REACTIVE POWER CONTROL STRATEGIES OF POWER PLANTS CONNECTED TO 22KV NETWORK

František Bernáth

Doctoral Degree Programme (4), FEEC BUT

E-mail: xberna07@stud.feec.vutbr.cz

Supervised by: Petr Mastný

E-mail: mastny@feec.vutbr.cz

Abstract: This work is devoted to the possibilities of solution the negative impact of dispersed generation to the voltage control in distribution network in the Czech Republic. According the basic laws of electrical engineering voltage rises in the point of common coupling (pcc) by the operation of power source. Higher proportion of distributed generation causes problems with exceeding of voltage limits. One of the possibilities how to reach prescribed voltage margins is dispatching control of power plants' reactive power. The type of control strategy is important question which will be shown by modeling of real 22kV network with photovoltaic energy sources (PVE).

Keywords: distributed generation; reactive power; short circuit power in pcc; operational guideline of the distribution networks

1. INTRODUCTION

One of the technical problems associated to integration of distributed sources is voltage deviation. The work focuses on the problems of overvoltage and undervoltage in distribution network (DN) which are connected to the operation of distributed generation. Sources (in most cases PVEs) connected to DN cause voltage growth, which depends from their production diagram (and short circuit impedance in pcc) and therefore the voltage characteristics are unpredictable. One of the way how to eliminate negative impact of PVEs on voltage is reactive power control of power plants. Generally if power plant consumes reactive power (inductive mode) – it downgrades the voltage and if one produces reactive power (capacitive mode) – it causes rise in voltage. Actually most of PVEs connected to dispatching control (obligated over 100kWp) are ridden according the prescribed power factor. This is one of the control strategies. Except this are present others analyzed by modeling of real 22kV DN.

2. MODELLING OF EFFECT OF PVE ON VOLTAGE IN DN 22KV

The subject of research is the real part of 22kV distribution system, which is supplied from two points, but is operated as a radial network; since connection points are separated by line disconnectors according to Figure 1. The aim was to determine the effect of PV plants in the following cases:

- The impact of PV plants to the voltage, if the reactive power of PV plants is given by the power factor. Following cases were considered: $\cos \varphi_0 = 1$, $\cos \varphi_1 = 0.95_{ind}$, $\cos \varphi_2 = 0.95_{cap}$.
- The impact of PV plant to voltage if constant reactive power Q is desired. There were considered inductive and capacitive reactive powers with absolute value $Q = 0.328 \times P_{iPVE}$.

Modeling was implemented in Matlab Simulink software. There has been assumed constant load in the individual nodes 22/0.4kV with values of 30% of the nominal rated power of distribution transformers.

Totally are present 6 PV plants with installed power of 8.369 MW. Total power of calculated load is 2.151 MW (30% of the sum of rated powers of distribution transformers 22/0.4kV).

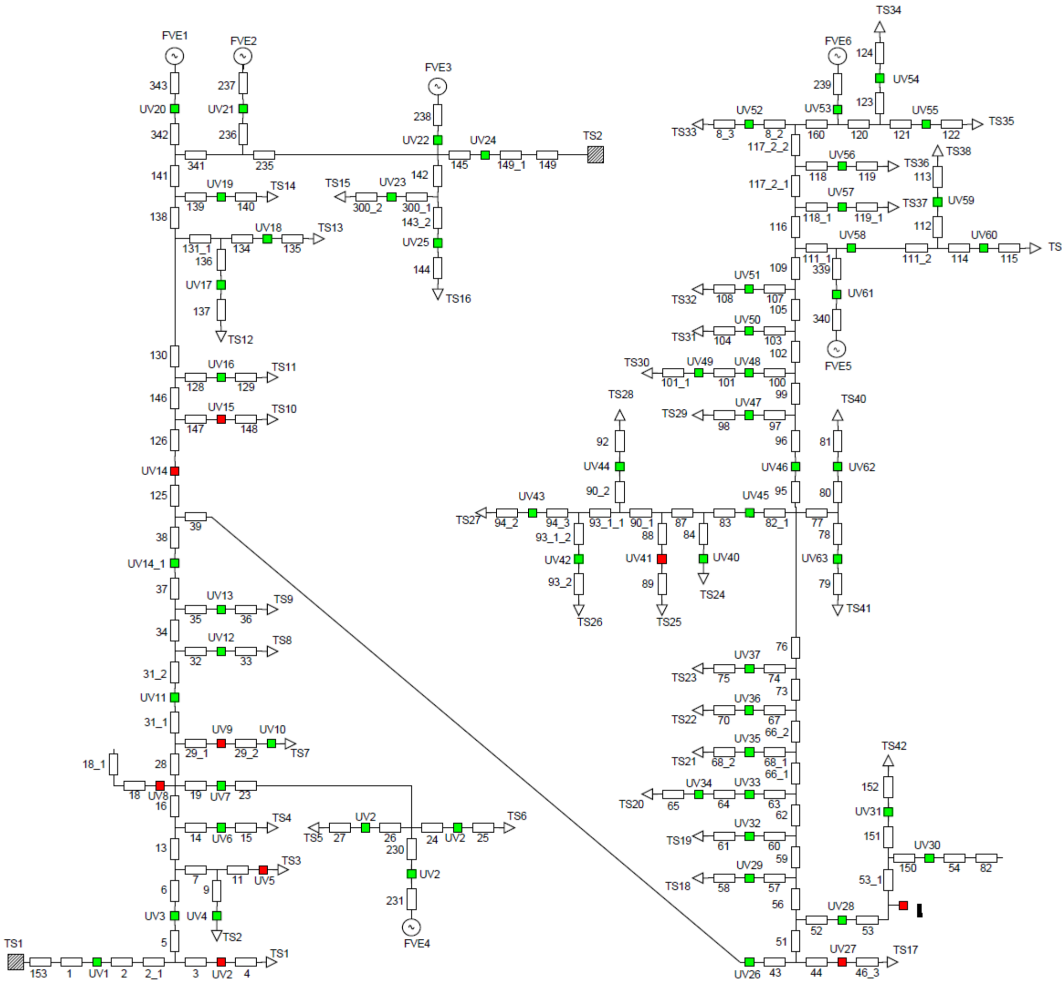

Figure 1: Scheme of modelled distribution network

2.1. IMPACT OF POWER PLANTS (WITH POWER FACTOR COS Φ = 1) TO VOLTAGE

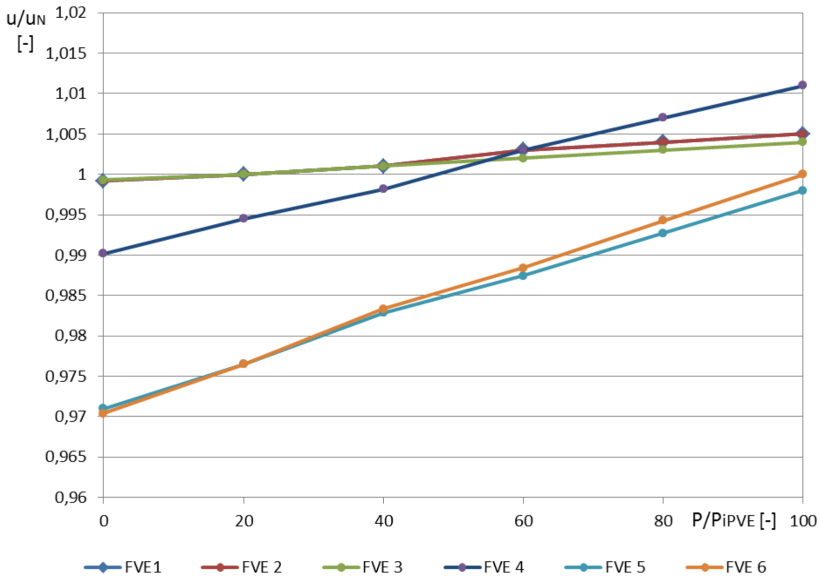

Figure 2: Voltage characteristics at point of common coupling of power plants (power factor of plants: cos φ = 1)

In the first case of the modeling there were calculated voltage characteristics (from steady state operations at powers of PVEs: 0 - 20% - 40% - 60% - 80% - 100% of P_{iPVE}) in pcc for individual PV plants. The premise is synchronous behavior of PV plants with respect to a smaller distance between them.

Characteristics show a nearly linear dependence of voltage on the performance of PV plants according to Figure 2. Table 1 demonstrates that 3 PV plants do not satisfy the permissible value (max. 2% at MV level) of a permanent change in voltage due to its operation. Most probably, connection study did not consider the cumulative effect of other PV plants.

Relative voltage growth caused by the operation of PVEs 1 - 6						
Name	PVE1	PVE2	PVE3	PVE4	PVE5	PVE6
u_1 (p.u.)	0.9992	0.9992	0.9993	0.9902	0.9710	0.9704
u_2 (p.u.)	1.0050	1.0050	1.0040	1.0110	0.9980	1.0000
Δu (%)	**0.58**	**0.58**	**0.47**	**2.08**	**2.7**	**2.96**

Table 1: Relative voltage steps caused by the operation of PVEs

Undesired growth can be eliminated by reactive power control of power plant. In practice, most PV plants are equipped with compensation units. Their dimension is such that they have to be able to provide power factor 0.95 even at maximum active power. For example in case of 1MW they have to dispose with reactive power of 328kVAr (inductive and reactive).

2.2. IMPACT OF POWER PLANTS (WITH POWER FACTOR COS Φ = 0,95| TO VOLTAGE

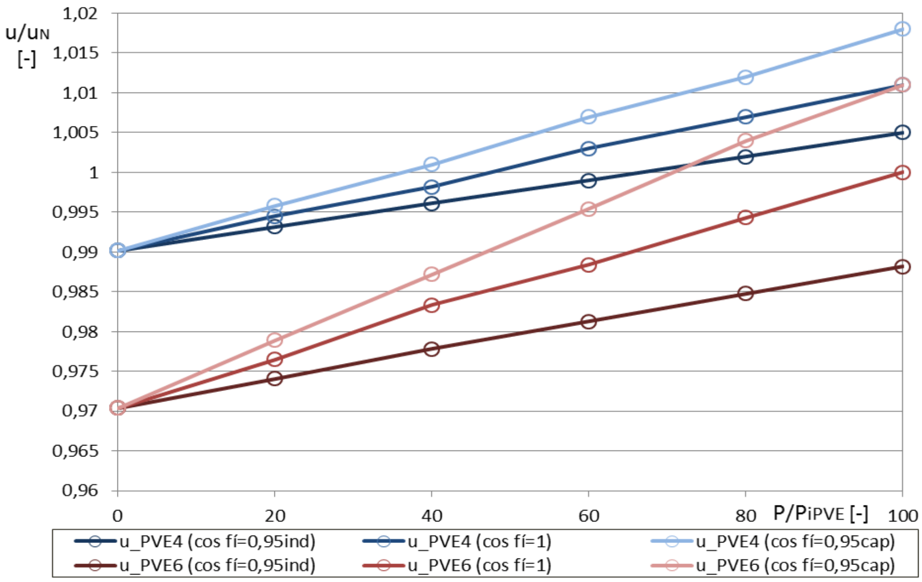

Figure 3: Voltage characteristics in point of common coupling of power plants with different power factors (cos $\varphi = 0.95_{cap}$; 1 ; 0.95_{ind})

Relative voltage steps of PVE4, PVE6 if operate with different cos φ						
Name	PVE4	PVE4	PVE4	PVE6	PVE6	PVE6
cos φ	1	0.95_{ind}	0.95_{cap}	1	0.95_{ind}	0.95_{cap}
u_1 (p.u.)	0.9902	0.9902	0.9902	0.9704	0.9704	0.9704
u_2 (p.u.)	1.0110	1.0050	1.0180	1.0000	0.9882	1.0110
Δu (%)	**2.08**	**1.48**	**2.78**	**2.96**	**1.78**	**4.06**

Table 2: Relative voltage steps of PVE4, PVE6 if operate with different cos φ

Voltage characteristics in Figure 2 are related to PVE4 and PVE6. They demonstrate that the capacitive mode amplifies the voltage growth depending on the intensity of active power and inductive mode eliminates the voltage growth according to Table II.

Compared to the power factor cos φ = 1, the degree of influence of compensation units (when P_{PVE} = 100% of P_i) is expressed by Table III.

Relative change in voltage compared to the reference state cos φ = 1						
Name	PVE4	PVE4	PVE4	PVE6	PVE6	PVE6
cos φ	1	0.95_{ind}	0.95_{cap}	1	0.95_{ind}	0.95_{cap}
$_{\Delta}u / \Delta u_i$ (%)	**0.00**	**-28.35**	**33.65**	**0.00**	**-39.86**	**37.16**

Where Δu_i *is initial voltage growth (voltage growth from no load to maximal load of source with cos φ = 1).*

Table 3: Relative change in voltage compared to reference state cos φ = 1

2.3. IMPACT OF POWER PLANTS (WITH CONSTANT REACTIVE POWER) TO VOLTAGE

Characteristics in Fig. 4 are the subject of PVE6. Yellow and black lines represent the characteristic behavior when Q_{cap}, respectively Q_{ind} operation is adapted. Compared to the basic line (cos φ = 1) are present a vertical shifts.

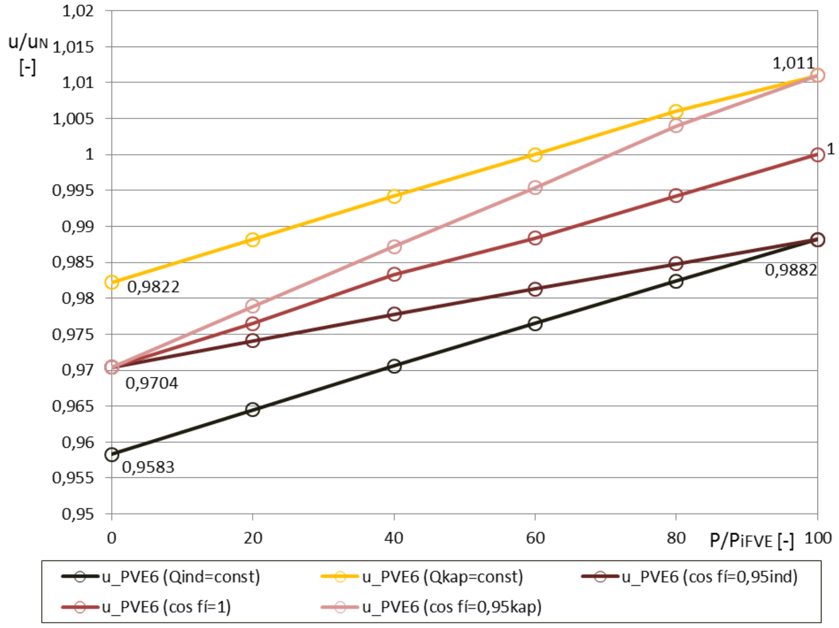

Figure 4: Voltage characteristics in point of common coupling of power plants

3. REACTIVE POWER CONTROL STRATEGY SELECTION

The choice of uniform reactive power control strategy is a key point to achieve the voltage stability within the prescribed limits in network with high penetration of dispersed sources. Currently used control strategy based on desired power factor provides the opportunity to eliminate voltage growth if inductive mode of operation is adapted . Degree of influence depends on the angle of short-circuit impedance in pcc. This value is generally within the range from 25% to 40% of the initial growth (when cos φ = 1).

Capacitive mode is not applicable, since it further increases the voltage. PV plants are despite this fact equipped with compensating device that has a capacitive reactive power (compensation capacitors) of considerable dimensions (0.328 x P_{MAX}).

Positive part of reactive power control strategy according to desired power factor is the fact that it reduces (their own) impact of PVE on the voltage, what was the reason for installing these units. However this strategy does not respect actual voltage.

Control strategy according desired reactive power value does not reduce the relative voltage change and cannot therefore be considered as a systemic solution.

Very positive behavior in term of stability of the voltage control has a characteristic curve Q = f (P) on Fig. 5 (the control curve is marked by red). The aim is to achieve zero-voltage growth. However, PVE4 does not have this option, since the voltage at the maximum active power and reactive inductive power is about 0.6% higher than the voltage at zero power and reactive capacitive power.

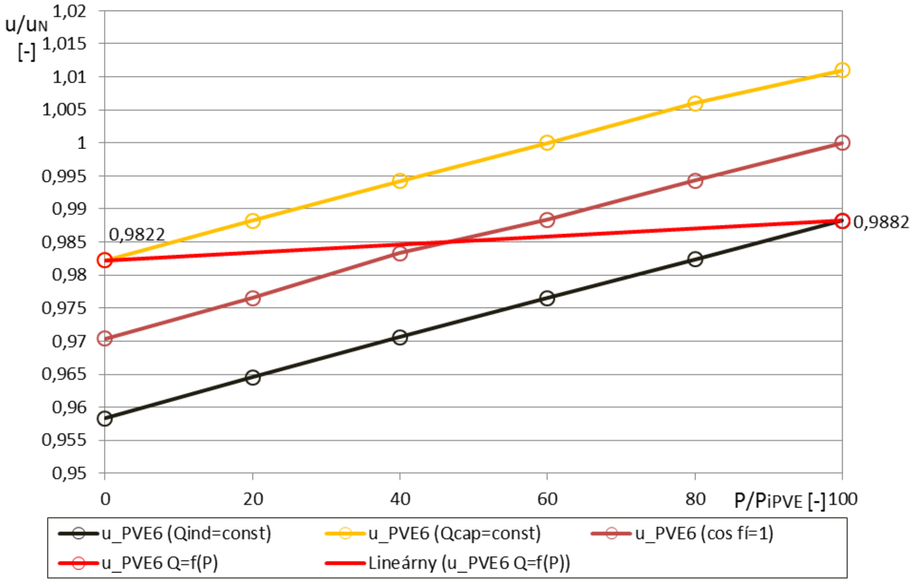

Figure 5: Voltage curve of PVE6 if reactive power control strategy is based according function Q = f(P)

This form of control strategy is applicable only in case of stepped compensation (inverters cannot provide reactive power during no load).

These strategies are a form of forwarded control (without feedback control) whereas the actual voltage is not considered.

The ideal way to support voltage stability is feedback type control of reactive power according to the desired voltage. This form of regulation would require a consistent superior sophisticated system that will consider voltages in selected nodes.

4. CONCLUSION

The choice of reactive power control strategy determines resulting impact on voltage stability terms. This work demonstrated mechanisms how individual strategies are influencing voltage curves.

REFERENCES

[1] Habrych, R.: Regulace napětí a jalového výkonu v distribučních soustavách 110kV. Proceedings of 13th international scientific Conference Electric Power Engineering 2012, Brno, ISBN 978-80-214-4514-7

[2] Kašpírek, M.: Dopad provozu OZE na garantované standardy kvality napětí. Sborník konference Energetické rušení, Brno 2012, ISBN 978-80-260-3431-5