VOLTAGE CONTROL BY REACTIVE POWER REGULATION OF DISPERSED SOURCES

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Abstract: Installation of new power sources affects local quality of voltage at the point of connection. The most serious problem for the distribution network is a permanent change in voltage due to operation of new sources. The intensity of change depends both on the short-circuit power at the connection, but also from the powers supplied to the node power system (ES). The work is devoted to dispatching control of reactive power of power sources as a tool to improve the conditions of voltage control system. Specifically, the current approach to technical solution is evaluated. In the same time there is a proposal how to optimize using of compensation units of plants.

Key words: Reactive power, short circuit power, short-circuit impedance, rules of operation of the distribution system

1. INTRODUCTION

The development of the power generation basement of the power system of Czech Republic in terms of the adaptation of renewable energy is in the stage of unstable development. In the conditions of the Czech Republic the photovoltaic (PV), wind and biomass plants are relevant from point of energy potential. The first two are unpredictable in terms of production diagram and causes increased demand to the management of the power system. The effects of the massive construction of new sources with character of unpredictability can be divided into systemic and local. Systemic problems are linked to power balance in grid and possible overloading of the transmission or distribution system. Local effects are related to the location of the plant connected to the distribution system. By its operation affects parameters of the quality of voltage in the connection point, respectively in the vicinity.

Connection of the power plant causes a voltage step in the point of connection. Operation rules of distribution network prescribe a maximum limit of a permanent change of voltage in a connection point from earlier voltage value as follows:

- 2% for plants connected to medium voltage level,
- 3% for plants connected to low voltage level.

Evaluation of compliance of planned sources with this condition of voltage change lives under the study of plant connectivity where calculations are made with prescribed algorithm. Despite favorable studies distribution system operator captured increased number of voltage problems. Corridors defined by EN 5016 were more often exceeded after launching new plants. Typical mechanisms, how the limits are exceeded are the subject of the next chapter. Generally voltage step is determined by impedance of lines and cables (short-circuit impedance at the connection point) and time-dependent power (active, reactive) production.

2. MECHANISMS OF VOLTAGE CHANGES DUE TO OPERATION OF PLANT

Voltage control in power network is based on the coordinated control of voltage drops in the grid. Voltage drops on the network elements (transformers 6/440kV, lines and cables of whole variety of voltage levels) are cumulatively added. This method of voltage control encounters to problems when centralized power system is transforming into a decentralized, i.e. in the case of high penetration of decentralized production. Typical mechanism of exceeding voltage limits is illustrated in Figure 1. According to EN ČSN 50160 must be 95% of the voltage values (average 10min. RMS) during one week in the range from 90% to 110% of U_N.

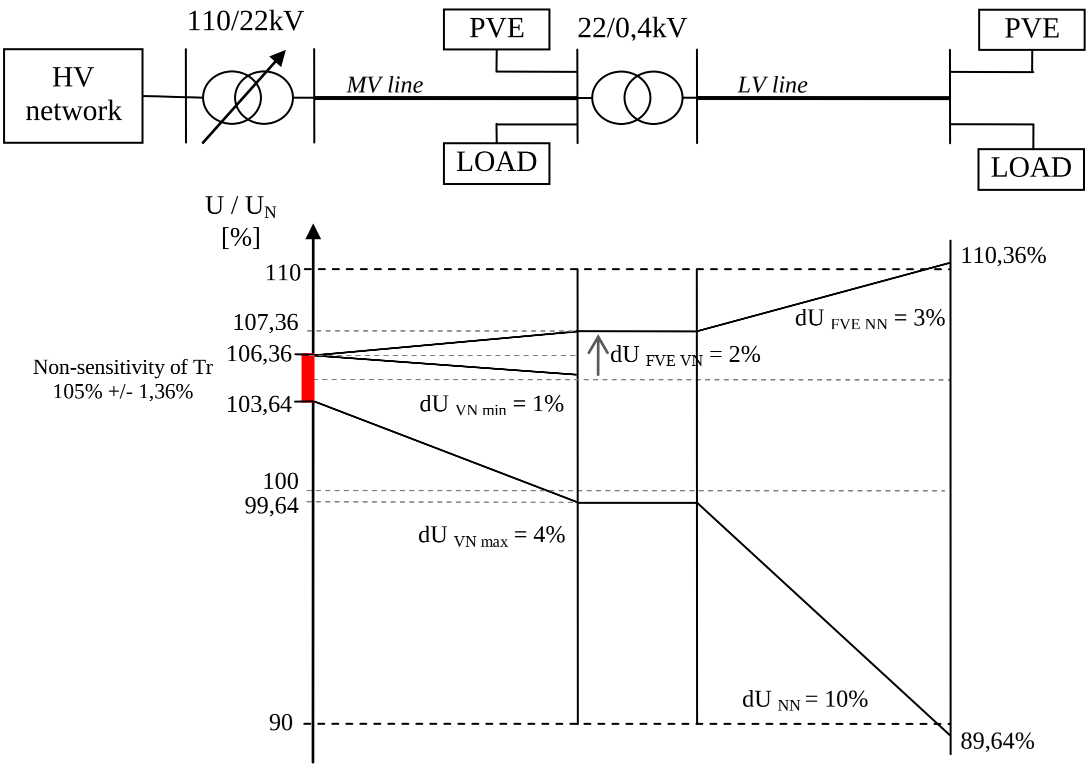

Figure 1: Mechanism of exceeding voltage limits due to operation of PVE [2]

To the Figure 1 is important to note that due to clearness of illustration there is not considered voltage drop on the transformers. Voltage controller of 110/22kV transformer works with insensitivity + / - 300V, which means + / -1.36%. This illustrative example calculates with tap changer setting of transformer to 105% U_N, which is usual setting. From this initial voltage point (105%) are derived other voltages of the system. HV lines are loaded so intensively that its voltage drop is within the range 1 to 4%. LV air lines causes the voltage drops due to loading from 0 to 10%. Figure 1 demonstrates right away 2 ways of crossing voltage limits. The overvoltage occurs when there is weak loading of MV and LV lines. Operated PV plant connected to the HV and LV cause maximum allowable increment in voltage, i.e.: 2, respectively. 3%. This state would require adjustment of distribution transformer's tap changers, but the change is limited to the possibility of the undervoltage for LV end-customers.

The increment of voltage occurs due to the reverse power flow direction from decentralized sources through the lines. The situation is demonstrated in Figure 2. Line is characterized by longitudinal impedance Z composed of active resistance R_L and inductive reactance X_L. The beginning of the line is connected to the node of network which is common for group of load characterized by impedance Z. PV plant produces pure active power.

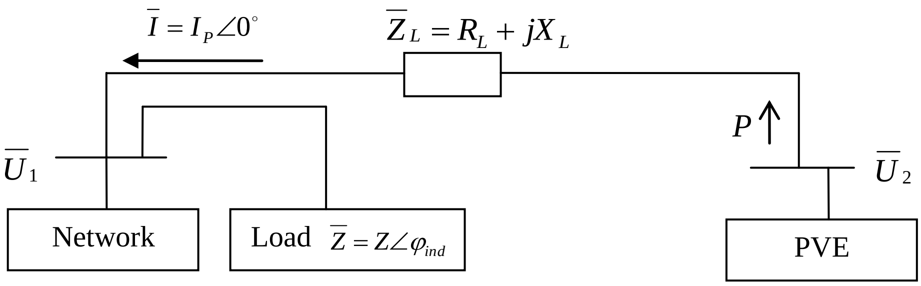

Figure 2: Line model for voltage growth assessment

Situation in Figure 2 can be redrawn into the following equivalent circuit.

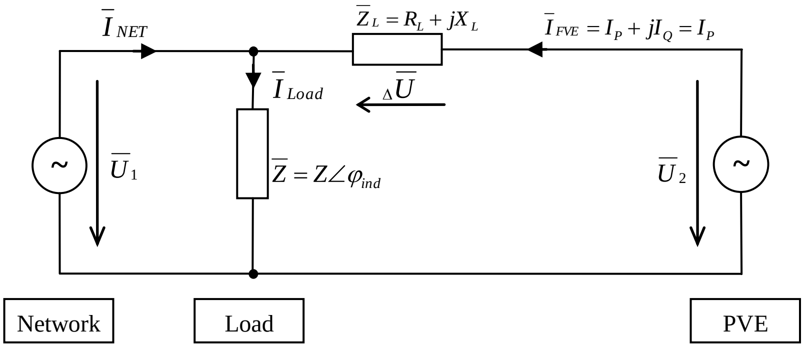

Figure 3: Equivalent circuit for voltage growth assessment

Voltage drop in the direction of current flow in Figure 2 is characterized by a second Kirchhoff and Ohm's law as follows:

$$\overline{U}_2 = \overline{U}_1 + _\Delta\overline{U} \tag{1}$$

$$\overline{U}_2 = \overline{U}_1 + \left(R + jX_L\right) \cdot I_P \tag{2}$$

Total current that flows through the network is characterized by the first Kirchhoff law ref. to (3).

$$\overline{I}_{NET} = \overline{I}_{Load} - \overline{I}_{FVE} \tag{3}$$

Equivalent circuit on Figure 3 behaves according to the following phasor diagram. The ratio R_L: X_L = 1:3 is used whereas MV line is considered.

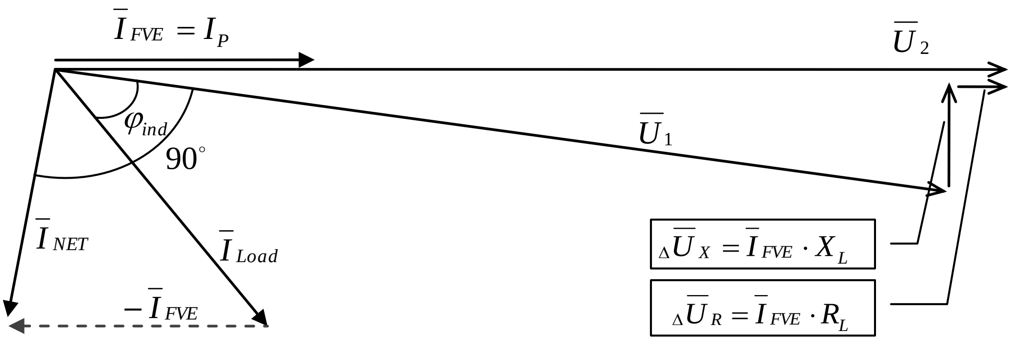

Figure 4: Phasor diagram

The following facts come from phasor diagram.

- Phasor's module of voltage U_2 is higher than module U_1. Operation of power plant leads to increment of voltage in the point of connection installation. The intensity and propagation depends from the line impedances.

- The projection of phasor of voltage U_2 on the U_1 axis shows that voltage drop is dependent mainly from ohmic resistance of line; reactance causes phase shift between the phasors U_1 and U_2. This is fact is valid only if reactive power is not transferred through the line.
- In this particular example, phasor diagram refers to the case where the production of active power just equals to consumption of load characterized by impedance Z. This is evidenced by the power flow through the node - network, which is reactive, since phasors U_1 and I_{NET} are perpendicular. The fact that the phasor of voltage U_1 overtake current phasor by 90 ° (just in this specific case) signals that reactive power from network is delivered to meet the requirements of reactive power - reactance of load and reactance of line (PVE).

A particular case of voltage changes in point of common coupling in rhythms of daily diagram of production in is illustrated in Figure 5. This is a 1MW PV connected to DS 22kV.

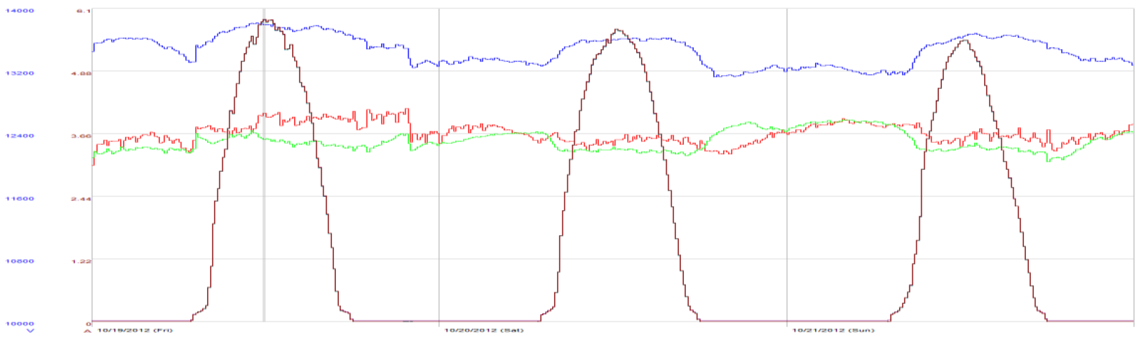

Figure 5: Voltage changes due to operation of PVE [3]

Practical measurements have shown that voltage changes may not be reflected in all three phases as well. Distribution system operator has difficult task of maintaining voltage within the prescribed limits. Since the changes are in the rhythms of daily production diagram of plants, the adjustment of transformers' tap changers is not real (currently mounted distribution transformers allow only no load switching of tap changers). Reducing short-circuit impedance by strengthening lines is also not seen as a systemic solution. The only option is the supervisory control of reactive power of PVE.

3. REACTIVE POWER CONTROLL OF DECENTRALIZED SOURCES

The impact of reactive power (inductive and capacitive) to voltage change is demonstrated by phasor diagrams (Figure 7, 8) which refers to following equivalent circuit.

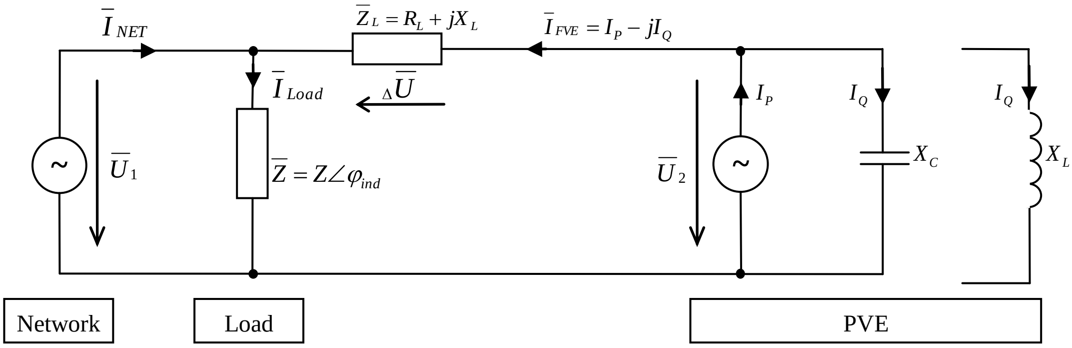

Figure 6: Equivalent circuit for voltage change assessment of PVE with reactive power

It is the considered sink drawing mode for equivalent circuit, resulting to phasor diagrams (Figure 6.7). Relations (1), (2), (3) are valid for drawing phasor diagrams. Reactive current of PV is drawn in proportion 0.33 x I_P, which is the ratio at power factor cos φ = 0.95 (tg φ = 0.33).

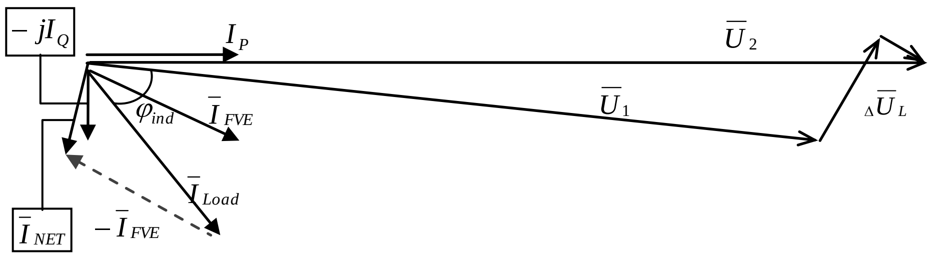

Figure 7: Phasor diagram of PV plant operation with capacitor – PVE supplies reactive power

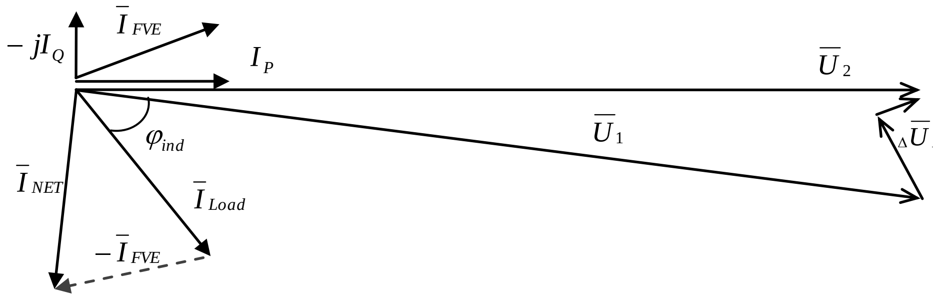

Figure 8: Phasor diagram of PV plant operation with reactor – PVE consumes reactive power

Current Operational rules of distribution network prescribes to equip PV plants (with power above 0.1MW) with supervisory reactive power controller which provide 5 five steps according to the desired power factor value. The extreme value of the power factor is cos φ = 0.95 ind. and 0.95 cap.

Phasor diagrams (7, 8) show the behavior of voltage in these two limit cases. It is clear from them that installation of capacitors to ensure cos φ = 0.95 cap is not relevant, since capacitors increase the voltage at node FVE. It means useless investments.

Another downside is the control parameter which is now power factor. Operator loses in the case of low production or no production available reactive power to regulate the voltage at the connection point.

Due to this problem it is necessary to transform the existing terms of the realization of supervisory reactive power control into the regulation with desired value of voltage. In that case, the supervisory control would be unattended (the operator do not have to enter the desired power factor value changes), and reactive power unit would dynamically respond to changes in voltage at node of connection. While used both - the capacitive and inductive mode of operation.

4. CONCLUSION

The work deals with the relationship between the operation of PV plant voltage changes. Phasor diagrams reveals problems with current approach to supervisory PF control which should be modified.

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