Technical University of Denmark

31778 Distributed energy technologies modelling and control

Assignment 3 - Distribution grid modelling

Jorge Montalvo Arvizu
s192184

Spring 2020

1 Introduction

Given the distribution grid reliability requirements, it is necessary to control the system parameters and analyze it to prevent any issues. Variables such as voltage are of upmost importance for DSO's to secure a quality service to end-users. In this report, a three-phase system is analyzed and the calculations are also compared to a designed system in SimPowerSystems/Simulink.

2 Parameters

Given the data, the following parameters were selected and calculated:

$$S_{base} = 630\ kVA \qquad V_{base1} = 10\ kV \qquad V_{base2} = 0.4\ kV$$

$$Z_{base1} = \frac{V_{base1}^2}{S_{base}} = 158.7300\ \Omega \qquad Z_{base2} = \frac{V_{base2}^2}{S_{base}} = 0.2540\ \Omega$$

$$R_t = 2 \cdot Z_{base2} \cdot r_2 = 0.0026\ \Omega \qquad X_t = 2 \cdot Z_{base2} \cdot x_2 = 0.0100\ \Omega$$

$$R_l = r_1 \cdot l = 0.0778\ \Omega \qquad X_l = x_{l,1} \cdot l = 0.0360\ \Omega$$

$$R_{total} = R_t + R_l = 0.0804\ \Omega \qquad X_{total} = X_t + X_l = 0.0460\ \Omega$$

$$P_R = 100\ kW + 80\ kW = 180E3\ W \qquad X_R = 50E3\ \text{VAr}$$

3 Voltage Drop

The voltage drop across the transformer and the line is calculated using the complete and approximated formula as follows:

$$\text{Complete} \rightarrow \Delta \boldsymbol{V} = \frac{RP_R + XQ_R}{V_R^*} + j\frac{XP_R - RQ_R}{V_R^*}$$

$$\text{Approximated} \rightarrow \Delta \boldsymbol{V} \approx \frac{RP_R + XQ_R}{V_R^*} \quad \text{or} \quad \mathbb{R}(\Delta \boldsymbol{V}) \text{ from Complete}$$

Transformer:

$$\text{Complete} \rightarrow \Delta \boldsymbol{V} = \frac{0.0026 \cdot 180E3 + 0.01 \cdot 50E3}{400} + j\frac{0.01 \cdot 180E3 - 0.0026 \cdot 50E3}{400} = 2.42 + j4.175\ V$$

$$\rightarrow |\Delta \boldsymbol{V}| = 4.8257\ V$$

$$\text{Approximated} \rightarrow \Delta \boldsymbol{V} \approx \mathbb{R}(\Delta \boldsymbol{V}) = 2.42\ V$$

Line:

$$\text{Complete} \rightarrow \Delta \boldsymbol{V} = \frac{0.0778 \cdot 180E3 + .036 \cdot 50E3}{400} + j\frac{.036 \cdot 180E3 - 0.0778 \cdot 50E3}{400} = 39.51 + j6.48\ V$$

$$\rightarrow |\Delta \boldsymbol{V}| = 40.04\ V$$

$$\text{Approximated} \rightarrow \Delta \boldsymbol{V} \approx \mathbb{R}(\Delta \boldsymbol{V}) = 39.51\ V$$

The previous calculated values are then simulated on Simulink, giving the following results:

Transformer:

$$\text{Mag} \rightarrow \Delta \boldsymbol{V} = (1 - 0.9929) \cdot 400 = 2.84\ V$$

$$\text{Mag, Ang} \rightarrow \Delta \boldsymbol{V} = (1\underline{/0^\circ} - 0.9929\underline{/-0.6678^\circ}) \cdot 400 = 2.867 + j4.629V$$

$$\rightarrow |\Delta \boldsymbol{V}| = 5.445\ V$$

Line:

$$\text{Mag} \rightarrow \Delta \boldsymbol{V} = (0.9929 - 0.8805) \cdot 400 = 44.96\ V$$

$$\text{Mag, Ang} \rightarrow \Delta \boldsymbol{V} = (0.9929\underline{/-0.6678^\circ} - 0.8805\underline{/-1.738^\circ}) \cdot 400 = 45.095 + j6.053V$$

$$\rightarrow |\Delta \boldsymbol{V}| = 45.49\ V$$

It can be seen from the results that the calculated vs. simulated voltage drops are a little bit different. This difference occurs because of the assumption on the voltage drop formula that $V_R^* = V_S (\approx V_{nom})$.

4 Joule Losses

By simulating the system, the phase current was obtained for the line and transformer.[1] Given that the transformer is simulated with a magnetization resistance, the power losses through the core of the transformer were also calculated from the simulation's results. These power losses occur because of the eddy current at the transformer.

$$\begin{aligned}|I_{ph}| &= 306.2\ A\\ |I_{core}| &= |I_{excitation} - I_{magnetization}| = 0.07249\ A\\ R_{core} &= 500pu \cdot Z_{base1} = 79365\ \Omega\\ P_{loss} &= 3 \cdot |I|^2 \cdot R\end{aligned}$$

Transformer:

$$\begin{aligned}P_r &= 3 \cdot 306.2^2 \cdot 0.0026 = 731.32\ W\\ P_{core} &= 3 \cdot 0.07249^2 \cdot 79365 = 1251.1\ W\\ P_{loss} &= P_r + P_{core} = 1982.5\ W\end{aligned}$$

Line:

$$P_{loss} = 3 \cdot 306.2^2 \cdot 0.0778 = 21883\ W$$

Whereas the simulation results are:

Transformer:

$$P_{loss} = 1971\ W$$

Line:

$$P_{loss} = 21888\ W$$

5 Voltage Control

In order to achieve a new voltage drop of $\Delta V = 0.05 \cdot V_{nom}$, the approximated active and reactive power were calculated from the simplified formula as follows:

$$\begin{aligned}\Delta \boldsymbol{V} \approx \frac{RP_L + XQ_L}{V_L^*} &\rightarrow P_L \approx \frac{V_{nom}\Delta V - XQ_L}{R}\\ &\rightarrow Q_R \approx \frac{V_{nom}\Delta V - RP_L}{X}\end{aligned}$$

The results are:

$$\begin{aligned}P_L &\approx \frac{400^2 \cdot 0.05 - 0.046 \cdot 50E3}{0.0804} = 70896\ W\\ P_2 &= P_L - P_1 = 70896 - 100000 = -29104\ W\\ Q_L &\approx \frac{400^2 \cdot 0.05 - 0.0804 \cdot 180E3}{0.046} = -140700\ \text{VAR}\\ Q_2 &= Q_L - Q_1 = -140700 - 50000 = -190700\ \text{VAR}\end{aligned}$$

[1] Notice that, since the analyzed system is a three-phase balanced system, it is only necessary to use the current of one phase to calculate power losses.

Then, these results were entered into the model to probe and calculate the simulated voltage drop after the adjustment, the following are the results:

With active power control:

$$V_2 = 0.9477\ pu$$
$$\Delta V = 1 - 0.9477 = 0.0523\ pu$$

With reactive power control:

$$V_2 = 0.9423\ pu$$
$$\Delta V = 1.004 - 0.9423 = 0.0617\ pu$$

However, with the active power control, the load would need to generate power and inject it into the grid, which isn't possible since the load isn't a generator. It might be possible for a demand-response end-user to decrease its active power consumption but unless there's a generator connected at the terminals of the load, it isn't possible to control the active power as generated.
Regarding the reactive power control, this solution seems plausible but the current at the elements must be taken into account. In this case, the phase current at the line is $350\underline{/30.54^\circ}\ A$, which is bigger than the maximum current limit at 315 A. Thus, this solution isn't plausible as well.

6 Voltage Control - K-droop

In this final case, a new load was added into the system with a voltage controller connected at its terminal. This controller contains the K-droop which was calculated following the Ziegler-Nichols method:

- Start the simulation with $K_u = 1$
- Increase K_u until the controller's response starts to oscillate
- Calculate $K_p = 0.5 \cdot K_u$
- Then, $K_{droop} = \frac{-1}{K_p}$

The derived K_{droop} is 0.0952 or 9.52%. With this controller's value, the reactive power from the controller is derived with two cases:

$V_{setpoint}$ **= 0.95**:

$$Q_2 = -69940 \text{ VAr} \quad \text{at steady state}$$
$$V_2 = 0.9056 \quad \text{at steady state}$$

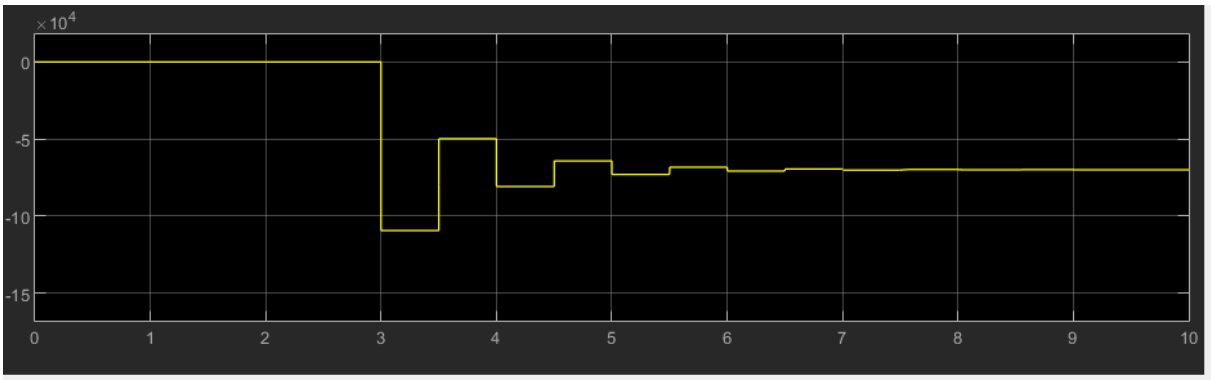

Figure 1: Reactive power at setpoint 0.95 [VAr vs time]

$V_{setpoint}$ **= 1.05**:

$$Q_2 = -150000 \text{ VAr} \quad \text{at steady state}$$
$$V_2 = 0.9307 \quad \text{at steady state}$$
$$I_L = 319.3\ A \quad \text{at steady state}$$

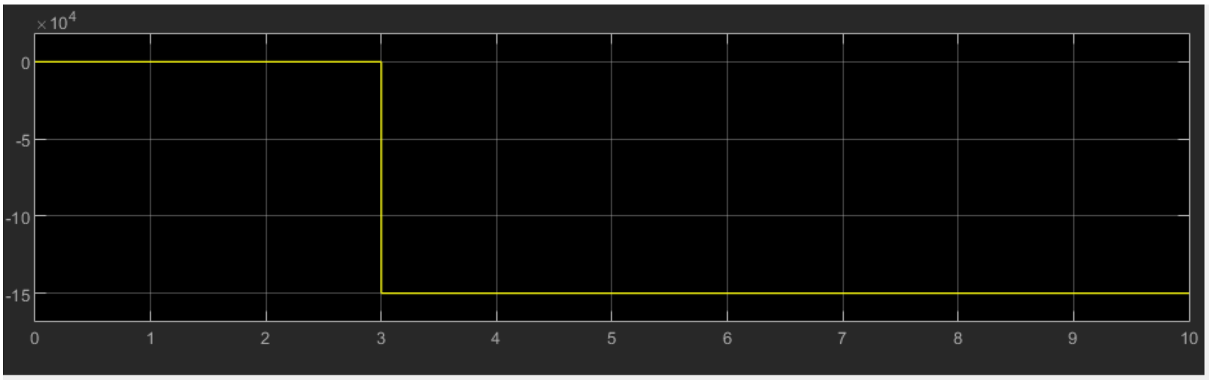

Figure 2: Reactive power at setpoint 1.05 [VAr vs time]

It can be seen from figure 1 that the controller's response settles at -69904 VAr. With K_droop at almost 10%, the response is less intense given it's formula, as expected; this means that a 10% change in the voltage causes 100% change in the reactive power output. And from figure 2, the response is quite aggressive for the current K_{droop} since the setpoint is set at 1.05 the reactive power is saturated at its minimum value (-150 kVAr). Also, even though the voltage level increased compared to the previous case, the current at the line exceeds it's thermal limit as in section 5 which should be avoided.

7 Conclusion

It is important to take into account all the parameters in the distribution grids, being voltage control one of the most important ones. By controlling the reactive and active power in the distribution grid, optimal voltage drops can be obtained and also avoid unacceptable situations as exceeding the thermal limit of the line in the system. It is then necessary to analyze the different scenarios with the available simulation tools and theoretical knowledge.