EE-208 ASYNCHRONOUS and SYNCHRONOUS MACHINES

Transient Response Analysis of a Synchronous Machine on an Infinite Bus System

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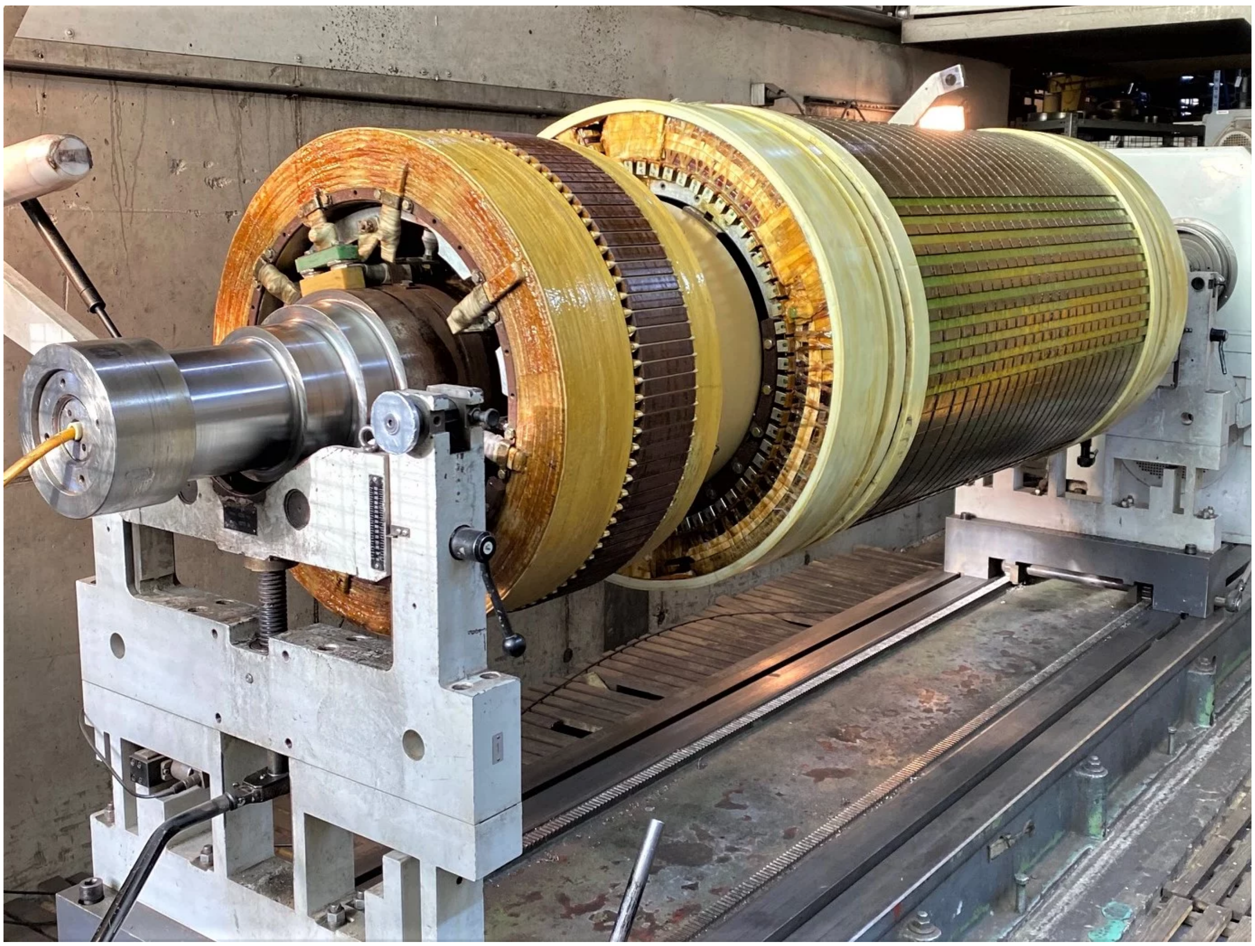


Problem Statement

- To study infinite bus systems and the applications and advantages of the same.
- To understand the working of a single synchronous machine on Infinite bus systems.
- Simulation to analyse the transient response of the synchronous generator upon addition of load to the infinite bus system.

Introduction

The power system is continually being subjected to changes or disturbances of various forms: faults, load changes, connection/disconnection of generators etc. As the power network is a complex electro-mechanical system, these events cause oscillations in the speed and angles of machines and in power flows along the lines. Transient stability analysis is the study of the system in response to these changes and is used to determine if the system will be stable after a given disturbance. For proper operation of the system, it is essential to ensure that after a given disturbance, the system settles down to a new, stable condition.

Earlier, the response of a load/generation area to changes in load was considered and the frequency deviation from the rated value was predicted. For power/frequency control analysis, it was possible to linearise the system representation about its operating point and hence the application of the Laplace Transform was possible. However, transient stability analysis is generally concerned with the analysis of the effects of major disturbances, such as line faults.

An allied problem is the study of steady-state (or dynamic) stability. This is used to determine if a certain system condition is stable and to look at the response for small fluctuations. As with load/frequency control, linear analysis can be used for steady-state stability analysis. On the other hand, transient stability analysis involves major disturbances. If a three-phase fault occurs close to a machine, then the ability of that machine to transfer power changes from possibly 100% to zero. Hence, we must consider a much wider response range and the analysis is essentially non-linear.

For that reason, the transient analysis of a power network in adequate detail is a formidable task and is one of the major studies involved in power systems analysis. In the past, considerable simplifying assumptions were used to allow for some analysis of transient stability. This often involved considering one machine connected to an infinite system (constant voltage and frequency) through a transmission line. With the improved digital computer resources, it is now possible to investigate the transient stability of extensive systems consisting of many machines.

The significant components for transient stability are:

- The network before, during and after the transient disturbance.
- The loads and their characteristics.
- The parameters of the synchronous generators.
- The excitation systems of the generators.
- The turbine and speed governors.

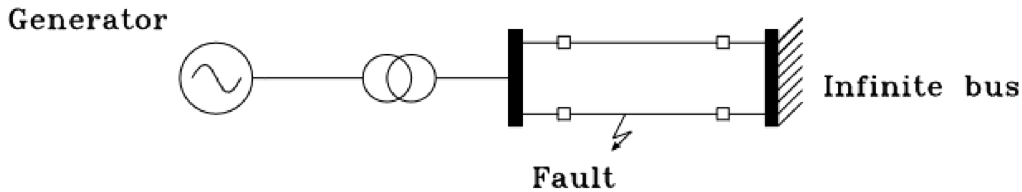


Figure1 : Single Machine Infinite Bus

Figure 1 above shows a single machine connected to an infinite bus through parallel transmission lines. The lines have circuit breakers installed at each end. A fault occurs at some point along the second transmission line. The objective is to determine the behaviour of the system before the fault, during the fault and after the fault has been cleared by opening the faulted transmission line. To do this we need to consider the representation of both the electrical and mechanical aspects of this system.

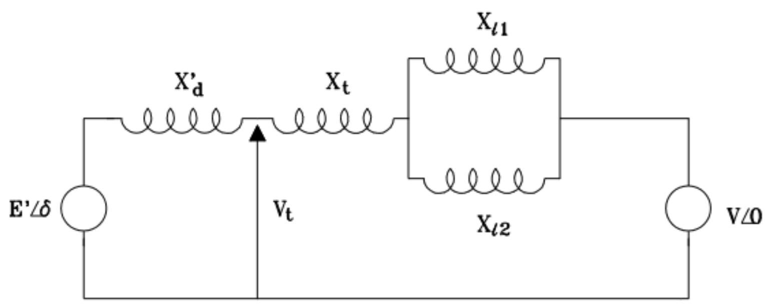


Figure 2 Representation of system

Figure 2 shows the equivalent circuit of the network. The synchronous is represented as a constant voltage E' behind the transient reactance Xd ' . The voltage behind transient reactance makes an angle of δ with the infinite bus voltage and this is equal to the machine rotor angle. The terminal voltage of the generator is Vt and the transformer reactance is Xt. The reactances of the lines are Xl1 and Xl2 .

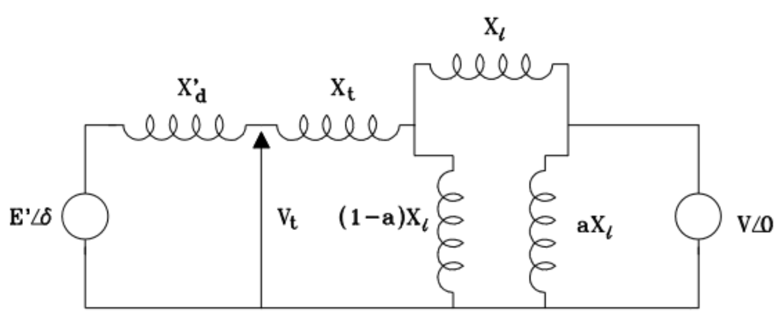


Figure 3 Network with fault

Improvement of Transient Stability

The main factors and controls which enhance transient stability are :

- Excitation systems
- Turbine valve control
- Faster fault clearing times
- Single pole operation of circuit breakers
- Minimise transformer reactances
- Series capacitor compensation of lines
- Additional transmission lines
- Load shedding
- Breaking resistors

Literature Review

In large power systems generators are required to maintain synchronism with the grid in order to provide standard service to customer utilization. Long distance AC transmission is often subjected to stability problems which affect the transmission capacity. Thyristor controlled series compensator (TCSC) is such an important device in the FACTS family that it is widely recognized as an effective and economical means to solve the power system stability problem. The variable impedance capability of TCSC is used as a series compensator in the transmission system for enhancing the transient stability of Single Machine Infinite Bus.[1]

The study of the dynamic behaviour and transient stability of the single-machine infinite bus (SMIB) with Power System Stabilizer and Parameters Variation Effects has also been performed. The idea of power system stabilizer (PSS) or supplementary excitation control is to apply a signal through the excitation system to produce additional damping torque of the generator in a power system at all operating and system conditions.[2]

Stability Enhancement in the SMIB system can also be performed by implementing Artificial Intelligence based techniques. As the power system is highly complex and nonlinear therefore it is not possible to predict its behavior at every point of time. Modern power systems are operated close to their stability limits. Stability issues mainly related to low frequency oscillations (0.2-3) Hz. are important in every power system which may lead to consequent blackouts and outages in the power system. These problems are generally related to the compensation of reactive power in the power system. Therefore modern power systems are equipped with power electronically controlled devices called flexible AC transmission systems (FACTS). These FACTS devices operate efficiently if their parameters are optimally tuned.

Constant Voltage on an Infinite Bus

Consider generators G1, G2, G3……Gn connected to an infinite bus as shown in the figure 4 below:

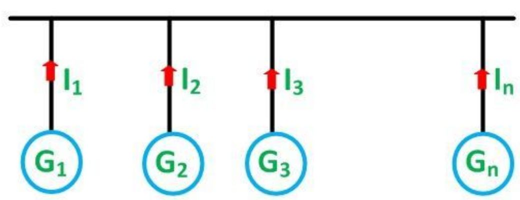


Figure 4: Infinite Bus System

Let, V be the terminal voltage of the bus,
E be the induced emf of each generator,
Z_s is the synchronous impedance of each generator,
n is the number of generators in parallel

$V = E - IZ_{Seq}$

$Z_{Seq} = Z_s/n$;When n is very large $Z_{Seq} \rightarrow 0$ and, therefore, $I\,Z_{Seq} \rightarrow 0$

Therefore, V = E (constant)[1]

Constant Frequency on an Infinite Bus

$$= J + J + J + \cdots \ldots . + J \text{ (n times)} = nJ$$

$$\text{Acceleration of alternator} = \frac{\text{Accelerating torque}}{\text{Moment of inertia}} = \frac{T_a}{\Sigma J} = \frac{T_a}{nJ}$$

Let, J be the moment of inertia of each alternator.The total moment of inertia of all n alternators is given asIf the value of n is very large, nJ is also very large.

Therefore, acceleration → 0, and the speed is constant.

The above equation shows that the constant voltage and frequency of the bus depend on the number of machines operating parallel.[1]

Advantages of Parallel Operation of Generators

- Several Generators can supply a bigger load rather than one big machine. Bigger and heavy machinery always require more maintenance and are not very economical[2].
- The higher the rating of the generator, the bigger the size of the setup will be. It is very difficult to manage a single large alternator which may range around 1000 MVA or more. If we are using small individual units connected in parallel, it will be easier to maintain considering its size[3].
- A number of machines can be added without disturbing initial installation according to the requirement to fulfill the increasing future demand of load[2].
- Reliability of the whole power system increases.High reliability on a single machine means if the only Generator in the system fails, power is cut and the load demands are not supplied[4].
- One or more alternators may shut down during the period of light loads. Thus, the remaining alternator operates at near or full load with greater efficiency[2].
- It allows for one or more generators to be shut down for preventive maintenance and inspection without disturbing the continuity of supply.
- Advantage of synchronous condensers compared to shunt capacitors is that shunt capacitors generate constant reactive power whereas synchronous condensers are able to deliver different reactive power levels by varying the excitation of the machine[5].

Applications

Parallel operation of Generators is very common. In fact, other than emergency generators, rarely there is a case where a single generator supplies the load in a power system. Various areas of application are ~

- Generators operating in parallel on a ship.
- Generators in an oil rig in the middle of the sea.
- Synchronous motors are used in generating stations and in substations connected to the bus bars to improve the power factor. These machines when over excited deliver the reactive power to the grid and helps to improve the power factor of the system. The reactive power delivered by the synchronous motors can be adjusted by varying the field excitation of the motor. These motors used for power factor correction applications can also be termed as "synchronous condensers"[5].
- Synchronous motors are also used to regulate the voltage at the end of transmission lines.
- In textile and paper industries synchronous motors are employed to attain a wide range of speeds with variable frequency drive systems.

Work Done In The Project

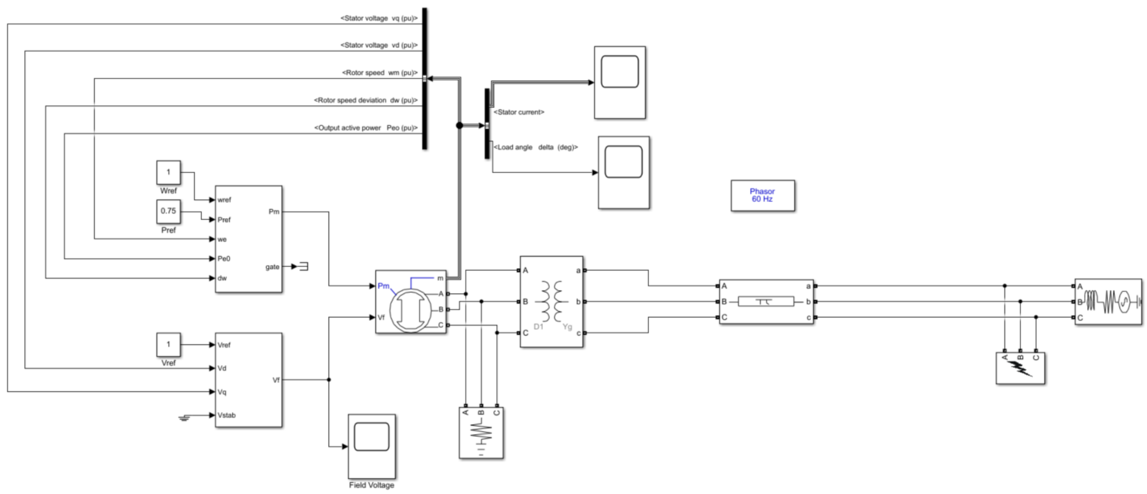
In this project we aim to model and analyze the Single Machine Infinite Bus System with different load conditions and topologies.

We use MATLAB simulink to simulate these conditions, we have considered the following conditions:

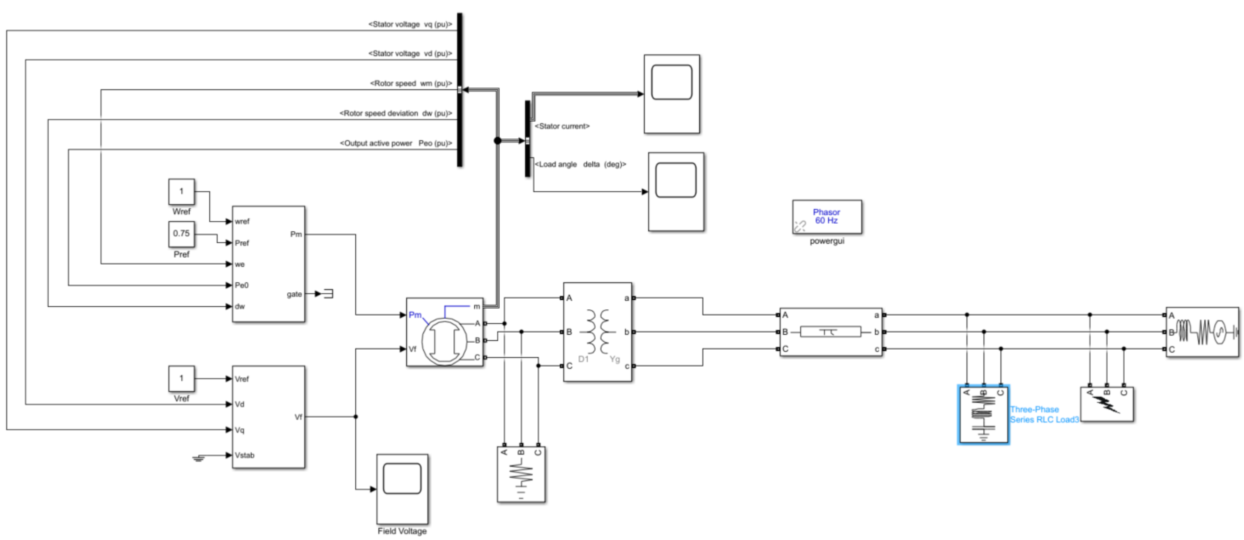
1. Infinite Bus system without load.
2. Infinite Bus system with $Load_1$.
3. $Load_1$ is before the transmission line and $Load_2$ is after the transmission line.

These 3 conditions are individually modelled and analyzed. The components used in these models are listed below:

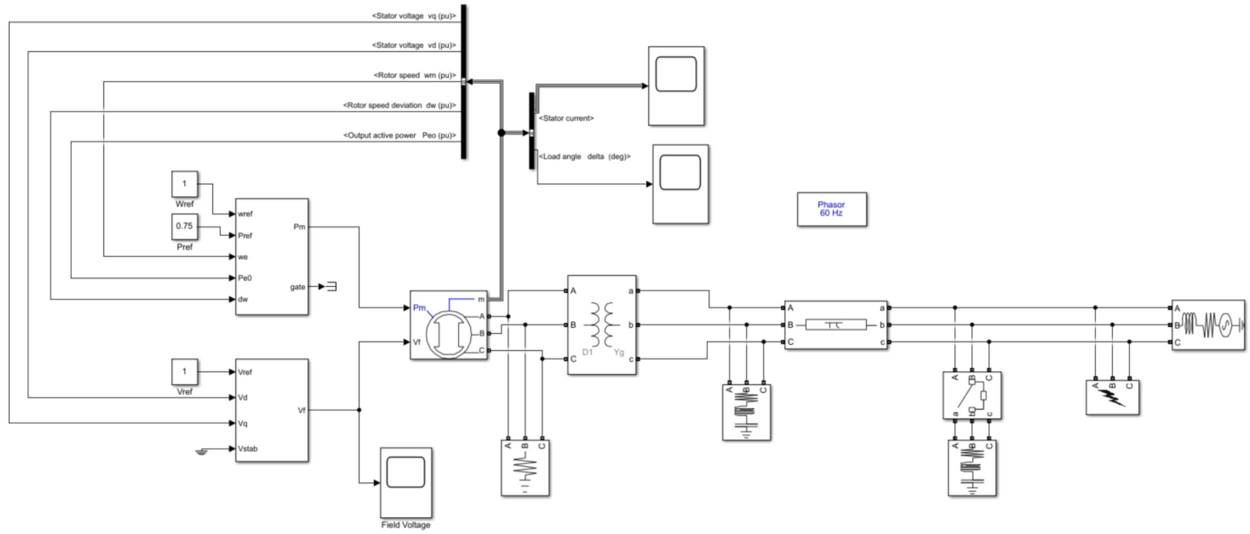
Condition 1.



Condition 2.



Condition 3.



Results

Condition 1.

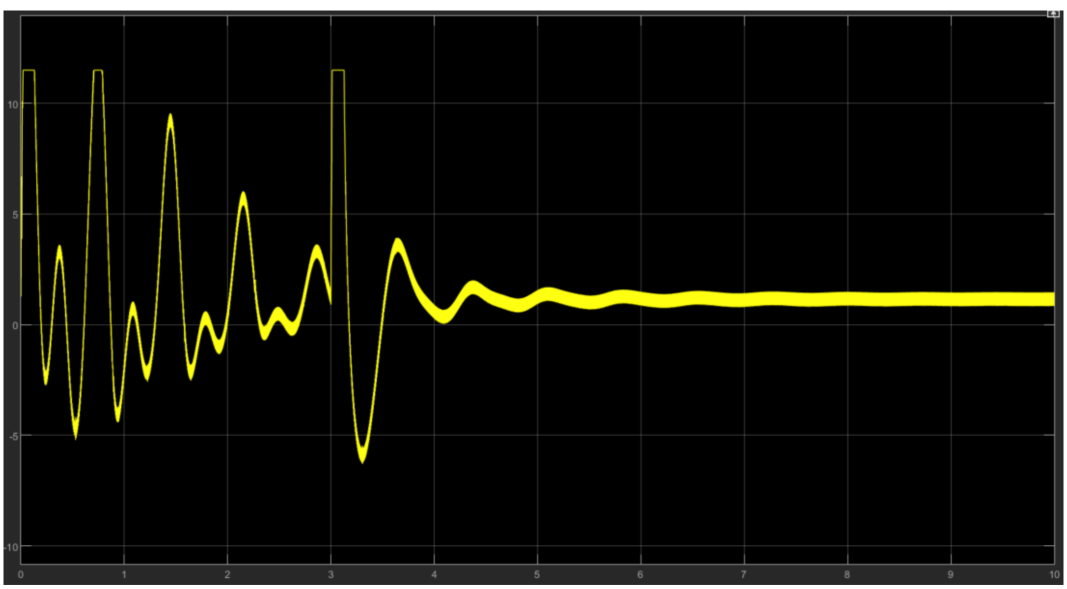


Figure5: Field Voltage vs Time:

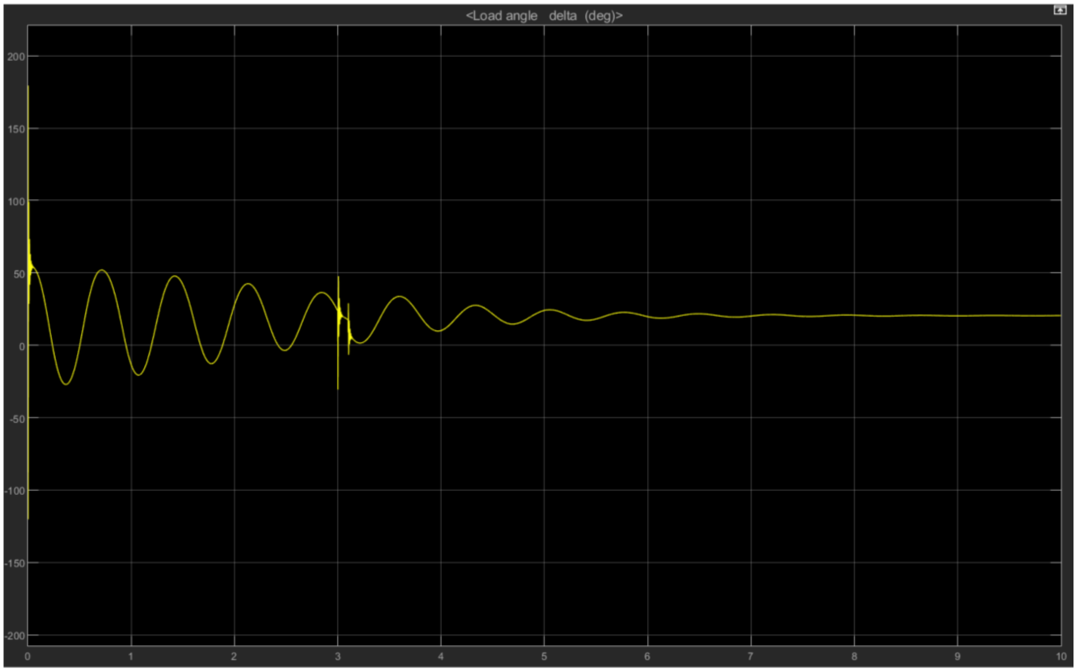


FIgure6: Load Angle vs Time:

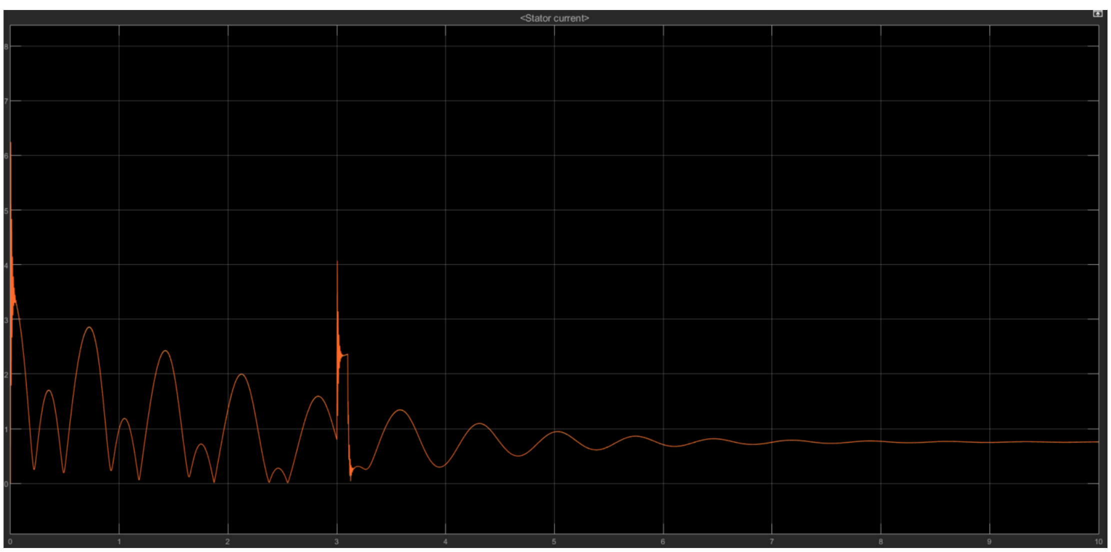


FIgure7: Stator Current vs Time

In this condition we see that due to the fault a transient occurs at 3/3.1 sec, but as the damping of the generator settles the fault settles as well.

Condition 2.

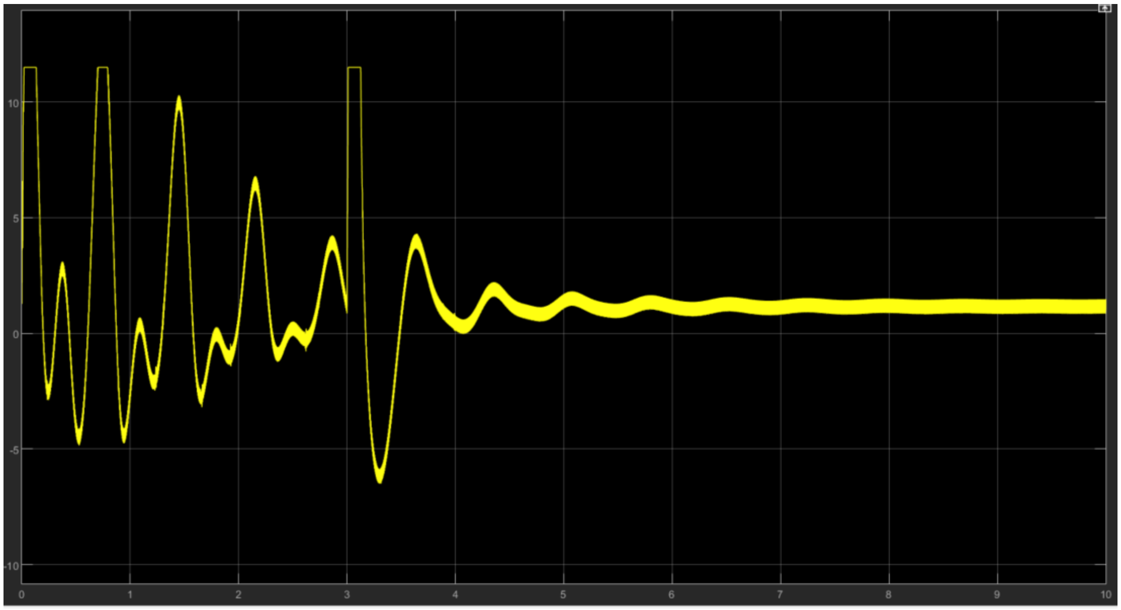


FIgure8: Field Voltage vs Time

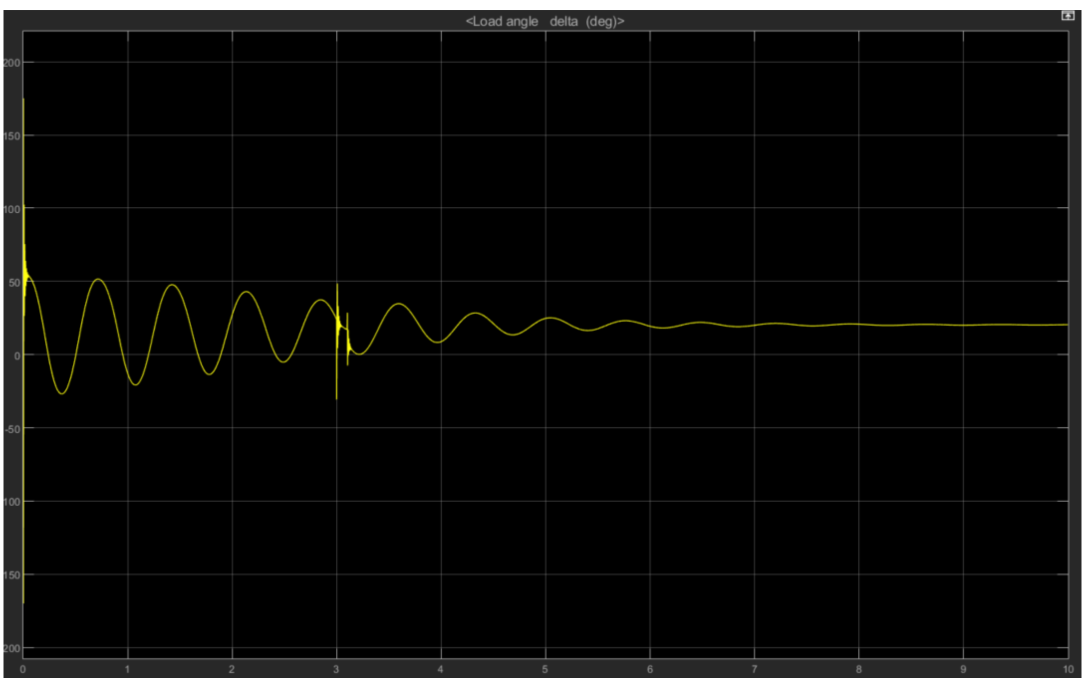


Figure9: Load Angle vs Time:

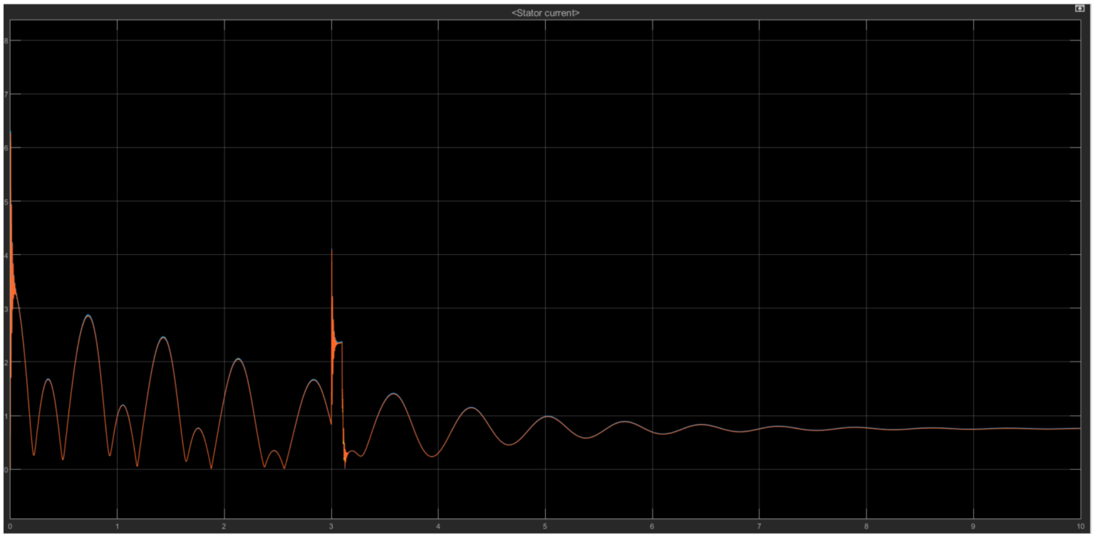


Figure10: Stator Current vs Time

In this condition we add a load and test the line current, the stator current decreases since this is a RLC load.

Condition 3.

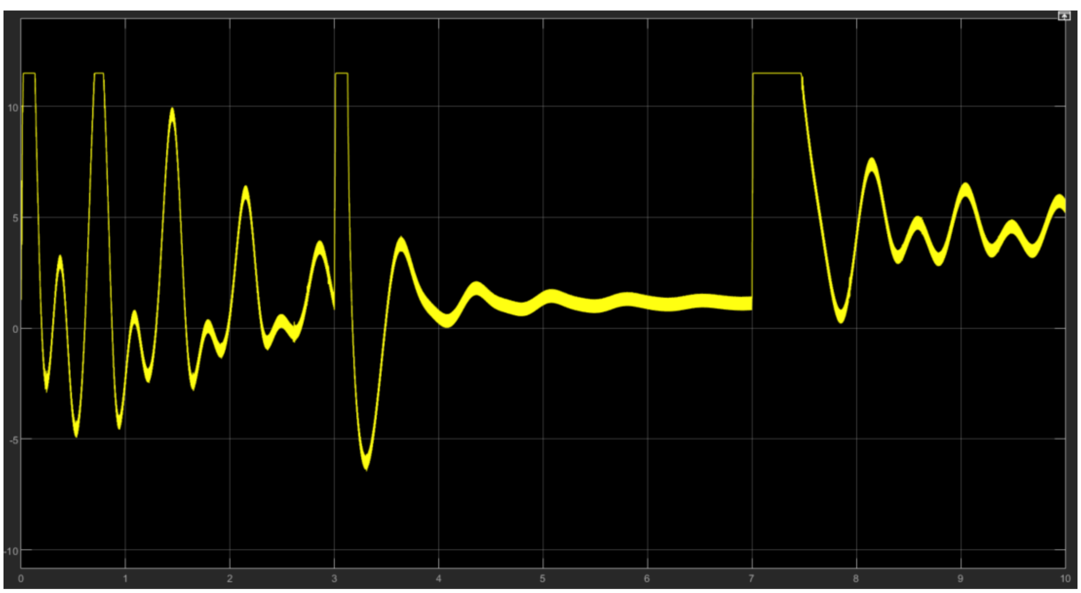


Figure11: Field Voltage vs Time

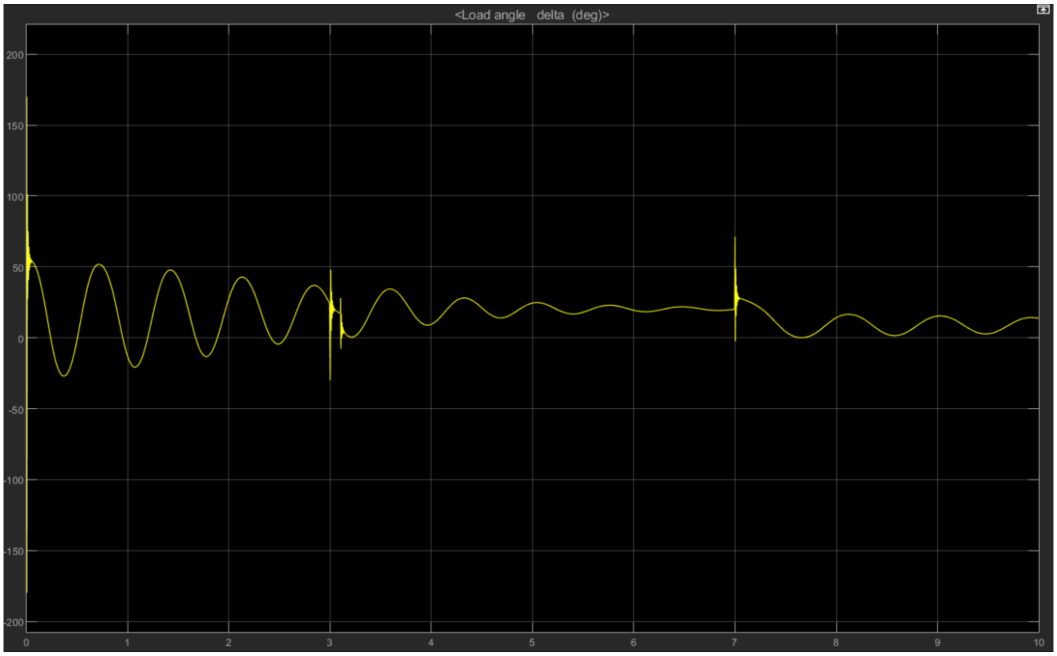


Figure12: Load Angle vs Time

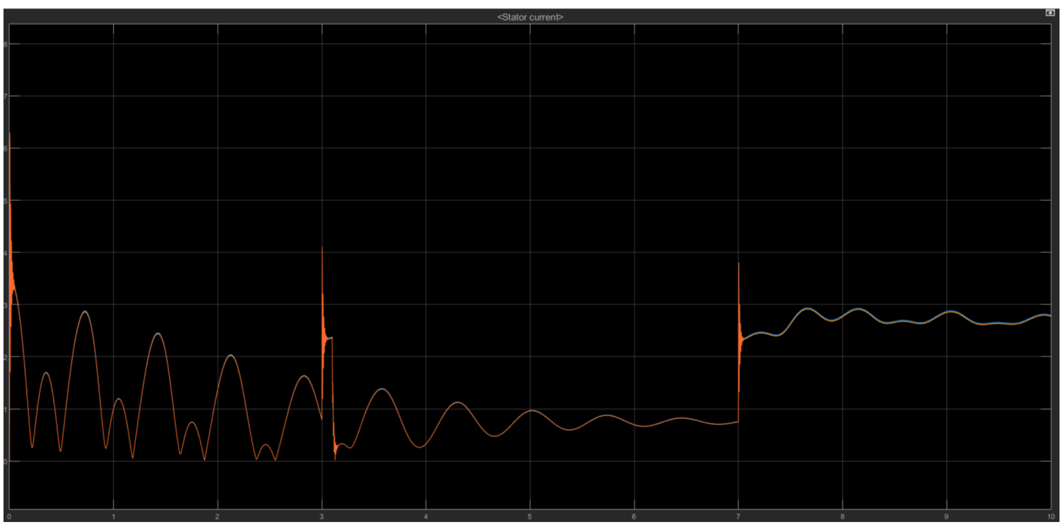


FIgure13: Stator Current vs Time

The first damping graph is of the synchronous generator when we start the simulation .The synchronous generator itself is having some oscillation which gets settled about 3 seconds, but here the fault occurs but eventually when the load angle gets settled. We are connecting our load at this point. Here we see the stable response value of the system increases and then settles.

Conclusion

Transient Response on addition/removal of load from the transmission lines can be observed in the Stator Current, Field Voltage, and Load Angle of the synchronous machine when connected to an infinite bus system.

As the load introduced to the system connected to infinite bus-bars and is increased, the load angle decreases, power factor further drops and armature current increases due to reduced power factor; active component being constant.

We observe that in condition 3, where the load is connected after the transmission line, the nominal phase-to-phase voltages decrease due to the depreciating resistance of the line, this reduces the power input to the load.

Fault introduced here is basically changing the resistance of the load, this causes a transient. The Transient Response eventually dies out with time and leaves behind a stable constant voltage and frequency across the whole transmission line.

References

[1] https://circuitglobe.com/infinite-bus.html

[2] https://circuitglobe.com/parallel-operation-of-alternators.html

[3] https://www.allumiax.com/blog

[4]https://www.electrical4u.com/parallel-operation-of-alternator

[5] https://qr.ae/pGXmtx, Sherley Wang

[6] https://youtu.be/RX5Xj1keQIc

[7] https://ieeexplore.ieee.org/

[8] http://research.iaun.ac.ir/pd/shahgholianold/pdfs/PaperC_4794.pdf

[9] G. Shahgholian Ghfarokhi, M. Arezoomand and H. Mahmoodian, "Analysis and simulation of the single-machine infinite-bus with power system stabilizer and parameters variation effects," 2007 International Conference on Intelligent and Advanced Systems, 2007, pp. 167-171, doi: 10.1109/ICIAS.2007.4658368.

[10] P. K. Gandhi, "Transient stability enhancement of single machine infinite bus system," *2013 International Conference on Advanced Computing and Communication Systems*, 2013, pp. 1-6, doi: 10.1109/ICACCS.2013.6938736.

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