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Transient Stability Analysis of IEEE-9 Bus Electrical Power System

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Abstract: ***Power system stability is an important aspect which determines the stability of the system. This paper deals with the rotor angle stability of IEEE 9-bus system consists of three generators and nine buses. To demonstrate the performance of the system, a three phase fault is introduced on different locations. The nature of the rotor angle excitation voltage and speed for all three generators are discussed. As the fault is cleared the system takes its own time to settle down.***

Keywords: ***Transient stability, three phase fault, multi machine, load flow.***

1. Introduction

Generation, transmission and distribution are generally the three stages in power system. The electrical power is generated mainly by using synchronous generators in the first stage of generation. Power system are designed to supply continuous power that maintains voltage stability due to unwanted events, like lightening, short circuit between the phase wires of the transmission lines, accidents or any other unpredictable events and the ground faults which may occur is called a fault. Due to these faults occurring in the system, one or many generators may be severely disturbed causing an imbalance between demand and generation [1].

It has become a necessity to maintain synchronism because the system is expanding day-by-day and these results in installation of larger machines now-a-days. Thus increase in use of electricity has cause planning for future expansion and has become increasingly complex. The lines become overloaded, voltage at each bus are decreased and generators become unable to supply active and reactive power to the system, under abnormal operation of power system. This condition represents a contingency [2].

Operation and the system operator must take an action to restore safe operation of power systems. To solve these problems of overloaded transmission lines and increasing load demand, two solutions can be applied. One is by increasing power generation and another by constructing new transmission line. The increasing cost of addition and modifications have made it imperative that utilities consider a range of design options, and performed detailed studies of the effect on the system of each option, based on a number of assumptions:

- Normal and abnormal operating conditions
- Peak and off-peak loadings
- Present and future years of operation

Stability of power system has been and continues to be one of the major concerns in system operation. One of the important studies, which should be included in designing of an electric power system, is "Transient Stability". Transient stability gives the evaluation of the power system's ability to withstand or sustain large disturbances and to survive transition to a normal operating condition.

The disturbances can be faults such as:

- Short circuit on a transmission line,
- Loss of generator
- Loss of load
- Involves large excursions of generator rotor angles
- Power flows
- Bus voltages and other system variables
- Gain of load or loss of a portion of a transmission network [3].

It is important that, while steady state stability is a function only of operating condition, transient stability is a function of both the operating condition and disturbance(s). Frequent analysis is required for various other types of disturbances that needed to be considered [4]. Power quality indicates to a wide variety of electromagnetic phenomena that characterize the voltage and current at a given time and at specified location. For properly understanding stability, the classification is important for significant power system stability analysis. Power system stability is classified on the basis of nature of resulting system instability (voltage and frequency stability), the size of disturbance (small and large disturbance) short term and long term stability (timeframe stability). In other words, stability is broadly classified as steady state stability and dynamic stability. The ability of the system to change from one operating point to another operating point under the condition of load changes called as steady state stability. Transient stability depends on both initial operating state of the system and the state when disturbance occurs in the system [5]. The post disturbance steady state operation will be different from that of prior disturbance. Due to insufficient synchronizing torque, instability is in the form of a periodic drift.

In case of transient stability studies, repeatedly considered disturbances are the short circuits of various types. Out of all these faults, generally the three phase short-circuit at the generator bus is the most severe one, the reason being – it causes maximum acceleration of the machine connected [6].

Large numbers of simulations are carried out regularly during planning stages to gain exact knowledge of the system. Simulink is an interactive environment for analyzing, modeling and simulating a wide variety of dynamic systems. It also provides a graphical user interface (GUI) for building or constructing block diagram models. From the library of standard components, a system is configured in terms of block diagram representation. The block diagram representation can be constructed easily and it quickly displays the simulation results [7].

Simulink is basically useful for analyzing the effects of non-linearity on the nature of the system and is also an ideal research tool [8].

Yet, even a well-designed and normally operated system may face the threat of transient instability. The aim of the investigation is to analyze or study the behavior (nature) of the synchronous machine in particular, the angular position of the rotor with respect to time after the fault occurs in the system [9]. One of the sections describes the development of IEEE-9 bus system model. The case study of IEEE-9 bus system and the results from the case study are presented in various sections respectively. The simulation of this model is carried out in MATLAB software. The proposed work is tested on three systems IEEE-9bus, power systems and real system under normal and abnormal operating conditions [10].

2. IEEE 9 BUS SYSTEM:

The single line diagram of a three machine power system is given below in fig. (1). This paper consists of three generators, transformers and loads. Generators, transformers and loads are given in appendixin this system. Generator G1 is connected to slack bus 1, whereas generator G2 and G3 are connected to PV-bus. Load A, B and C are connected in bus bars 5, 6 and 8 respectively. The total generation is 567MVA and total load is 321MW.We have considered two cases. In first case, we have considered without three phase fault and another case is considered with three phase.

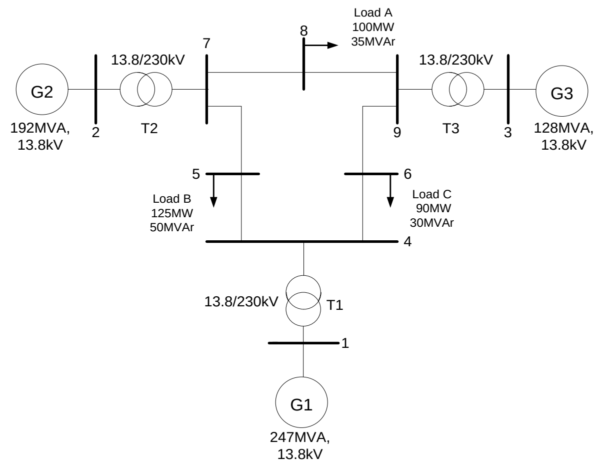

Figure 1: SLD of IEEE 9 Bus System

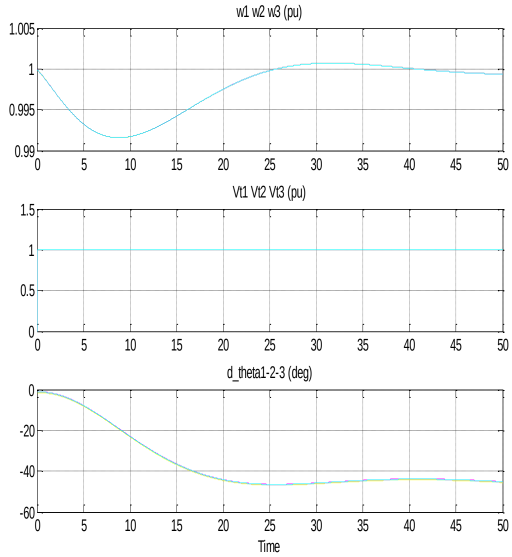

Fig.2: Without fault Generator Waveform

NOTE: The color coding for all the 3 generators in above are same for the rest of the figures. The waveform of generator one is indicated by yellow color, the waveform of generator second is indicated by pink color and similarly the waveform of generator third is indicated by blue color.

3. LOAD FLOW:

BUS CLASSIFICATION:

A node at which one or many lines, one or many loads and generators are connected is called as BUS. Each node or bus is associated with 4 quantities, such as magnitude of voltage, phage angle of voltage, active and reactive power in load flow. The buses are classified into 3 categories, depending on the quantities that have been specified.
Buses are classified as follows.

Load bus:

This bus has no generator connected to the load. The real and reactive power are specified. It is expected to figure out the voltage magnitude and phase angle through load flow solutions. It is essential to give only P_d and Q_d at such bus as at a load bus voltage can be allowed to vary within allowable values.

Generator bus or voltage controlled bus:

In this bus, the voltage magnitude corresponding to the generator voltage and real power P_g corresponds to its rating are given. It is expected to find out the reactive power generation Q_g and phase angle of the bus voltage.

Slack / Swing bus:

It is assumed that the voltage magnitude $|V|$ and voltage phase θ are known, for the Slack Bus, where in real and reactive powers P_g and Q_g are acquired through the load flow solution.

It is necessary to have the knowledge of pre-fault voltages magnitudes, in transient stability. The important data obtained from the power flow study consists of real and reactive powers on transmission lines, magnitudes and phase angles of bus voltages, real and reactive powers at generator buses and other variables being specified. The before fault (pre-fault) conditions can be acquired from results of load flow studies by the Newton-Raphson (N-R) iteration method.

The method used in the practical method of load flow solution of large power networks is Newton-Raphson method. By the choice of slack bus Convergence (focusing) is not affected. This method commences with initial guesses of all unknown variables like voltage angles at generator buses and voltage magnitude, angles at load buses.

- In planning stages, power flow analysis is very essential for new networks or addition to existing systems, meeting increase load demand, adding new generator sites and locating new transmission sites.
- Nodal voltages and phase angles are given by load flow solution.
- The bus voltages are also determined. The voltage levels at certain buses should be within the closed tolerances.
- System transmission losses are also minimized.
- The Economic system operation with respect to fuel cost to generate all the power needed.
- The line flows can be figured out. The line should not be overloaded, i.e. should not operate close to their stability or thermal limits [11], [12].

Table 1: Classification of Buses

BUS No.	***TYPES OF BUS***
1	SWING BUS
2	PQ BUS
3	PV BUS
4	TRANSFORMER
5	LOAD (B) BUS
6	LOAD (C) BUS
7	TRANSFORMER
8	LOAD (A) BUS
9	TRANSFORMER

RESULTS:

A 3-phase fault is introduced on different generators and the results are shown below.

1. **3-phase fault on Generator 1 (i.e.Swing bus)**

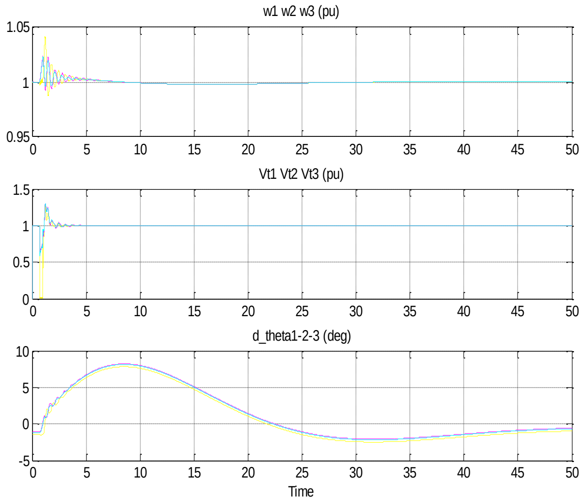

Fig.3: L-L-L-G fault at Generator

2. **3-phase fault on Generator 2 (i.e. PQ bus)**

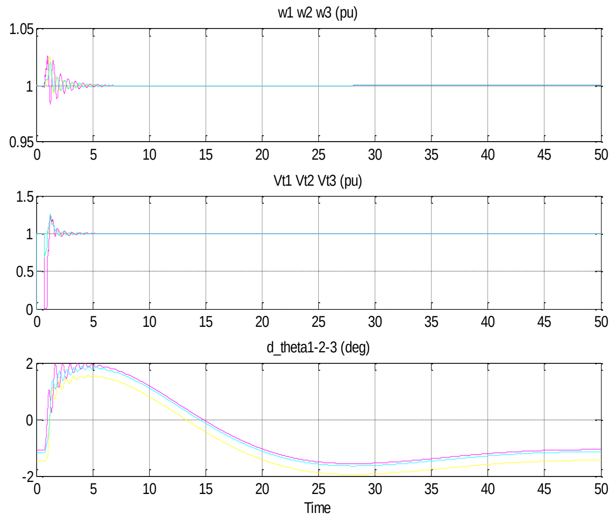

Fig.4: L-L-L-G fault at Generator 2

3. **3-phase fault on Generator (i.e. PV bus)**

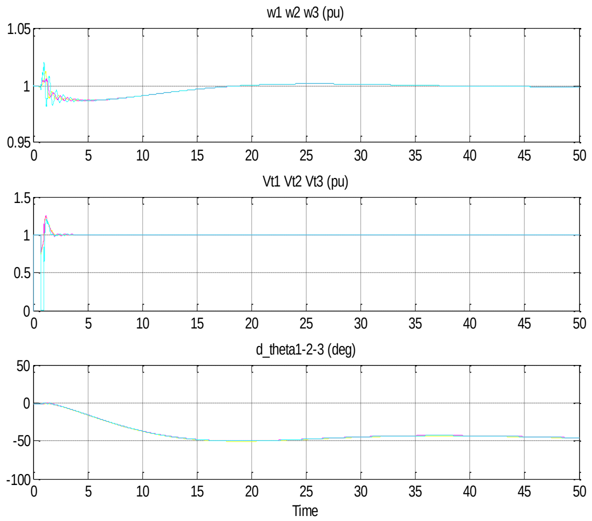

Fig.5: L-L-L-G fault at Generator 3

The fault is introduced at 0.7 sec, which is cleared after 1 sec and then nature of speed of each generator excitation voltage and rotor angle deviation is shown in fig 3, 4 and 5.

Table 2: Fault location and settling time of fault

FAULT LOCATION	SETTLING TIME	FAULT LOCATION
1	45 sec	1
2	30 sec	2
3	28 sec	3

Table 2 indicates that if the fault occurs at swing bus, system takes more time to settle down.

The three phase fault is created at generator 1, 2, 3 at time 0.7 sec and is cleared after time 1 sec. The results show that the rotor speed is fluctuated during fault condition and it will be stable at 1 pu. The voltage of machine will be constant i.e. 1 pu in without fault condition and during fault, first it will drop at zero and then fluctuate up to 1 sec and finally it will get cleared. Under the influence of fault, the generator rotor angle increases to maximum, subsequently decreases to minimum and settles to a steady state value.

CONCLUSION:

In this paper the stability of the IEEE 9-Bus Electrical Power System has been studied. The behavior of different faults (L-L-L-G, L-L-L, L-L-G,L-G and L-L) has been investigated. To make the system stable, the time required is more and in order to reduce the time we can use FACTS devices.

Before fault, we observed that the system take few seconds to get stable i.e. any system before fault first rises to its peak value or maximum value and then becomes constant. Similarly, after fault it is observed that the system requires considerably more time to become stable and even sudden changes in the system is observed i.e. change in speed, voltage and rotor angle deviation is also observed. In order to analyze the system behavior, the simulation model of the IEEE 9-bus system has been build and related simulation results have been presented.

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