SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING

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Name of Module: (Power Systems Analysis, POWS4601)

TU Dublin – Grangegorman

Transient Stability Analysis

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1. Lab Objectives

The aim of this laboratory experiment is to understand the concept of transient stability of a power system when temporary faults occur in a power system.

1.1. Introduction

The effects of temporary faults on the power system are analysed in the transient stability analysis, where swing curve of the generator rotor angle decides whether if the generator will remain connected to the power system even after the fault occurs. When the fault occurs all the power is going to ground so therefore, analyzing the system voltage and power flow.

The system shown in figure 1 shows a generator connecting an infinite bus via two lines.

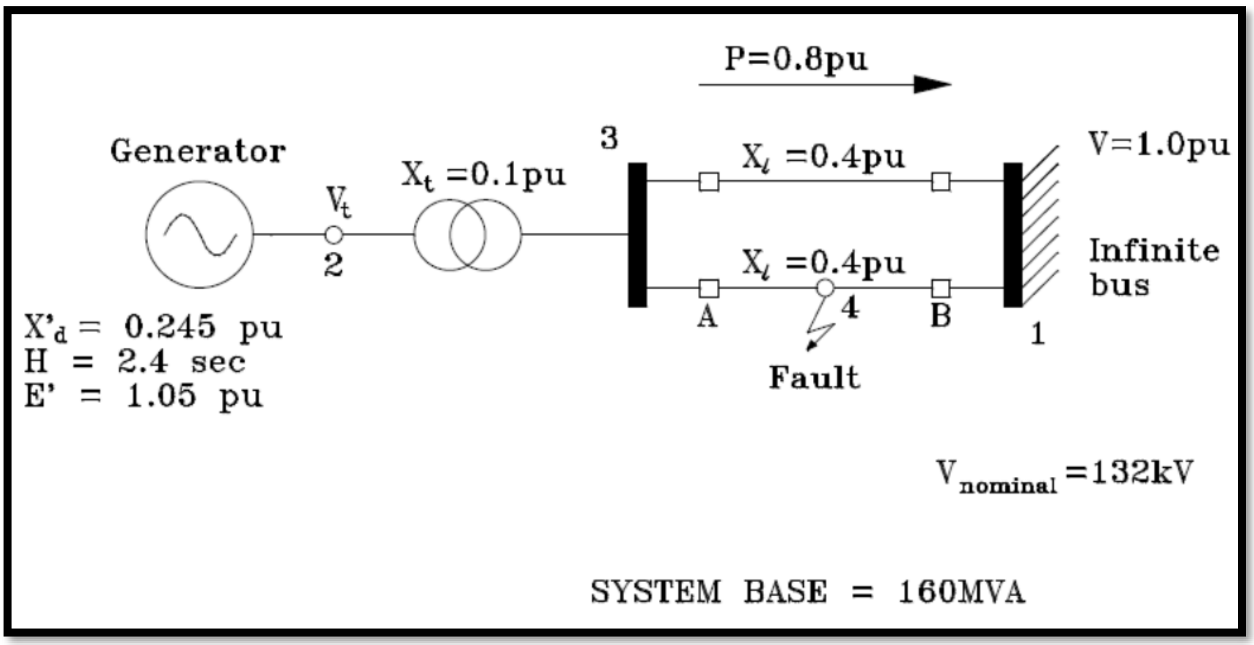


Figure 1 - Testing this power system

The system stability is going to be investigated using the given code and the multiple factors will be tested to see which affect stability. The clearing time (Tc) is the time permits until the breakers at points A and B switches, isolating the fault.
Altering critical clearing time to measure the system stability. This time in seconds is used as a measure of the system stability to observe the longest time the breakers can remain closed until instability take place.

2. Lab Procedure

2.1. Stable Condition

The stable program was run for a short fault by changing clearing time (TC) to twice the time to application of the fault (TF) so, therefore $TC = 2 \times TF$ and observing the output.

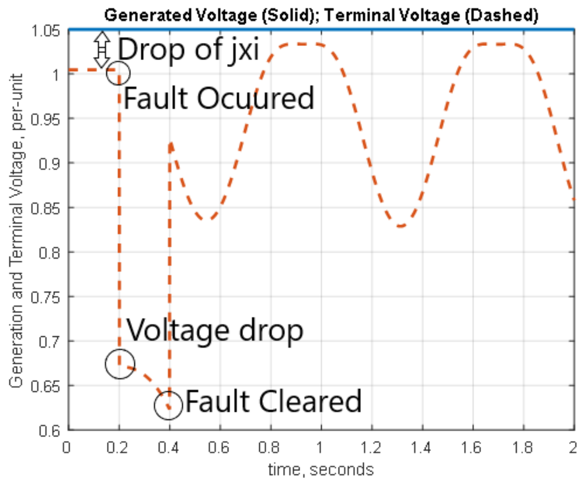


Figure 2 – Generated voltage output of the stable system

The generated voltage graph that is shown in figure 2 shows the fault occurred at 0.2 seconds and fault was cleared at 0.4 seconds which means it took 0.2 seconds to clear the fault in the system indicating the fault was cleaned quickly in the system so therefore the system is stable. The difference between 1.05V to 1V is due to the Jxi.

The plot below in figure 3 is rotor angle/time known as the swing curve, which determines the stability of the system. The angle delta is converted to a time value which helps measuring stability.

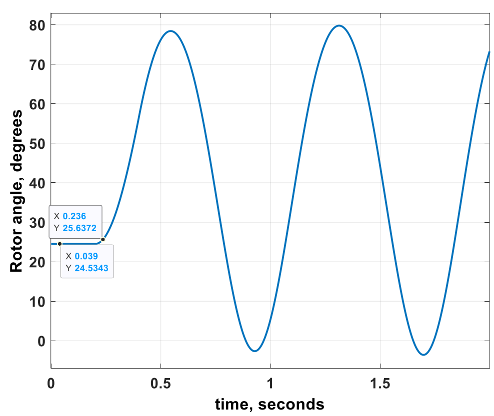
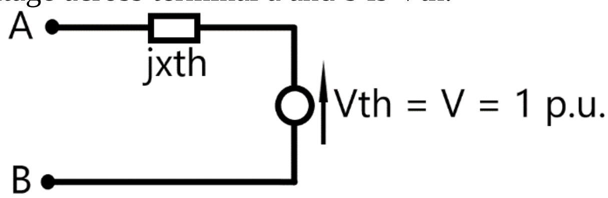


Figure 3 - Swing Curve

The initial rotor angle is 24.5343 showing by the simulator which matches to the calculated rotor angle as shown below. Under normal loading conditions at 0.2 seconds the angle start increasing. Delta δ doesn't increase during the stable conditions. Delta increases when the electrical power drops, increasing accelerating power.

Since we are given the following and trying to find load angle delta:
$P_E = 0.8$
$V = 1\, p.u.$
$E = 1.05\, p.u.$
$\delta = ?$

Taking the thevenin equivalent circuit and looking at the system From generator percpective, When its open circuit the current is zero therefore, voltage drop across the jxth is zero, therefore, voltage across terminal a and b is Vth.



$$X_{th} = X'_d + X_t + \frac{X_L}{2}$$
$$X = 0.245 + 0.1 + \frac{0.4}{2} = 0.545 \text{ p.u.}$$

Using the derived power equation to find the value of delta δ.

$$P_E = \frac{VE}{X} Sin\, \delta$$
$$\delta = \sin^{-1}\left(\frac{P_E X}{VE}\right)$$
$$\delta = \sin^{-1}\left(\frac{0.8 \times 0.545}{1 \times 1.05}\right) = \mathbf{24.53°}$$

2.2. Unstable Condition

The program was run for an unstable fault by changing clearing time, $TC = TSIM$, (simulation time), which leads the output to an unstable.

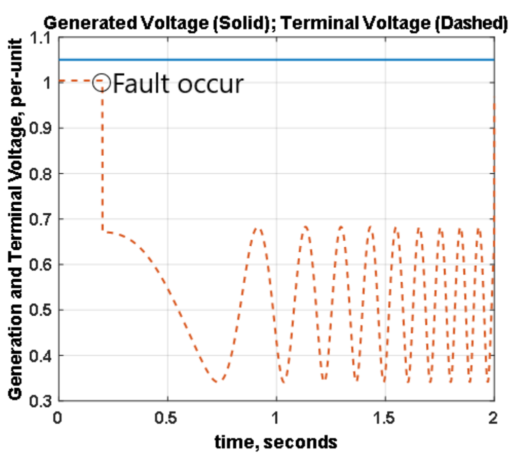


Figure 5 - Instability output of generated voltage

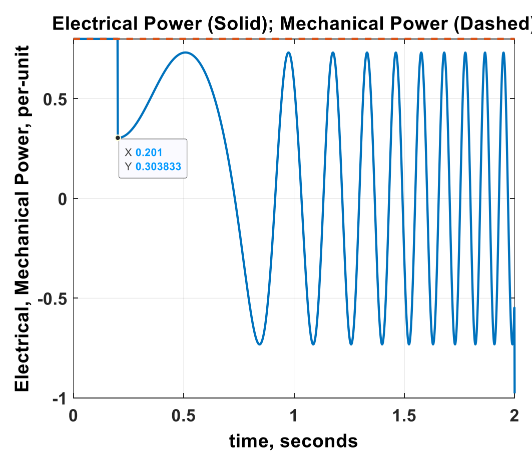


Figure 4 - Output of Mechanical power in an unstable system

Figure 4 shows unstable condition where we can see fault happened and it dropped rapidly and continues to degrade and stabilizes at 0.51 per unit even though expect values should be 1 per unit. Which indicates that it is an unstable system, a sustained fault which leads to instability.

Delta δ independently increases in an unstable environment as the generator losses control, which puts system out of phase.

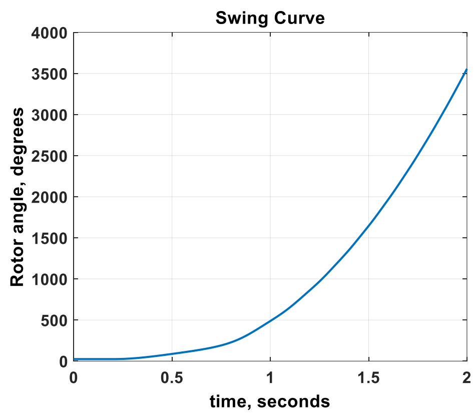


Figure 6 - Swing curve of an unstable system

2.3. Critical Clearing Time

The critical clearing time in short Tcc corresponds to the maximum time the fault goes from stable to unstable. The idea is to vary the clearing times (Tc) to determine the critical clearing time, Tcc for the fault conditions and looking at the swing curve graph to decide the value of the critical clearing angle Tcc.

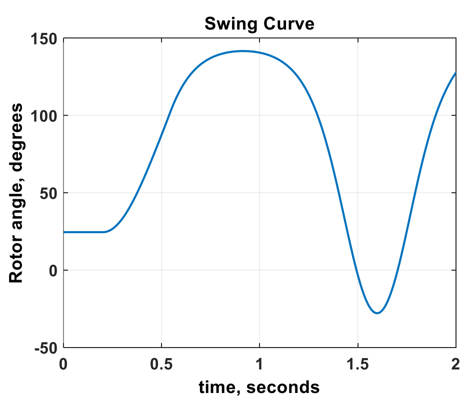


Figure 7 - Stable critical curve at 0.542s (Tc)

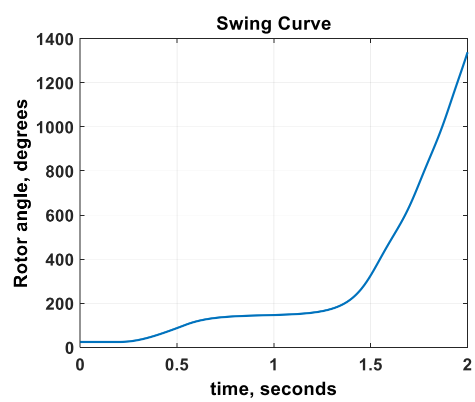
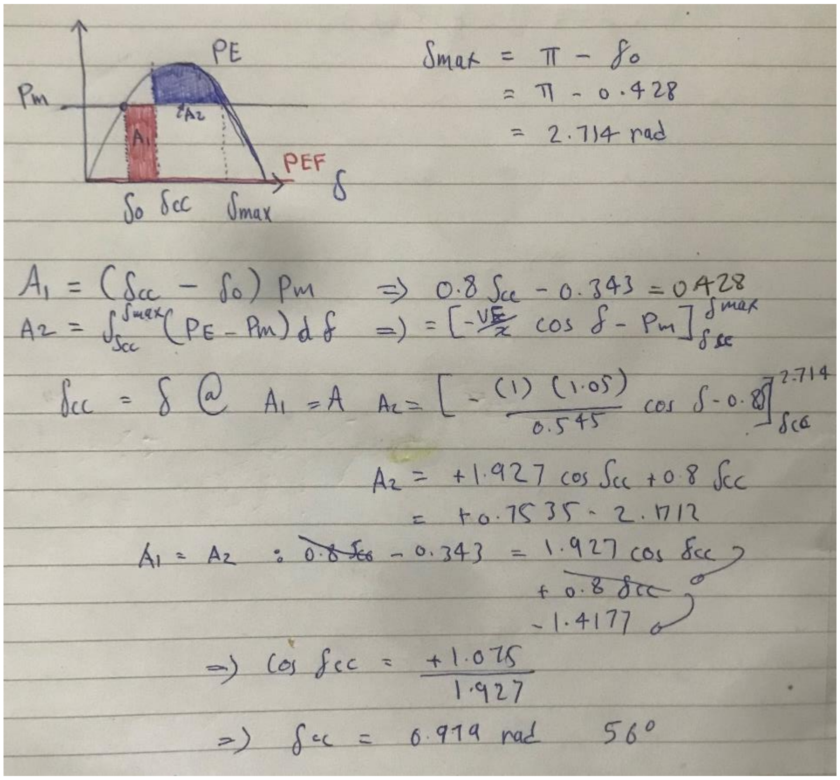


Figure 8 - Unstable after 0.542s (Tc)

Which means that we can run the fault for 0.542 seconds long as a stable system shown in figure 7 otherwise the system will go unstable as shown in figure 8. It takes 3.42 seconds long for a system can sustains a fault before it goes unstable because fault happens at 0.2 seconds.

Calculating the critical clearing angle for this fault.



2.4. Fault Reactance

Increasing the fault reactance (Xf = 0.2 p.u) and analyzing the swing curves for a range of clearing times and observing the effect of fault reactance on the system stability system.

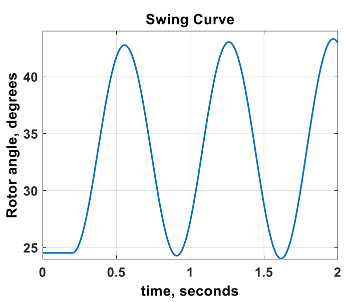


Figure 10 - 0.4s TC

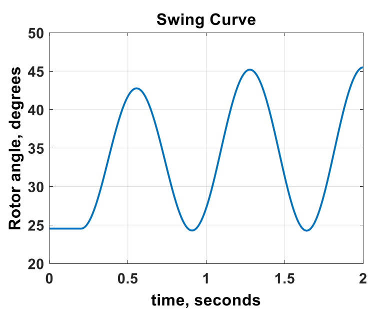


Figure 11 - 1s TC

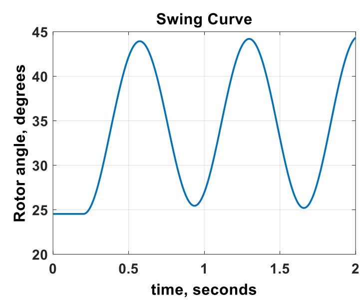


Figure 9 - 2s TC

When increasing the fault reactance Xf to 0.2 power unit and keeping the original settings of the system, we notice that the swing curve graph of the system is becoming more stable as caring out few tests by increase the clearing time Tc to 0.4s, 1s and 2s. We see that the system is still stable even if we increase the Tc up to 2s.

2.5. Power Transfer

Mechanical power Pm also affects the system stability and changing the mechanical input to Pm = 0.4 power unit and analyzing the swing curve for a range of clearing times and observing the effect of power input on the system stability.

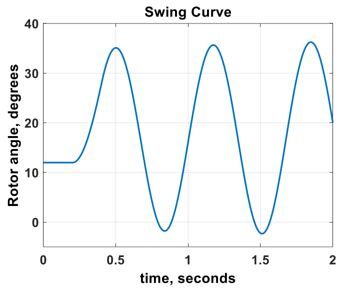


Figure 14 - 0.4s TC

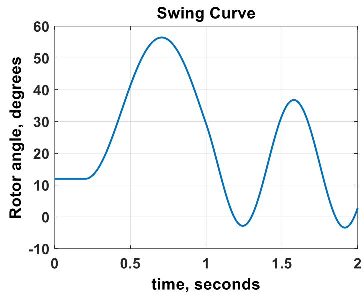


Figure 13 - 1s TC

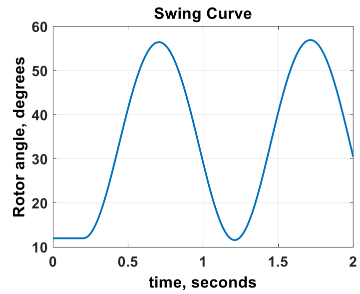


Figure 12 - 2s TC

When increasing the Mechanical power Pm to 0.4 power unit and keeping the original settings of the system, we notice that the swing curve graph of the system is becoming more stable as caring out few tests by increase the clearing time Tc to 0.4s, 1s and 2s. We see that the system is also still stable even if we increase the Tc up to 2s.

2.6. Generator Inertia

The inertia is described as the generator's capability to stay in motion. Finding out new critical clearing times Tcc for generator inertias by doubling the inertias and half its present value.

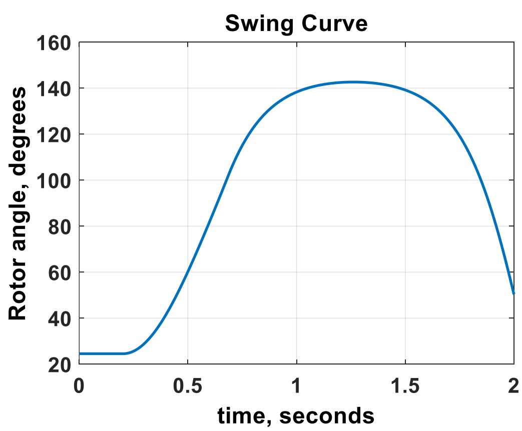


Figure 15 - Stable condition at Tc 0.684s

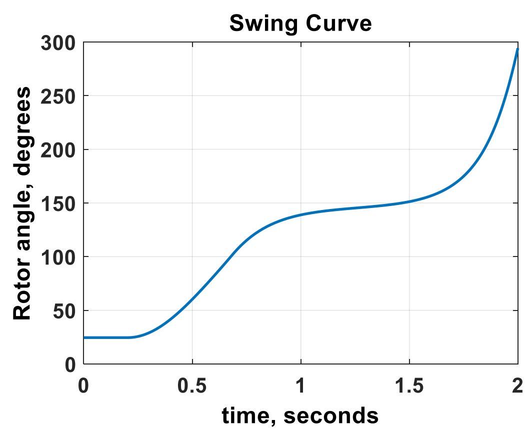


Figure 16 - Unstable condition at Tc 0.685s

Which means that we can run the fault for 0.684 seconds long as a stable system shown in figure 7 otherwise the system will go unstable as shown in figure 8. It takes 4.684 seconds long for a system can sustains a fault before it goes unstable because fault happens at 0.2 seconds.

The inertia can be calculated using the swing equation where P_A is the accelerating power, and the acceleration is determined by two things: the electrical frequency, f, and the inertia of the generator, H. We can manipulate the formula to find inertia.

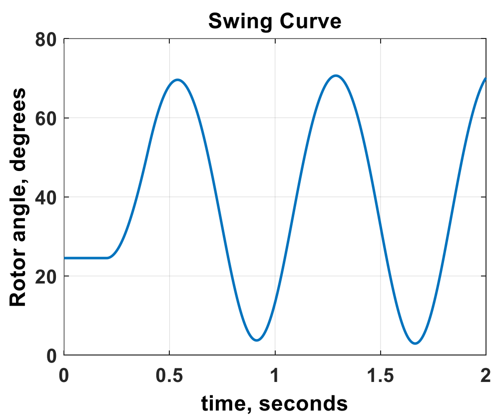
$$a = \frac{\pi f}{H} P_A$$

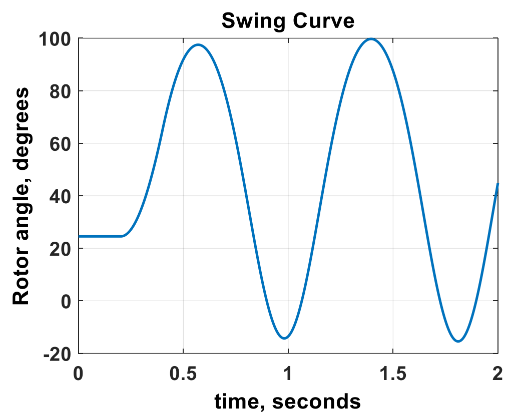
$$H = \frac{\pi f (P_M - P_E)}{a}$$

2.7. Distance to Fault

The distance to the fault (d), where d is the distance from the infinite bus which affects the amount of resistance present before the fault and so will affect the faulty system.

Analyzing the critical clearing times Tcc for distance (d) values at 0.25 p.u. and 0.75 p.u.





Calculating critical clearing time:

Critical clearing time:

during fault : $PA = Pm - P_{EF} = 0.8$ p.u.

$\Rightarrow a = \frac{\pi f}{H} \cdot P_A = \frac{\pi (50)}{2.4} \cdot (0.8)$

$= \frac{50}{3} \pi$ rad/s^2

This is constant through out this fault.

$w = \int a \, dt$

If $a = a(t)$ then this is ~~thicky~~ tricky $\Rightarrow$ numerical solution

but if $a =$ constant then ....

$w = a \cdot t + C_w$

@ $t = 0$: $w = 0$ so $C_w = 0$

and $\delta = \int w \, dt = at^2 + C_\delta$

@ $t = 0$: $\delta = \delta_0$ so $C_\delta = \delta_0$

$\Rightarrow \delta = at^2 + \delta_0$

$\Rightarrow \delta_{cc} = at^2_{cc} + \delta_0$

$\Rightarrow 0.979 = \frac{50\pi}{30} t_{cc}^2 + 0.428$

$\Rightarrow t_{cc} = 0.103$ s

3. Conculsion

Electrical power (PE) or the real power is proportional to the voltage angle, δ and PE will change over time.
If the load is big the delta δ is big, and if the load is small the delta δ will be small. Voltage angle delta δ is called load angle. If the delta is positive, it's a generator and if the delta is negative, it's a load.
Faults effects the stability of the system.

4. References

[1] Jane, C., 2021. Lab Transient Stability Analysis.