER STATION ON VOLT-VAR REGULATION OF DISTRIBUTED ENERGY SOURCES

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Abstract: This article is focused on the influence of reactive power compensation on the secondary side of the distribution transformer on the Volt-Var regulation of distributed power sources in LV networks. The paper shows the mutual effects of compensation and Volt-Var control on a simple simulation in PSS® Sincal. The first part of the paper is dedicated to the description of the simulated scheme and parameterization of individual components. In the second part the results of the simulation are summarized, the contraindications identified, and recommendations are given.

Keywords: distributed energy sources, reactive power compensation, Volt-Var regulation

1 INTRODUCTION

The power system is currently undergoing many changes. Share of distributed power sources is increasing, the character of appliances is changing and the number of cable lines is rising. These changes must be adapted to the way the electricity system operates. Reactive power flows are one of the problems to be addressed. Distributed power sources use reactive power to stabilize the voltage at the connection point, which then passes to the networks of higher voltage levels. Other sources of reactive power are consumers of electricity themselves, where due to the increasing numbers of appliances with inverters, it is possible to expect an increase in consumption of capacitive character. Network elements themselves are also a significant source of reactive power. For the above reasons, distributors are starting to consider compensation at the low voltage (LV) level.

The transfer of active power is accompanied by reactive power, which does not do any active work. However, reactive power transmission on the network elements causes active losses and voltage drops. Reactive power also blocks the transmission capacity of network elements that could be used to transmit active power.

2 LOW VOLTAGE NETWORK SIMULATION

The main subject of the simulation is to assess the effect of compensation and implementation of $Q(U)$ (Volt-Var) regulation of distributed sources at LV level during selected operating conditions. At the same time, the contraindication of compensation on the secondary side of the DT (Distribution Transformer) to $Q(U)$ source control in terms of stable and economical operation of the whole network is also assessed. For better demonstration of interconnections between $Q(U)$ regulation and compensation, a model of only one medium voltage (MV) branch formed by cable, at the end of which is one distribution transformer 22 / 0.4 kV, is used first. The scheme of the simulated network including the monitored parameters is in Figure 1.

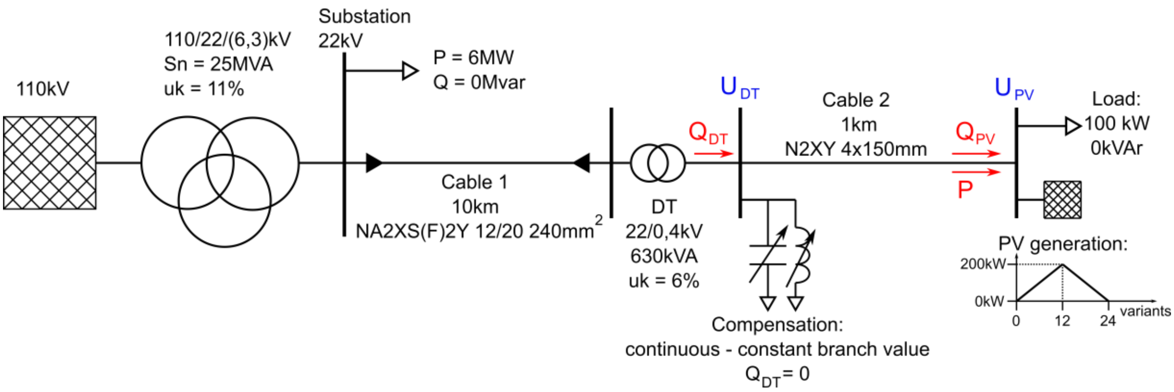


Figure 1: Schematics of simulated network with $Q(U)$ regulation of PV power source and compensation on LV side of DT

The simulation was performed in the PSS® Sincal 14.5 software. The load profile mode was used for the simulations. This mode enables the calculation of steady-state sets in which the P (active power) and Q (reactive power) of the source and load changes. In the computational program, these individual steady state sets are seen as the behaviour of source and load over time. The calculation was set on a daily basis in steps of 1h. With this setting, it was possible to create 24 separate steady-states. Since the simulation did not model the daily load curves, these individual steady-state runs with respect to the parameterization of the source and load powers are referred below as states.

The LV network that is the subject of this simulation is fed from a 22 / 0.4 kV distribution transformer with a nominal apparent power 630 kVA. The transformer is parameterized according to [1]. On its secondary side, there is a compensation, which allows continuous regulation to zero Q flow through DT ($Q_{DT} = 0$). The compensation means being the ideal compensator. The secondary side of the transformer is connected with a 1 km long LV cable N2XY 150 mm^2. The LV line was selected from the element library available in PSS® Sincal. The specific impedance of this line is: $\bar{Z}_k = R_k + jX_k = 0{,}124 + \mathrm{j}0{,}078\ \Omega/\mathrm{km}$. The cable was chosen intentionally because it has a low specific reactance compared to the specific resistance. This should lead to higher Q values provided by $Q(U)$ regulation of power supply. The use of cable in the simulation also takes into account the trend of expansion of low-voltage cabling.

At the end of the LV line is considered a node to which a constant load with a P of 100 kW and a $\cos\varphi = 1$ is connected, as well as a power source with a maximum $P_{max} = 200$ kW. The power supply is parameterized as a linear ramp where the P rises linearly from 0 kW to 200 kW in steps of 0 to 12 and decreases from 200 kW to 0 kW in steps of 12 to 24. This setting of the power source and load ensures the transmitted P profile over LV line in the range of 100 kW (direction of P flow from MV to LV) to -100 kW.

The simulation is a set of 24 steady-state runs. The input parameter that changes in these individual steady-state runs is only the P produced by the PV. The load remains constant. The monitored parameters are the voltage in the DT and PV nodes and the Q provided by the PV within the $Q(U)$ control (its setting is described in section 2.1). Three variants are then tested with respect to compensation in DT and $Q(U)$ source control. These variants are as follows:

- without compensation and $Q(U)$ control,
- without compensation, with $Q(U)$ control,
- with compensation and $Q(U)$ control.

2.1 Q (U) SOURCE CONTROL

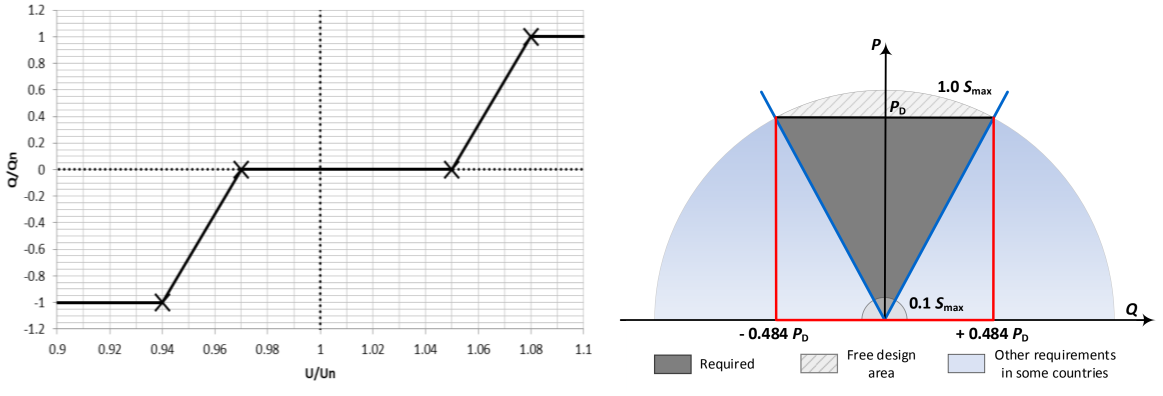
The $Q(U)$ control is primarily used to compensate the ΔU (voltage drop) caused by the P by Q. Ideally, the voltage increase due to P supply should be suppressed by Q consumption. In a simplified form, the ΔU across the series impedance, which forms resistance and reactance (e.g. line or transformer), can be expressed by equation (1).

$$\Delta U \approx \frac{P}{U_{\text{L-N}}} \cdot R + \frac{Q}{U_{\text{L-N}}} \cdot X \qquad (\text{V}) \tag{1}$$

Where R (Ω) is the series resistance, X (Ω) is the series reactance, P (W) is the single-phase transmitted active power, Q (VAr) is the single-phase transmitted reactive power, and $U_{\text{L-N}}$ (V) is the line-to-neutral value of the voltage. The reactive power of inductive character is considered in this paper.

The equation (1) applies when we consider both P and Q consumption. Then just this voltage drop decreases the voltage in the PV node. It can be seen from the equation (1) that while the part of the ΔU caused by the transmission of P through the line is dependent on the R, the part of the ΔU caused by the transmission of Q is proportional to the X. If the direction of P or Q is reversed, it is necessary to respect this fact and change the sign of P or Q in equation (1).

It follows from the above equation that the efficiency of voltage regulation by Q injection is strongly dependent on the X, respectively the principle of compensating the ΔU caused by the transfer of P by Q depends on the R/X (ratio of resistance to reactance). From [2] it follows that while overhead LV lines have the R/X ~ 2.3, LV cable lines have the R/X ~ 5.4. Voltage regulation is the more efficient, the lower the R/X is. Therefore, the regulation is more effective in overhead LV networks than in cable networks. For comparison, the overhead MV lines have the R/X ~ 1.2.



a. b.

Figure 2: a. Setting the Q (U) source control, b. Requirements for reactive power supply / consumption

The parameterization of the $Q(U)$ characteristics of the PV control is set according to the setting example given in the valid Annex No. 4 PPDS (Czech rules for the operation of distribution networks) [3]. The setting of the characteristics is shown in Figure 2 a.

In addition to the application of the $Q(U)$ characteristics, amount of Q support is also affected by PQ diagram which is also defined in [3]. The duty to enable voltage support by Q is within the cosφ = 0.9 (blue area of Figure 2 b.). Conventional inverters are usually designed to a maximum Q value that corresponds to the Q value at rated P and a cosφ = 0.9 (red area of Figure 2 b.).

In the simulation, the source is set according to the red area of Figure 2 b. The $Q(U)$ control is allowed even though P provided by PV is zero. This has the advantage that the power supply can compensate (or at least reduce) the ΔU due to P consumption by supplying Q. In these load-dominant conditions, this behaviour can emulate e.g. an electric vehicle charging station equipped with $Q(U)$ control.

The combination of the type and length of the LV line and the nominal P of the source and the load was intentionally chosen so that the voltage is within the permissible limits even when the $Q(U)$ control is switched off. To demonstrate the effect of compensation on $Q(U)$ control, the line cross-section was selected so that the power supply did not deliver its maximum Q when the $Q(U)$ was switched on, i.e. the voltage was between 0.94Un and 1.08Un.

3 SIMULATION RESULTS

The simulation results are shown in Figure 3. In the first part of the figure, the active power is at the end of the LV line. This power is a set parameter and is the same for all three variants. In the second part of the graph, there is the Q at the end of the LV line Q_{PV}. Since there is no power source / consumption of Q other than PV, this value can be considered as a value provided by the Q (U) control. It can be seen from this that if the $Q(U)$ control is switched off, the PV does not produce or consume any Q. When the control is switched on, the PV supplies / consumes Q that corresponds to the U_{PV} voltage according to the set control curve $Q(U)$ (Figure 2 a.). The Q supply / consumption will then cause a voltage drop (in positive / negative direction). If the transmitted P is low and the voltage at the PV is within the dead band of $Q(U)$ control, the PV does not supply or consume any Q.

If both the $Q(U)$ control and the compensation are switched on, it can be seen from the Q_{PV} that this value is greater than when the compensation is switched off. In a condition where 100 kW is transferred to the load through the line, the difference in Q is approximately 10 kVAr. This increase occurs only if the power supply PV is not at the maximum Q, i.e. the voltage U_{PV} is within the limits $0.94U_n$ – $0.97U_n$ and $1.05U_n$ – $1.08U_n$ according to Figure 2 a. This Q_{PV} increase is caused by the fact that Q does not pass through DT and therefore does not cause the ΔU on the MV line and especially on the distribution transformer. In equation (1), the part of ΔU in which the Q appears, is only relevant for the X of the LV line.

In Figure 3, the voltage in the DT node is also plotted. It can be seen from this curve that when the compensation is switched on, the voltage is slightly higher than the value when the compensation is switched off (both states without $Q(U)$ control). This is due to the fact, that even though the load is only active, the transmission of this power over the LV line produces Q on the LV line X. This Q with off compensation is not compensated and causes ΔU in negative direction. On the other hand, when $Q(U)$ control is on and compensation is off, the supply of Q through the distribution transformer causes a positive ΔU and increases the voltage in the DT when the P is consumed (variants 1-4 and 20-24). Conversely, the Q consumption at an increased voltage at the PV node causes a negative ΔU at the secondary side of the DT (variants 10-14).

4 CONCLUSION

The results shows that when the compensation is switched on, the section of the grid on which the controlled ΔU occurs by regulating the Q is reduced. The control is then limited only to the LV line, which usually has a larger R/X and thus the control is less efficient. This results in a greater amount of Q provided by the $Q(U)$ control.

Under the conditions of the simulation, an extreme increase of approximately 10kVAr occurred. If the PV were closer to DT, it could be expected that the amount of Q would be even greater and this Q could not affect the voltage due to the small value of X between PV node and DT node.

Compensation in LV networks with a high proportion of distributed generation sources should therefore be avoided.

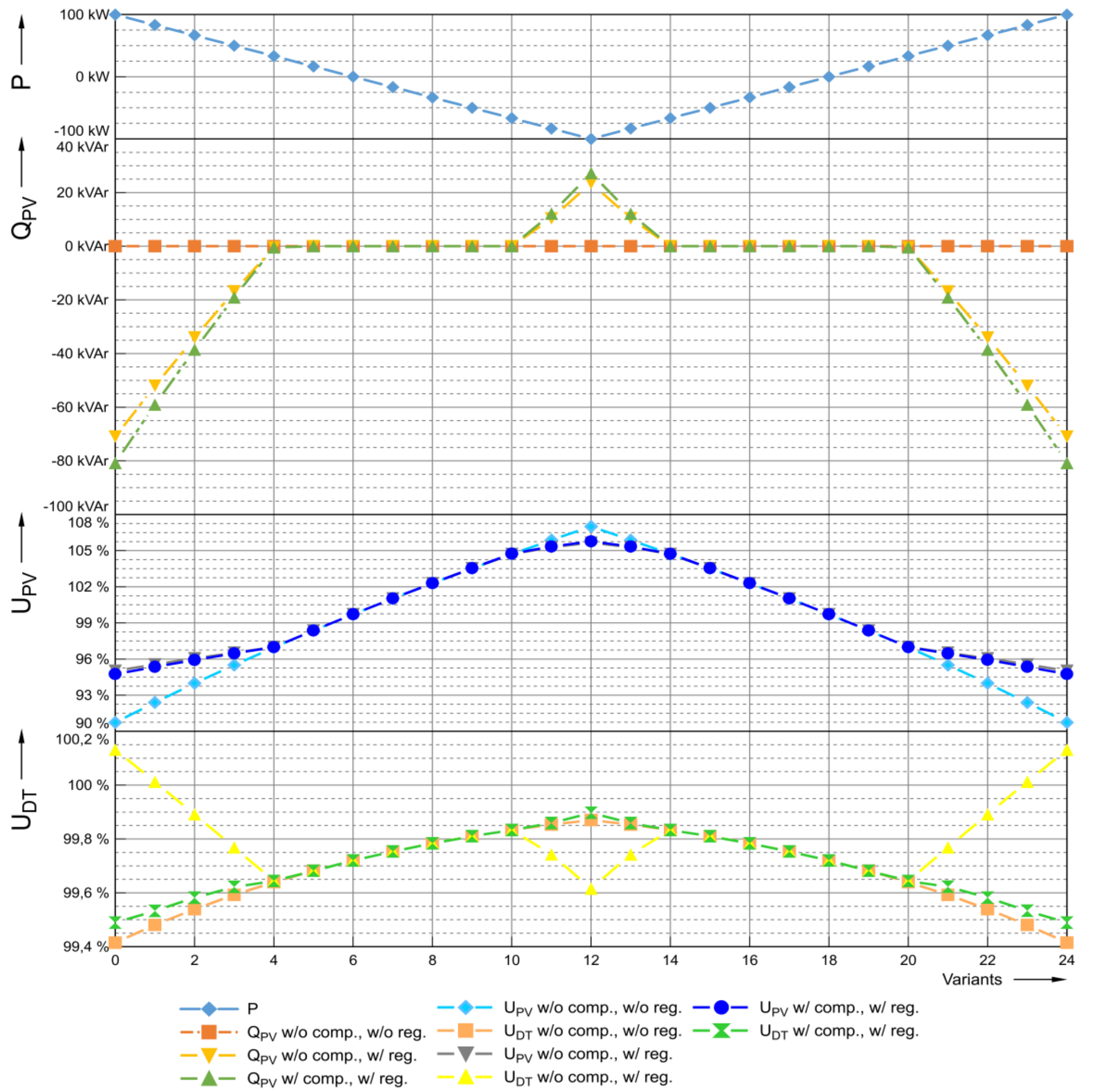


Figure 3: Voltage and reactive power profiles depending on the active power transmitted through LV cable

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