Appendix C – S5.2.5.10 Technical Note

Introduction

This technical note illustrates how the phase angle difference between voltage measured at the connection point and reactive power from a generating system might be used as a basis for assessing whether the generating system is damping a voltage oscillation or exacerbating it. Distinguishing between those plants damping or exacerbating an oscillation would assist timely actions to prevent adverse impacts on the power system or the generating system. The method below suggests a methodology for assessing the extent of participation, which could be very valuable for understanding what actions are most likely to be effective in managing an oscillation and its impact on power system security.

Explanation

In the standard simplified block diagram illustrated below, it is assumed that the measured signal of voltage (V) and reactive power (Q) have been measured at the connection point.

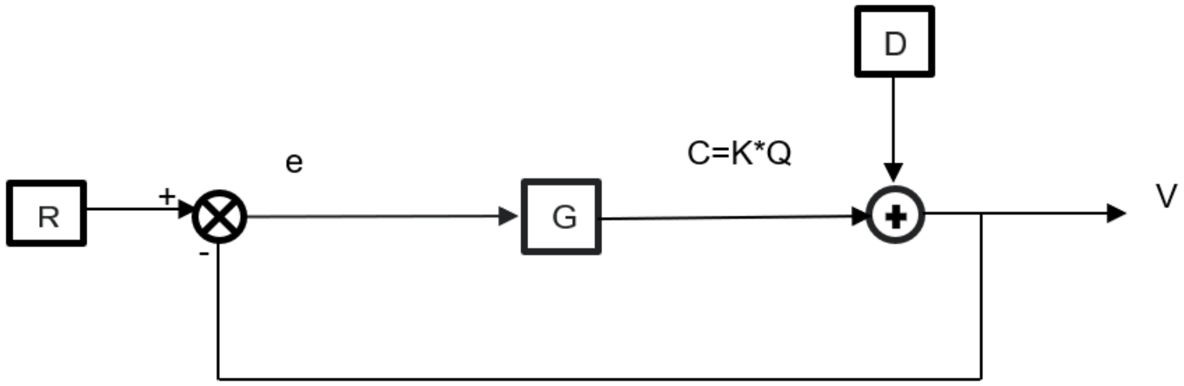

Figure 1 Simplified V-Q-control block diagram of a generator connected to a network

In this block diagram, R is the reference, G simplifies the entire control system of a voltage control loop of a generator equipped with Voltage-Droop characteristic, D is the disturbance (can be considered either internal or external disturbance) and V is the controlled voltage.

With the assumption that Voltage V will be comprised by the oscillatory disturbance D (either internal or external disturbance) and the effect of reference R times the transfer function G, V will be a signal with a dc offset and a sinusoidal component as follows

$$D = A\sin(\omega t) \qquad (1)$$

$$V = DC\_V + \mathrm{B}\sin(\omega t) \qquad (2)$$

For the purpose of providing damping by the generator, reactive power of the generator needs to have a cancelling term to the component to $A\sin(\omega t)$.

Mathematically, the maximum compensation will be when the term $-\sin(\omega t)$ is added to voltage V. As $-\sin(\omega t) = \sin(\omega t + 180)$ we can conclude that the best compensation to the oscillatory component of voltage will be provided with 180° phase shift. It is however noted that practically, considering the delays within the measurement devices and the control systems, achieving 180° phase will not be possible. Therefore, below we focus on the contribution of the damping that the generator can have by providing different phase shift between reactive power response and the voltage. This is done for the purpose of selecting a phase shift that can be selected as the angle that is selected to be the border of positive or adverse contribution in the protection system of the generator in response to unstable operation under S5.2.5.10 clause of NER.

Assuming that the phase difference between voltage and reactive power cannot always be 180° or close to it, below equations explore the impact of the change in the spectrum from 0 to 180°.

Considering the normalised voltage and reactive power around their equilibrium points we will have:

$$V = C + D \tag{3}$$

$$V = C + D = KQ + D \tag{4}$$

$$V = \mathrm{K}(\sin(\omega t + \theta) + \mathrm{A}\sin(\omega t) \tag{5}$$

$$\mathrm{V} = \mathrm{K}(\sin(\omega t)\cos(\theta) + \cos(\omega t)\sin(\theta)) + \mathrm{A}\sin(\omega t) \tag{6}$$

- In Eq.6 if $\theta = 0$, $\mathrm{V} = (\mathrm{K} + \mathrm{A}) * \sin(\omega t) + 0 * \cos(\omega t) = (K + A)\sin(\omega t)$. This shows that the oscillatory component has been magnified by the ratio of $\frac{(K+A)}{A}$ which means when voltage and reactive power are in the same phase a complete exacerbation and adverse contribution.
- In Eq.6, $0 < \theta < 90$, $\mathrm{V} = (\mathrm{K}\cos(\theta) + \mathrm{A}) * \sin(\omega t) + K\cos(\omega t)\sin(\theta)$. It is seen that the term $\sin(\omega t)$ has been magnified by the ratio $\frac{(K \cos(\theta)+A)}{A}$ which is smaller in magnitude given K is multiplied by $\cos(\theta)<0$.
  - It is also seen that there is a second oscillatory term appearing in the response with the magnitude of $K\cos(\omega t)\sin(\theta)$.
- In Eq.6, if $90 < \theta < 180$ $\mathrm{V} = (\mathrm{K}\cos(\theta) + \mathrm{A}) * \sin(\omega t) + \mathrm{K}\cos(\omega t)\sin(\theta)$. It can be seen that gain of $\sin(\omega t)$ can has been reduced because K is multiplied by a $\cos(\theta)$ which a negative value. Therefore, term $\sin(\omega t)$ has reduced by a factor $\frac{(-|K \cos(\theta)|+A)}{A}$.
  - It is also seen that there is a secondary oscillatory term which is reduced as θ proceeds towards 180 that $\sin(\theta)$ gets closer to 0.
- In Eq.6, if $\theta = 180$, $V = \mathrm{K}(\sin(\omega t)\cos(\theta) + \cos(\omega t)\sin(\theta)) + \mathrm{A}\sin(\omega t)$
  $= \mathrm{K}(\sin(\omega t) + 0) + \mathrm{A}\sin(\omega t)$
  $= (-K + A)\sin(\omega t)$

It can be observed that the maximum cancellation of the term $\sin(\omega t)$ at 180°.