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Transient Stability Analysis of the IEEE 9-Bus Electric Power System

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Abstract:

It is widely accepted that transient stability is an important aspect in designing and upgrading electric power system. This paper covers the modelling and the transient stability analysis of the IEEE 9 bus test system using ETAP. In this, for various faults on the test system fast fault clearing and load shed are analysed to bring back the system to the stability. Frequency is a reliable indicator if deficiency condition in the power system exists or not. Change in power demand or in production causes a fluctuation of the speed of the turbine-generator condition exists on the power system, resulting in fluctuation of the frequency of the power system. So rate of change of frequency is used as indicator of the transient stability of the system and to calculate the amount of load to be shed by adaptive load shedding and measures taken to maintain stability and frequency of the system.

Keywords: Power system stability, critical clearing time, transient stability, load shedding ,adaptive load shedding, rate of change of frequency

I. Introduction:

Traditional entities involved in securing adequate protection and control for the system have become inadequate [1]. To counteract each form of system instability, special protective algorithms have been designed independently in the power systems, e.g., underfrequency load shedding (UFLS) [2] and undervoltage load shedding (UVLS) [3] schemes. Conventional methods of system load shedding methods are too slow and do not accurately calculate the amount of load to be shed. This leads to insufficient or excessive load shedding[4]. The amount of load shed should be equal to or greater than the overload. Once the frequency drop is controlled and the frequency returns back to normal, some part of load can be restored in small increments [5]. Frequency in system is excellent indicator of overload and it is directly related to the real power. The most common scheme used for load shedding is under frequency load shedding scheme which curtails load in small amount of load if the frequency drops below the threshold value [6]. Various under frequency load shedding schemes have been developed that make use of both frequency and rate of change of frequency. One such adaptive under frequency load shedding scheme is based on rate of change of frequency (df/dt) and takes into account the magnitude of the disturbance. The amount of load to be shed depends on the rate of change of frequency [7][8].

In this paper conventional under frequency load shedding (ULFS) and adaptive load shedding methods are studied through IEEE 9 bus test system simulated on ETAP. The amount of load to be shed and reaction time of both methods are compared through graphs. The initial rate of change of frequency on occurrence of disturbance is proportional to the power imbalance which can be used to calculate the amount of load to be shed. This scheme will improve the load shedding operation as well as shed optimal amount of load taking into account frequency measurements from various buses, operating conditions and system topology.

II. Power System Stability:

will actuate both generator and transmission network voltage regulators; the generator speed variations will actuate prime mover governors; and the voltage and frequency variations will affect the system loads to varying degrees depending on Power system stability is the ability of the system, for a given initial operating condition, to regain a normal state of equilibrium after being subjected to a disturbance. Stability is a condition of equilibrium between opposing forces; instability results when a disturbance leads to a sustained imbalance between the opposing forces.

The response of the power system to a disturbance may involve much of the equipment. For instance, a fault on a critical element followed by its isolation by protective relays will cause variations in power flows, network bus voltages, and machine rotor speeds; the voltage variations their individual characteristics. Further, devices used to protect individual equipment may respond to variations in system variables and thereby affect the power system performance. A typical modern power system is thus a very high-order multivariable process whose dynamic performance is influenced by a wide array of devices with different response rates and characteristics. Hence, instability in a power system may occur in many different ways depending on the system topology, operating mode, and the form of the disturbance.

Fig.1 shows a possible classification of power system stability into various categories and subcategories.

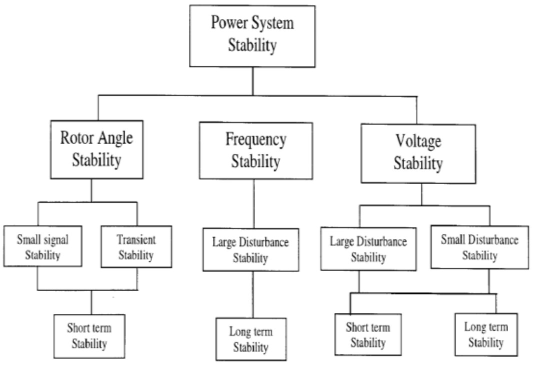

Fig.1.Classification of power system stability[9].

In this paper the focus is on transient stability.

A. Large disturbance rotor angle stability or Transient stability:

As it is commonly referred to, is concerned with the ability of the power system to maintain synchronism when subjected to a severe transient disturbance. The resulting system response involves large excursions of generator rotor angles and is influenced by the nonlinear power-angle relationship. Transient stability depends on both the initial operating state of the system and the severity of the disturbance. Usually, the disturbance alters the system such that the post-disturbance steady state operation will be different from that prior to the disturbance. Instability is in the form of aperiodic drift due to insufficient synchronizing torque, and is referred to as *first swing stability*.

In large power systems, transient instability may not always occur as first swing instability associated with a single mode; it could be as a result of increased peak deviation caused by superposition of several modes of oscillation causing large excursions of rotor angle beyond the first swing. The time frame of interest in transient stability studies is usually limited to 3 to 5 sec following the disturbance. It may extend to 10 sec for very large systems with dominant inter-area swings. Power systems experience a wide variety of disturbances. It is impractical and uneconomical to design the systems to be stable for every possible contingency. The design contingencies are selected on the basis that they have a reasonably high probability of occurrence.

B. Types of Power System Stability Controls and Possibilities for Advanced Control:

Stability controls are of many types, including:

- Generator excitation controls
- Prime mover controls, including fast valving
- Generator tripping
- Fast fault clearing
- High-speed reclosing, and single-pole switching
- Dynamic braking
- Load tripping and modulation
- Reactive power compensation switching or modulation (series and shunt)
- Current injection by voltage source inverter devices (STATCOM, UPFC, SMES, battery storage)
- Fast phase angle control
- HVDC link supplementary controls
- Adjustable-speed (doubly fed) synchronous machines
- Controlled separation and underfrequency load shedding.

To discriminate both conventional and load shedding Fast Fault Clearing& High Speed Reclosing, Load shedding approaches are preferred over the rest.

C. Fast Fault Clearing& High Speed Reclosing:

Clearing time of close-in faults can be less than three cycles using conventional protective relays and circuit breakers. Typical EHV circuit breakers have two-cycle opening time. One-cycle breakers have been developed (Berglund et al., 1974), but special breakers are seldom justified.

The synchronous stability problem has been fairly well solved by fast fault clearing, thyristor exciters, power system stabilizers, and a variety of other stability controls such as generator tripping. Fault clearing of severe short circuits can be less than three cycles (50 ms for 60 Hz frequency), and the effect of the faulted line outage on generator acceleration and stability may be greater than that of the fault itself.

D. Various Types of Load Shedding Approaches:

If a considerable amount of generation is lost or if the generation doesn't meet the requirements of load then the only effective way of correcting the imbalance would be to quickly shed loads before frequency falls so low that the power system collapses. Utilities would only resort to load shedding as a final measure and this action has the advantage of disconnecting selected loads for a relatively short period, rather than interrupting all consumers for extended periods. shedding load is a necessary means used as a last controllable resort to avoid system collapse. Therefore, the execution of the load shedding system must be fast and reliable.

Various load shedding methods are classified as below.

i .Conventional Load Shedding approach:

(a) Breaker Interlock Load Shedding

(b) Under-Frequency Relay (81) Load Shedding

(c) Programmable Logic controller-Based Load Shedding

ii. Adaptive load shedding approach:

In conventional load shedding methods response time (time between the detection of the need for load shedding, and action by the circuit breakers) during transient disturbances is often too long requiring even more load to be dropped. The inherent drawbacks of conventional based load shedding are overcome by adaptive load shedding approach.

III. DEVELOPMENT OF A MODEL OF THE IEEE 9 BUS SYSTEM :

The WSCC 9 bus system[11],Fig.2 is used as our test system. For this case we chose the following loading. Load bus 5 was supposedly having a load demand of 125 + j520 MVA, bus6 a load demand of 90 + j 30 MVA and load bus 8 having demand of 100 + j35 MVA. The generator and line data are given in Appendix A.

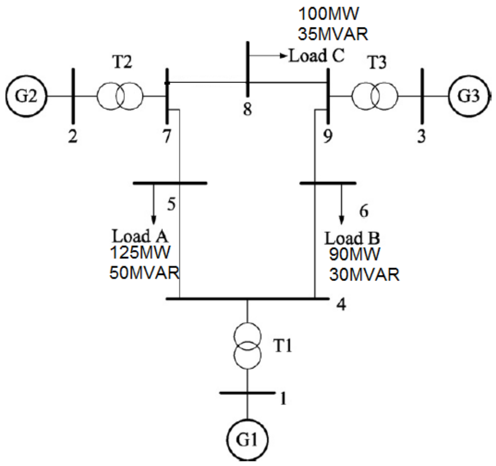

Fig.2. 3 Machine 9 bus Power System[11]

IV. Primary Load-Shedding Module Operation:

An accumulated priority/load table is calculated for each contingency. It is a table in which each row has a priority and a load which is the sum of the loads of this particular priority and all preceding priorities of all load bus bars which are part of the individual contingency. The amount of load to be shed is calculated as per the following equation:

Amount of load to be shed[14]

$$= 1.1*[P_{trip} – (\sum_{x=1}^{n} \delta P_x - \delta P_{trip})] \quad (1)$$

where

Ptrip, δPtrip= 2-s prior generated power and spinning reserve of a lost machine, respectively;

δPx =Spinning reserve of a running machine numbered x;

n =Total number of running machines prior to any trip.

Calculation of frequency Decay rate :

Relative Load Excess Factor L is defined by [10]

$$L = \frac{\sum L_i - \sum G_i}{\sum G_i} \quad (2)$$

Where G_i , L_i are the Total generation and Load of the system

Average rate of frequency change R becomes [10],

$$R= \frac{pL}{H} * \frac{f_2 - f_1}{1 - \frac{f_2^2}{f_1^1}} \quad (3)$$

H =Aggregate inertia constant
P =Power factor
L= Relative Load Excess Factor
f_1 =Operating frequency before fault
f_2=Frequency after fault.

V. Contingency simulation for 9 Bus Test System:

To demonstrate the effectiveness of the proposed methodology to determine the minimum load shedding two fault contingencies of the test system have been selected for computer simulation
to investigate the dynamic response of power systems.

A. CASE A:

The total generation of the system is 313.623MW and the total load demand is 312.602MW.After 0.2 sec the power system lost the generator 3(G3) due to various reasons unavoidable ,now the power system generation after the loss of G3 is 228.623.Then the relative load excess factor L of the system becomes 0.367 and the average rate of frequency change R becomes -1.608Hz/sec. At this rate in Conventional load shedding, let the breakers are supposed to operate after the frequency reaches 48.5Hz then the system frequency reaches that critical 48.5Hz after 0.932 sec only. If we include the tripping delay of 125ms then the frequency will decline further by 0.201Hz and reaches 48.229Hz. So load shedding will occur at a delay of 0.857sec(G3 lost at 0.2sec) after the loss of G3.By means 80MW load has to be shedded to bring back the system to stability, as followed by eq(1).

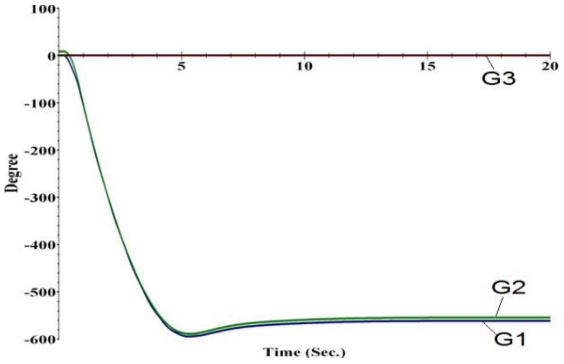

Fig.3. Absolute Power Angles of Generators after 80MW load shed @0.857 sec.

From the above Fig.3 ,we can conclude that Generators are not coming back to stability as they are falling apart. To bring the generators to stability we need to shed more load for conventional load shedding[15]. In the adaptive load shedding Based on the generation deficit calculations, a fast tripping command is generated through fast actuating relays. The Adaptive load-shedding module program has a fast cyclicity time of 5 ms. After the detection of load-shedding trigger, the overall execution of the program takes about 55-ms time, and the trip output relay has 5-ms actuation time. The overall load relief is achieved within 125-ms time. So if we shed the load 80MW, after the frequency starts declining and allowing 0.125ms reaction time to operate- at 0.325sec then, From the Fig.4 we can say that the generators are coming back to stability after the load shed followed by contingency.

So with fast switching and adaptive load shedding methods the amount of load to be shed can be minimized. Load amount must be preserved, due to the fast response time of the load shedding scheme[15].

Fig.5&Fig.6 shows the Generators electrical power and generator bus frequencies (alias buses 1,2&3) for adaptive load shedding method.

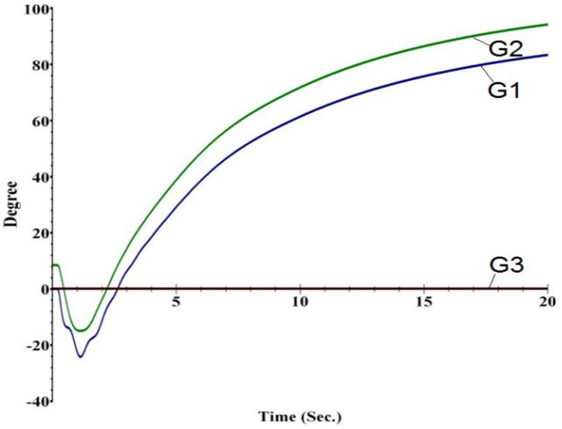

Fig.4. Absolute Power Angles of Generators after 80MW load shed @0.325 sec.

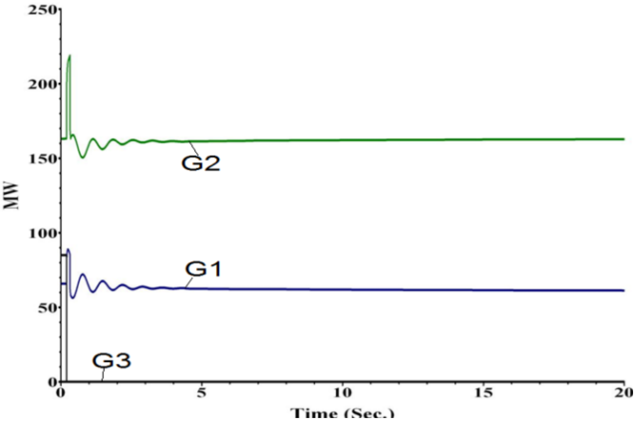

Fig.5 Generators Electrical Power

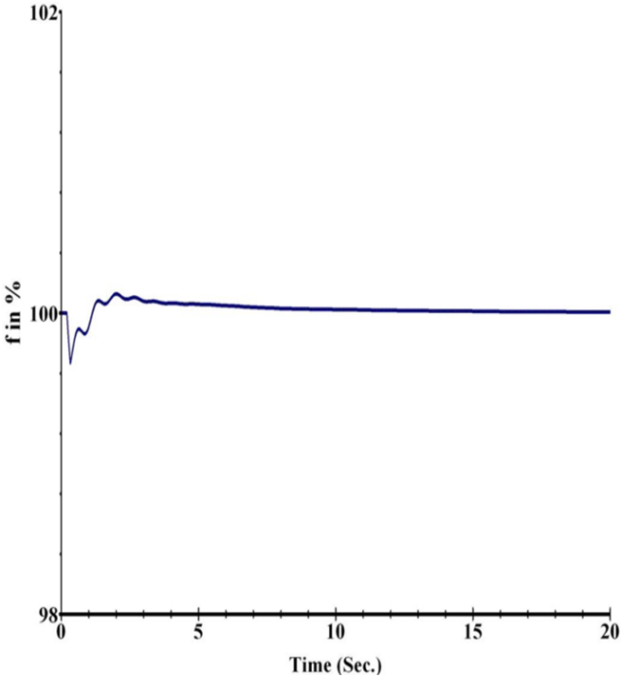

Fig.6 Generator Bus frequency

B. CASE B:

The total generation of the system is 313.623MW and the total load demand is 312.602MW.After 0.2 sec say the power system lost the generator 2(G2) due to various reasons unavoidable ,now the power system generation after the loss of G2 is 150.623MW.Then the relative load excess factor L of the system becomes 1.075 and the average rate of frequency change *R* becomes -4.71Hz/sec. At this rate in Conventional load shedding, let the breakers are supposed to operate after the frequency reaches 48.5Hz then the system frequency reaches that critical 48.5Hz after 0.318 sec only. If we include the tripping delay of 125ms then the frequency will decline further by 0.588Hz and reaches 47.912Hz. So load shedding will occur at a delay of 0.24sec(G2 lost at 0.2sec) after the loss of G2.By means 180MW load has to be shedded to bring back the system to stability.

From the Fig.7. ,we can conclude that Generators are not coming back to stability. To bring the generators to stability we need to shed more load through conventional load shedding. Same as in the case of above, through the Adaptive load-shedding if we shed the load 180MW only after the frequency starts declining and allowing 0.125ms reaction time to operate at 0.325sec, observe the Absolute Power Angles of Generators in fig.8. From the Fig.8 we can say that the generators are coming back to stability if 180MW load is shed at 0.325sec. So with fast switching and adaptive load shedding methods the amount of load to be shed can be minimized.

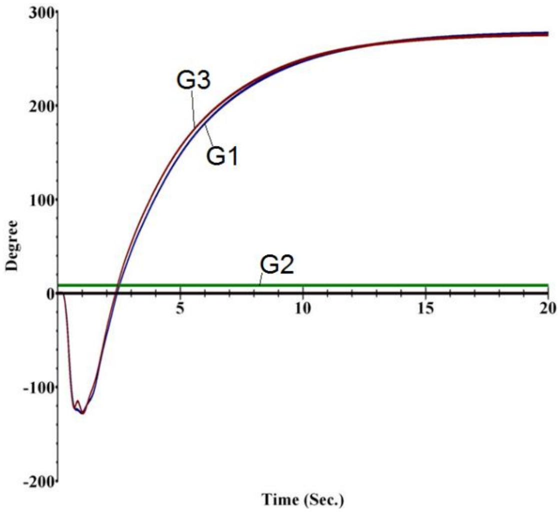

Fig.7. Absolute Power Angles of Generators after 180MW load shed @0.44 sec

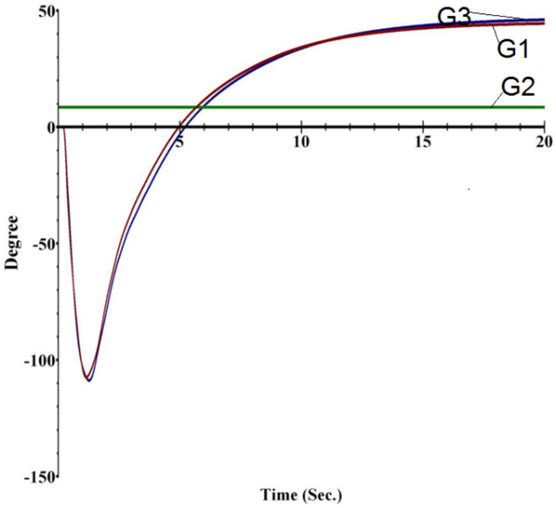

Fig.8. Absolute Power Angles of Generators after 180MW load shed @0.325 sec

Fig.9&Fig.10 shows the Generators electrical power and generator bus frequencies (alias buses 1,2&3) for adaptive load shedding method.

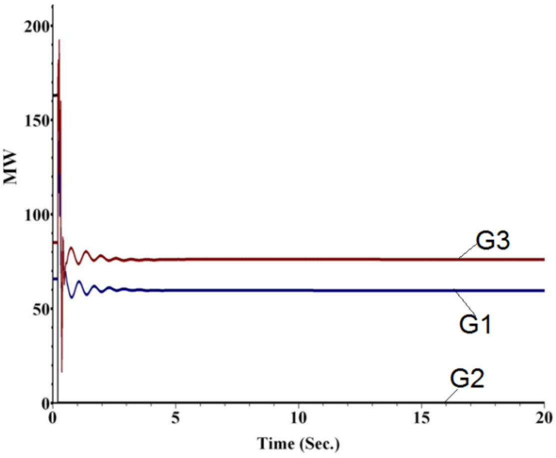

Fig.9

Generators Electrical Power

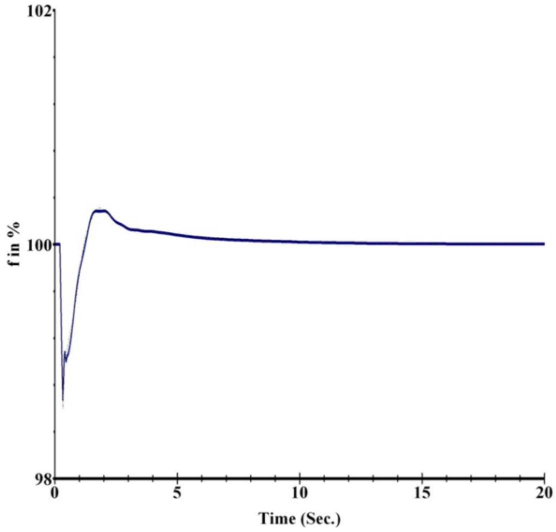

Fig.10

Generator Bus frequency

CONCLUSION:

In this paper the stability of the IEEE 9-bus system has been studied. Two contingencies has been simulated on the test system. Rate of change of is used as the operating principle. The subsequent changes of loss of generation in test system, its transient stability problems and its controlling methodologies through fast fault clearing and adaptive load shedding methods are discussed. By the implementation of the adaptive load shedding methods we can decrease the amount to be shed than the amount shedded in conventional load shedding methods.

REFERENCES:

[1] M. Begovic, D. Novosel, and M. Milisavljevic, “Trends in power system protection and control,” *Decision Support Syst.*, vol. 30, no. 3, pp. 269–278, Jan. 2001.

[2] C. Concordia, L. H. Fink, and G. Poullikkas, “Load shedding on an isolated system,” *IEEE Trans. Power Syst.*, vol. 10, no. 3, pp. 1467–1472,Aug. 1995.2.

[3] C. W. Taylor, “Concepts of undervoltage load shedding for voltage stability,”*IEEE Trans. Power Del.*, vol. 7, no. 2, pp. 480–488, Apr. 1992.

[4] A. V. Kulkarni, W. Gao, *and* J. Ning “*Study of Power System Load Shedding Scheme Based On Dynamic Simulation”,* Transmission and Distribution Conference and Exposition, 2010 IEEE PES .

[5] W. A. Elmore, *Protective relaying theory and applications*, Coral springs, FL: ABB, 1994.

[6] H. Bevrani, G. Ledwich and J. J. Ford, “On the use of df/dt in power system emergency control,” *IEEE/PES Power Systems Conference and Exposition, 2009*, pp. 1-6, March 15-18, 2009.

[7] H. Seyedi and M. Sanaye-Pasand, “Design of new load shedding special protection schemes for a double area power system,” American journal of Applied Sciences, Vol. 6, No. 2, pp. 317-327, Feb 2009.

[8] H. Seyedi, M. Sanaye-Pasand and M. R. Dadashzadeh, “Design and simulation of an adaptive load shedding algorithm using a real network,” IEEE Power India Conference, April 10-12, 2006.

[9] Farmer, Richard G. “*Power System Dynamics and Stability*”, *The Electric Power Engineering Handbook*, Ed. L.L. Grigsby,Boca Raton: CRC Press LLC, 2001.

[10]Stanley H.Horowitz,Arun G.Phadke, “*Power System Relaying”*, Third Edition, Research Studies Press Limited. ISBN: 978-0-470-05712-4.

[11] P. M. Anderson and A. A. Fouad,”*Power System Control and Stability”*.New York: IEEE Press, 1994.

[12] P. Kundar,” *Power System Stability and Control”*. New York: McGraw-Hill, 1994.

[13]Peter W.Sauer, M.A.Pai, *“Power System Dynamics and Stability”*, Prentice Hall,1998.

[14] Uchhrang K. Jethwa, *Member, IEEE*, Rajeev Kumar Bansal, Ninad Date, and Ranjeet Vaishnav, “*Comprehensive Load-Shedding System”,* IEEE Transactions On Industry Applications, Vol. 46, No. 2, March/April 2010.

[15] Shervin Shokooh ,Tanuj Khandelwal, Dr. Farrokh Shokooh , Jacques Tastet, Dr. JJ Dai *“ Intelligent Load Shedding Need for a Fast and Optimal Solution”*, IEEE, PCIC, Europe 2005.

Appendix A: 9 Bus System Data

Line Parameters:

Line	Resistance (p.u)	Reactance (p.u)	Susceptance (p.u)
1-4	0.0000	0.0576	0.0000
4-5	0.0170	0.0920	0.1580
5-6	0.0390	0.1700	0.3580
3-6	0.0000	0.0586	0.0000
6-7	0.0119	0.1008	0.2090
7-8	0.0085	0.0720	0.1490
8-2	0.0000	0.0625	0.0000
8-9	0.0320	0.1610	0.3060
9-4	0.0100	0.0850	0.1760

Machine Data:

Parameters	M/C 1	M/C 2	M/C 3
H(secs)	23.64	6.4	3.01
X_d(pu)	0.146	0.8958	1.3125
X'_d (pu)	0.0608	0.1198	0.1813
Xq(pu)	0.0969	0.8645	1.2578
X'_q (pu)	0.0969	0.1969	0.25
T'_{d0} (pu)	8.96	6.0	5.89
T'_{q0} (pu)	0.31	0.535	0.6

Exciter data:

Parameters	Exciter 1	Exciter 2	Exciter 3
K_A	20	20	20
T_A(sec)	0.2	0.2	0.2
K_E	1.0	1.0	1.0
T_E(sec)	0.314	0.314	0.314
K_F	0.063	0.063	0.063
T_F(sec)	0.35	0.35	0.35