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Transient Stability Analysis: Evaluation of IEEE 9 Bus System Under Line Fault Conditions

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Abstract: Switching is the most common practice in a grid network, which is done usually to shift the load or isolate the faulty part from the network. As the result network destabilizes when these kind of switching operation occurs. To stabilize the grid network, switching of appliances is required to adjust accordingly and network equipment needed to be analyzed for the improvement of grid network design. In this paper, the effect of the switching operation under fault line condition in a grid network 13.8kV/16.5kV/18kV/220kV is being analyzed, to evaluate the system stability in terms of branch power, generator current, system voltage and frequency. ETAP software is used to express the transient and power flow response of the presented grid network.

Keywords: IEEE 9 bus test system, Power Flow Analysis, Transient Analysis, line fault, ETAP

1.0 INTRODUCTION

Network studies under different condition using software tools is being focused from last two decades. These intelligent software tools make a revolution in the electrical engineering field. Any grid network consists of generator, feeder network and loads. Feeders having a backbone role in any electrical power system. Rapid switching take place in a grid network to insure the optimal flow of power towards the customers. Capacitor placement, network reconfiguration, synchronous generators attachment are the switching functions which normally occur in any power system. Due to this rapid switching process, instruments are losing their strength with the passage of time [1]. As the networks are under stress due to increase of power demand by the customers, so network can be destabilized and transient may occur in the network. So these events are required to monitored properly to avoid the instability and performance of the grid network [2]. It can be seen from literature that transient stability is the area of interest for researchers in last few years. Where different software tools are used to find out the characteristic behaviour of grid network as the response of switching process. In [3] Kavitha R, evaluated the IEEE 30 bus system under transient conditions using ETAP software. HC Chen et al modelled a cogeneration industrial system and transient stability of system is analyzed under three operating conditions using ETAP in [4]. A local station is modelled in [5]and transient stability of system is tested under fault conditions along with three loading types with and without SVC devices. In [6] Bind et al modelled a IEEE 9 bus system using Matlab software and system transient stability is analyzed under fault conditions. Modified IEEE 30 bus system is modelled by Oni et al [7] where system stability is analyzed by replacing the long high voltage AC line by high voltage DC line. For this analysis DigSILENT Power Factory is being used. Here Electrical Transient Analyzer program is used to high light the issues which can occur when switching process is practiced in a grid network. To identify the issues which can occur after switching process results as destabilization and disturbance in the various equipment's in the network, is the main objective of this research. A IEEE 9bus grid network is modelled and presented in this paper and transient analysis of grid network is done using ETAP software for off line grid monitoring purpose under fault condition at line 4.

The paper is structured as follows: segment 2 explains the modelling of grid network, which is modelled using practical grid data. Power flow of the grid network is included in Segment 3. And segment 4 explains the results which are achieved after transient analysis of the grid network. Lastly in segment 5 output of this presented paper is concluded.

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2.0 MODELLING OF GRID NETWORK.

The under study grid network 13.8kV/16.5kV/18kV/220kV shown in a signal line diagram. It can be seen that network have 3 generators having 16.5kV,18kV and 13.8kV respectively. Three transformers are used to step up the voltage level for all three generators up to 220kV to deliver the power towards the consumer's end. Six lines are used to deliver the power. And to node these lines, transformers and generators 9 bus are planted along with 21 circuit breakers to protect the grid network at fault conditions. ETAP software is used to model the grid network using practical data.

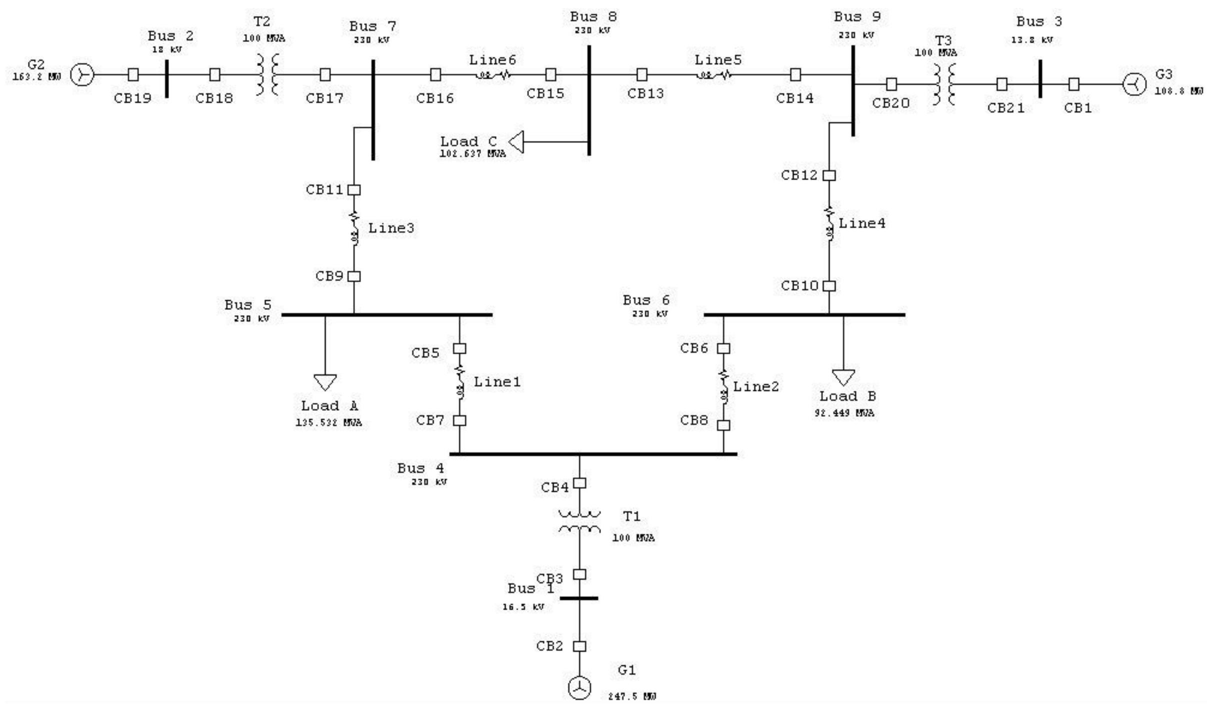

Fig 1. Single line Diagram of IEEE 9 Bus Grid Network

Table 1. Power Flow Report

ID	*Rating*	*Rated kV*	*MW*	*M_{var}*	*Amp*	*% PF*	*% Generation*	*% Loading*	*V_{termal}*
G1	*247.5 MW*	*16.5*	*71.337*	*26.96*	*2566*	*93.54*	*28.8*	*---*	*---*
G2	*163.2 MW*	*18*	*163*	*6.562*	*5105*	*99.92*	*99.9*	*---*	*---*
G3	*108.8 MW*	*13.8*	*85*	*10.88*	*3498*	*99.19*	*78.1*	*---*	*---*
Load A	*135.532 MVA*	*230*	*124.761*	*49.895*	*338.8*	*92.85*	*---*	*99.6*	*99.57*
Load B	*92.449 MVA*	*230*	*89.939*	*29.98*	*235*	*94.87*	*---*	*101.3*	*101.27*
Load C	*102.637 MVA*	*230*	*99.975*	*34.977*	*261.7*	*94.39*	*---*	*101.6*	*101.59*

3.0 POWER FLOW ANALYSIS

Multiple techniques are available to perform load flow analysis of a distribution system. Here Newton Raphson technique with 99 maximum iteration having 0.0001 solution precision is used.

$$\dot{I_\iota} = \frac{(P_{Gi}-P_{Di})-j(Q_{Gi}-Q_{Di})}{\hat{V_\iota}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\dot{V_\iota} = V_i(\cos\theta_i) + j(\sin\theta_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$P_i = V_i \sum_{j=1}^{n} V_j \left(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right) \ldots\ldots\ldots\ldots (3)$$

$$Q_i = V_i \sum_{j=1}^{n} V_j \left(G_{ij}\sin\theta_{ij} + B_{ij}\cos\theta_{ij}\right) \ldots\ldots\ldots\ldots (4)$$

Above stated equations are used to perform Load flow [8] and the results are tabulated in Table 1. The power generated by the three generators are 319.337+j44.402MVA and absorbed by the consumers load 314.674+j114.852 MVA and 4.663–j70.45 MVA are the losses occurred in branches which are lies between 9 buses.

4.0 TRANSIENT ANALYSIS RESULTS

Transient analysis is the one of the factors which is used to evaluate power transfer capability of transmission line [9]. Here fault in implant on transmission line 4 to the see its transient impact on the system. To evaluate the abnormality of the system at fault condition transient analysis is done for the modelled 9 bus system. Fault is placed at t=1.00 sec on line4 at t=1.116 sec both circuit breakers 10 and 12 goes into open state and isolate this faulty line from the grid network. The impact of the faulty isolated line4 can be seen from the Fig. 2,3,4,5. Following equations are used to express the power transfer and transient stability of network [9]:

$$\widetilde{E_s} = \widetilde{E_R}\cos\theta + j\sin\theta\left(\frac{P_R - jQ_R}{\widetilde{E_R^*}}\right) \qquad (5)$$

$$Z_c = \sqrt{\frac{L}{C}} \qquad (6)$$

$$P_R = \frac{E_S E_R}{Z_c \sin\theta}\sin\delta \qquad (7)$$

$$Q_R = \frac{E_S^2}{Z_c \sin\theta}(\cos\theta - \cos\delta) \qquad (8)$$

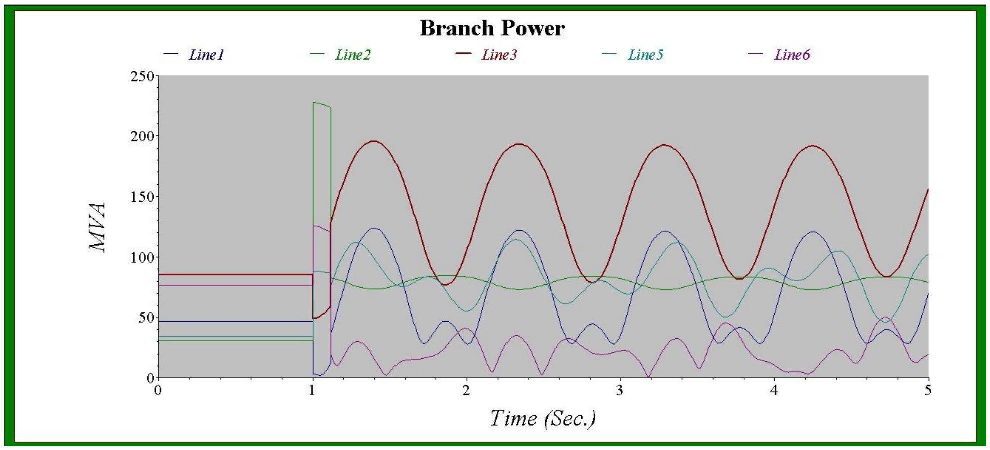

Fig 2. Branch Power

It is observed in Fig 2. that line1 drains more stable power as compare to the other lines. As G2 and G3 get imbalance due to fault on line4 as the result G1 have to provide more power through which tranformer1 get loaded and it also drains more power as a result more branch losses. occur in this region

Generator exciter current for transient studies can be expressed as [9]:

$$I_t\cos\emptyset = \frac{X_{ad} * i_{fd}\sin\delta_i}{X_s} \qquad (9)$$

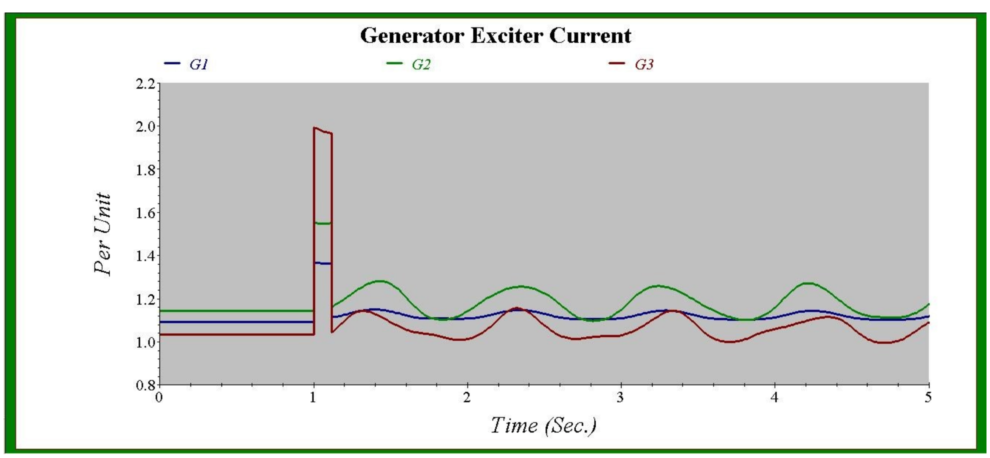

Fig 3. Generator Exciter Current

It can be evaluated through Fig 3. that G2 and G3 get imbalance on the isolation of faulty line4 but among three generators G3 behaves more unbalance while proving the exciter current. It can be seen in Fig 3. that by the isolation of faulted lin4 grid network frequency rises and more fluctuation of frequency occurred at bus6 and bus9 because these buses were interconnected by line4 before the fault.

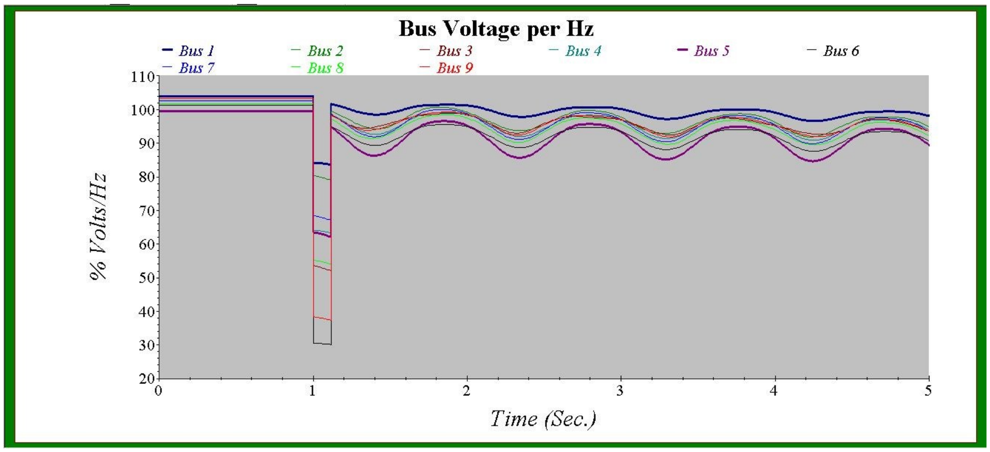

Fig 4. Bus Voltages

It can be seen from the Fig. 4. that network destabilizes after the fault and bus 5 having a maximum impact of the faulty isolated line4 in form of voltage drop because it is closer to the faulty region. And bus 1 having minimum impact because it was far from faulty region.

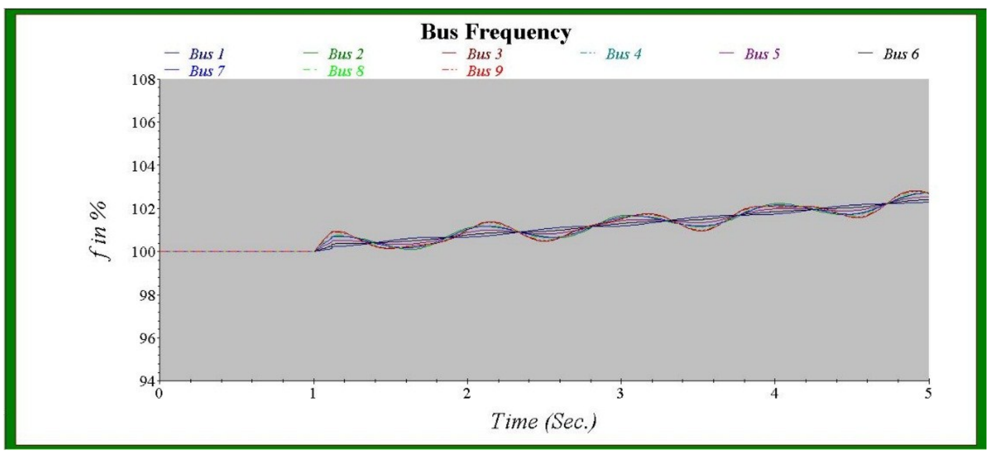

Fig 5. Buses frequency Comparison

It can be seen in Fig 5. that by the isolation of faulted lin4 grid network frequency rises and more fluctuation of frequency occurred at bus6 and bus9 because these buses were interconnected by line4 before the fault.

5.0 CONCLUSION

Through power flow analysis, power delivered and absorbed along with losses has been performed and effect of switching operation in terms of voltage, current, power and frequency has been evaluated using transient stability analysis of the modelled grid network. The impact of the line detachment on its surroundings at fault condition in a modelled grid network has been presented and it will help to decide the enhancement in rating of generators to avoid load shedding.

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