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An Approach of Transient Stability Analysis for Multimachine Based on Artificial Neural Network

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Abstract

The present work uses MATLAB Program to reenact the outcomes of best techniques for transient reliability examination, for instance, arrange strategy RAte of Change of Kinetic Energy (RACKE) and Step By Step (SBS) of underhanded strategy since it has more precision than each other strategy. The results of MATLAB Program is utilized to prepare Probabilistic Neural Network (PNN) method, this training data represented the rotor angle of each machine in power system verses time during 1 sec.(period time of fault), after training is finished , ANN ready to get results which concurred with the MATLAB program results. One of the speedy and accurate method of ANN, for example, Probabilistic Neural Network (PNN) was utilized to arrange the conduct of the power system relying upon its stability into (stable or unstable) , the results of this simulation , clarify that ANN is proficient to dissect transient stability of power system and doing classification .

Keywords: Power system modeling; Transient Stability; Voltage Stability, Artificial Neural Network, Integral of square error.

INTRODUCTION

The stable operation of a power system depends on the ability to continuously match the electrical output of generating units to the electrical load in the system. Power system stability has become an important issue to power industry. [1]

Transient stability concerns with the matter maintaining synchronism among all generators when the power system is suddenly subjected to severe disturbances such as fault or short circuits caused by lightning-strike[2]

At the point when a fault happens at the terminals of a synchronous generator the power output of the machine is extraordinarily diminished as it supply a basically inductive circuit. However the info power to the generator from the turbine has no time to change during the brief time of the fault and the rotor tries to pick up speed to store the abundance energy. On the off chance that fault holds on sufficiently long the rotor angle will expand persistently and synchronism will be lost. Subsequently the time of activity of the security and circuit breakers are terrifically important.[3]

MATHEMATICAL MODELING [4,5]

Once the Y matrix for each network condition (pre-fault, during and after fault) is computed, we can dispose of the considerable number of hubs aside from the inward generator hubs and get the Y matrix for the lessened network .The decrease can be accomplished by matrix activity on account of the way that every one of the hubs have zero infusion currents with the exception of the inside generator hubs. In a power system with n generators, the nodal equation can be composed as:

$$\begin{bmatrix} I_n \\ 0 \end{bmatrix} = \begin{bmatrix} Y_{nn} & Y_{nr} \\ Y_{rn} & Y_{rr} \end{bmatrix} \begin{bmatrix} V_n \\ V_r \end{bmatrix} \quad (1)$$

Where the is subscript n used to mean generator hubs and the subscript r is utilized for the rest of the hubs. Extending eqn. 1,

$$I_n = Y_{nn}V_n + Y_{nr}V_r \,, \; 0 = Y_{rn}V_n + Y_{rr}V_r$$

From which we dispense with V_r to discover

$$I_n = (Y_{nn} + Y_{nr}\, Y_{rr}^{-1} Y_{rn})V_n \quad (2)$$

Along these lines the coveted decreased matrix can be composed as takes after:

$$Y_R = (Y_{nn} + Y_{nr}\, Y_{rr}^{-1} Y_{rn}) \quad (3)$$

It has dimensions (n x n) where n is the number of generators.

Note that the network decrease illustrated by Eq. (1)-(3) is an advantageous analytical technique that can be utilized just when the loads are dealt with as constant impedances. For the power system under examination, during and after fault.

The power into the network at node I, is given by

$$P_{ei} = E_{ii}^2 \sum_{\substack{j=1 \\ j\neq i}}^{n} E_i\; E_j\, Y_{ij}\; \cos(\theta_{ij} - \delta_i + \delta_j) \quad (4) \quad i = 1,2,\dots,n$$

Where,

$$Y_{ij}^{-} = Y_{ij}\, \angle\theta_{ij} = G_{ij} + jB_{ij}$$

$$Y_{ii}^{-} = Y_{ii}\angle\theta_{ii} = G_{ii} + jB_{ii}$$

The equations of motion are then given by

$$\frac{2H_i}{\omega_R}\frac{d\omega_i}{dt} + D_i\omega_j = P_{mi} - [\, E_i^2 G_{ii} + \sum_{\substack{j=1 \\ j\neq i}}^{n} E_i\; E_j Y_{ij}\; \cos(\theta_{ij} - \delta_i + \delta_j)\,] \quad (5)$$

And $\frac{d\omega_i}{dt} = \omega_i - \omega_R$ i=1,2,…..,n (6)

It should be noted that prior to the disturbance (t=0)

$P_{mi0} = P_{ei}$;

There by ,

$$P_{mi0} = [\, E_i^2 G_{ii0} + \sum_{\substack{j=1 \\ j\neq i}}^{n} E_i \; E_j \; Y_{ij0} \cos(\theta_{ij0} - \delta_{i0} + \delta_{j0})] \quad (7)$$

The subscript 0 is used to is used to indicate the pre-transient conditions.

As the network changes due to switching during the fault, the corresponding values will be used in above equations.

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Methods of ANN

ANN have many methods for different application fields, below steps of operation for the method that used in this study Probabilistic Neural Network (PNN).[6,7]

Steps of PNN task :-

We are given the exemplar include vectors that make up the training set. For every one we know the class to which it belongs.

The following sets up the steps of solution by PNN:-

Step1. Read in the file of exemplar vectors and class numbers

Step2. Sort these into the K sets where each set contains one class of vectors

Step3. For every k characterize a Gaussian function focused on every exemplar vector in set k characterize the summed Gaussian output function Once the PNN is characterized, at that point we can feed vectors into it and classify them as follows:-

A. Read input vector and feed it to each Gaussian function in each class

B. For each group of hidden nodes, register all Gaussian functional values at the hidden nodes, eq.(8&9).

$$\boldsymbol{g_i} = \frac{\mathbf{1}}{\boldsymbol{ni}} \sum_{\boldsymbol{k=1}}^{\boldsymbol{ni}} \boldsymbol{e}^{\frac{-\|\boldsymbol{Xi}-\boldsymbol{Xik}\|}{\boldsymbol{\sigma^2}}} \quad \mathbf{(8)}$$

$$\boldsymbol{Y_{ik}} = \boldsymbol{e}^{\frac{-\|\boldsymbol{Xi}-\boldsymbol{Xik}\|^2}{\boldsymbol{\sigma^2}}} \quad (9)$$

C. For each group of hidden nodes, feed all its Gaussian functional values to the single output node for that group, eq.(10)

$$\boldsymbol{g_i(Xi)} = \frac{\boldsymbol{Yii+Yik}}{\mathbf{2}} \quad (10)$$

D. At each class output node, whole all the data sources and multiply by constant

E. Discover maximum value of all summed functional values at the output nodes. Eq.(11)

g_{out} =Max of ($g_1, g_2, \ldots, g_k$) (11)

2.1 –The proposed technique is represented as in Figure 1.

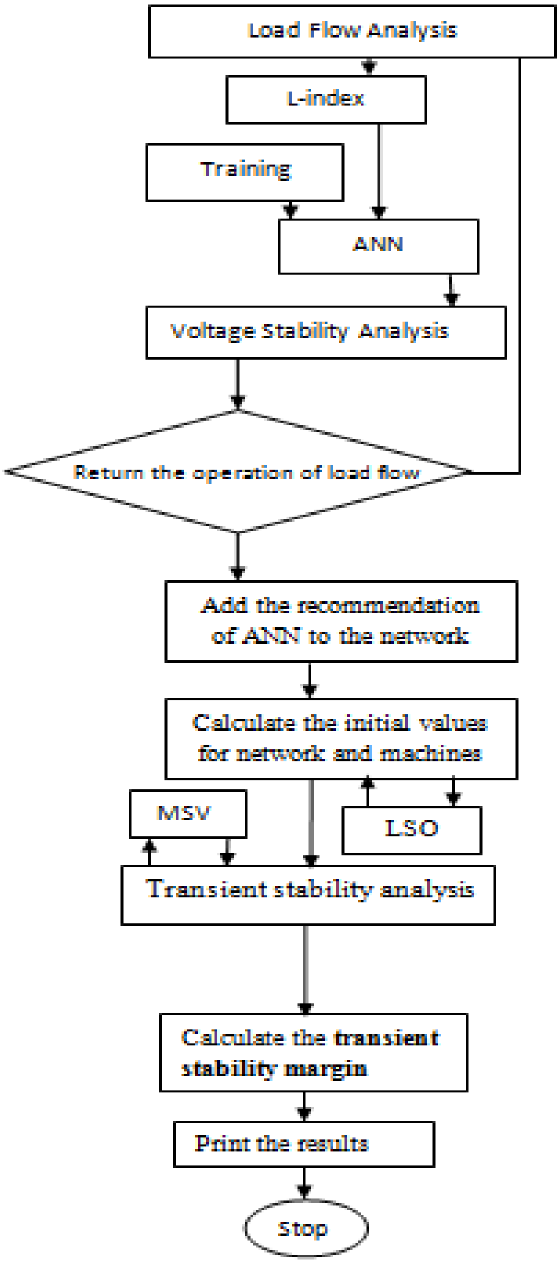

Figure 1. Flow chart of proposed technique.

Design ANN for testing system:

The ANN design consist of three layers input, hidden, output layer , the neuron number of each layer is 9,21,2 respectively as shown in table 1.

Table 1. Architecture of the ANN

Number of input nodes	9
Number of hidden layers	21
Number of output nodes	2
Mean Squared Error(MSE)	0.00001
Learning Rate	0.85
Momentum rate	0.80
Maximum Epochs	150

The steps of implemented neural network for the power system as follows:

i- Input layer: content of (9) neurons each neuron represents

(Fault location, Load multiplier, L_5, L_6, L_8, V_5, V_6, V_8, time)

ii- Hidden layer: content of (21) neurons calculate by (trail & error)

iii- Output layer: content of (2) neuron, represents (δ_2, δ_3).

iv- Activation function: The following activation function has been used.

A- Tan Sigmoid function for hidden layer.

B- Tan Sigmoid function for output layer.

v- Learning Rate = 0.85 computed by (trail & error).

vi- Momentum Rate = 0.80 computed by (trail & error).

Test system

IEEE-9bus power system is shown in Figure (2).It consists of three generators, three load buses and nine lines with the system data is given in Appendix I [8].

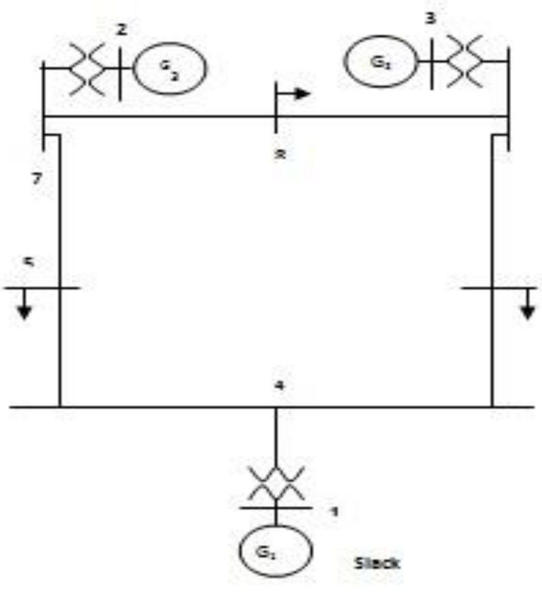

Figure 2. IEEE 9-bus power system.

The simulation of this system was first carried out using MATLAB program to analyze the transient stability of system when indirect fault F happened at line (7-8) near bus bar 8 or direct fault F happened at line (7-8) near bus bar 7 during 1 sec period time of fault, then the simulation was done by ANN depending on the result of MATLAB program for training its network, then testing it on the system to obtain the result of simulation .

Data set formulation for training of the ANN

Transient stability analysis is performed from the data along these lines got. L-index at critical machines and Minimum Singular Value (MSV) of the adjusted Jacobean matrix are figured. By performing Least Squares Optimization (LSO) the proposals of critical clearing time, rotor angles are processed.

The Neural Network is nourished with voltage profile and L-index of the load busses (5,6,8).The load multiplier and fault location are also sustained to the ANN as info .The objective output utilized for training the ANN are proposals of the Least Mean Square technique acquired after 3 cycle. The data utilized for training the ANN is appeared in tables 2&3.

Table 2. Data used for training the ANN

Input ANN				
Fault Location	Load Multiplier	1.10	1.20	1.30
Direct (near bus 7)	L5	0.91	0.89	0.87
	L6	0.90	0.88	0.86
	L8	0.82	0.80	0.77
	V5	1.013	1.012	1.011
	V6	1.02	1.01	1.01
	V8	0.996	0.994	0.992
	T_C	0.18	0.17	0.16
Indirect (near bus 8)	L5	0.91	0.89	0.87
	L6	0.90	0.88	0.86
	L8	0.82	0.80	0.77
	V5	1.013	1.012	1.011
	V6	1.02	1.01	1.01
	V8	0.996	0.994	0.992
	T_C	0.28	0.27	0.26

Table 3. Test Data

Fault Location	Tc sec.	Assessment Method		
		SBS	RACKE	ANN(PNN)
Direct (near bus 7)	0.16	stable	stable	stable
	0.17	critical	critical	critical
	0.18	unstable	unstable	unstable
Indirect (near bus 8)	0.26	stable	stable	stable
	0.27	critical	critical	critical
	0.28	unstable	unstable	unstable

RESULTS AND DISCUSSION

Load flow is performed for various load multiplier values .The real and reactive power loads are expanded by factor of 1.1, 1.2 &1.3 .The ANN was prepared with the 9 sets of data, acquired by performing load flow and transient stability analysis for various load multiplier values of 1.1,1.2 &1.3 at direct and indirect fault location.ANN met the union rule in 150 epochs .The data demonstrated in table (3) was utilized for testing the ANN . The data is gotten comparably as the training set . The ANN is tested for data relating to load multiplier values 1.10,1.20 and 1.30 .Proposal gave by the ANN are appeared in tables 4 &5 , the pre and post optimization parameters are appeared in table 5 .As demonstrated in table 5 the maximum L-Index value diminishes from 0.59 to 0.51 at Bus 8 ,a change of 8.5 % .The maximum voltage increment from 1.0 to 1.04 at Bus 2 , showing a change of 3.87 %. The MSV of the changed jacobian matrix increments from 0.99 to 1.89 , demonstrating increment in the voltage stability and transient stability margin .

At fault clearing the circuit breakers at both ends of line (7-8) are opened .The critical clearing time for the system as calculated by the indirect (Step By Step) method was (0.27 sec.). The execution time was(1.100 sec.). Table (6) shows the values of RACKE for the two machines of the system , machine no.2 has the largest negative RACKE compared with the remaining machine , so machine no.2 will be selected as the critical machine .

Table 4. Recommendations provided by ANN

V_5	0.9995	0.9998	1.0000
V_6	0.9999	0.9999	1.0000
V_8	0.9999	0.9990	0.9980
Tcc(sec.)	0.180	0.175	0.170
D	0.10	0.09	0.08

Table 5. Recommendations provided by ANN.

Load multiplier 1.3	Pre-optimaztion values	Post-optimization on values
L_j^2	2.51	2.0
L_8^{max}	0.59	0.51
E_2^{min}	1.0	1.04
MSV	0.993	1.894
Tcc(sec.)	0.17	0.19

Table 6. Values of RACKE for IEEE 9-bus system.

Gen. no.	RACKE (p.u)
2	-1033
3	-230

Table 7. Values of Tcc and execution times for each method

Faulted bus	Analysis method	Tcc(sec.)	Execution time(sec.)	Accuracy
8	SBS	0.27	1.100	100%
	RACKE	0.27	0.850	%100

The TABLE.7. gives the Tcc and execution times for each method ,and it show that RACKE method has lower execution time than SBS indirect method.

Result of ANN simulation fig (6 —7) is the same result that obtained by MATLAB-program (critical Gen.is stable at Tc <0.27 sec and unstable at Tc >0.27 sec but Gen.3 still stable at all Tc) and the results are lower in accuracy with that obtained by MATLAB- program as shown in table (7) , fig(8) show the simulation result of test system that obtained by direct (RACKE) method & by (ANN). In part of classification state of system stability (stable or unstable) using (PNN) method it can show from the result of testing tables ,table (8) to table (9) that methods of ANN is successfully efficiency to done this classification

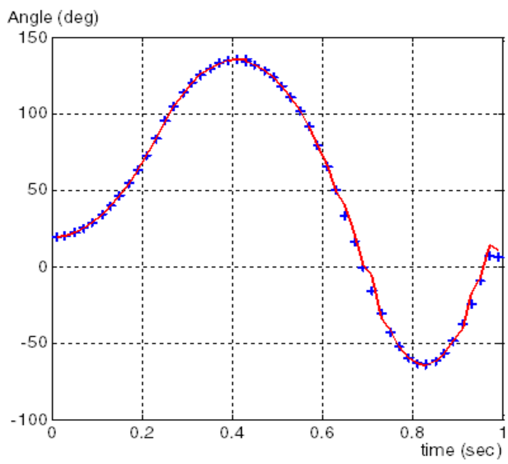

Figure 6a. Angle of critical Ge. at Tc =0.25 sec
+++ Output of MATLAB ---- Output of ANN

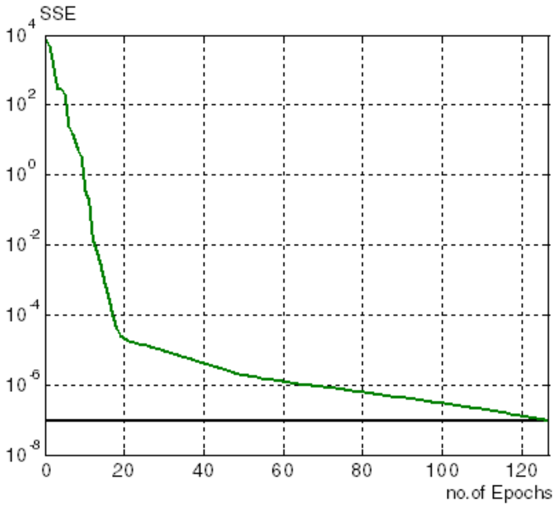

Figure 6b. SSE of critical Ge. at Tc =0.25 sec

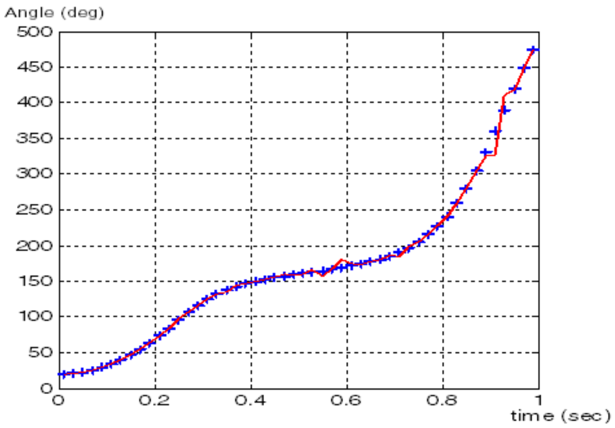

Figure7a. Angle of critical Ge. at Tc=0.27sec
+++ Output of MATLAB ---- Output of ANN

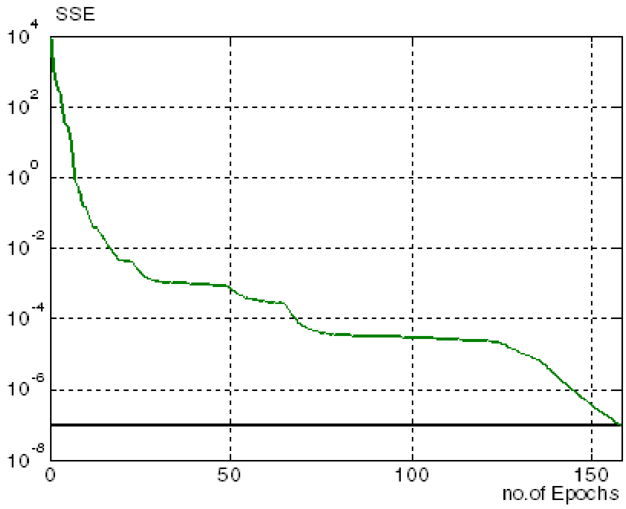

Figure 7b. SSE of critical Ge. at Tc=0.27 =0.27sec

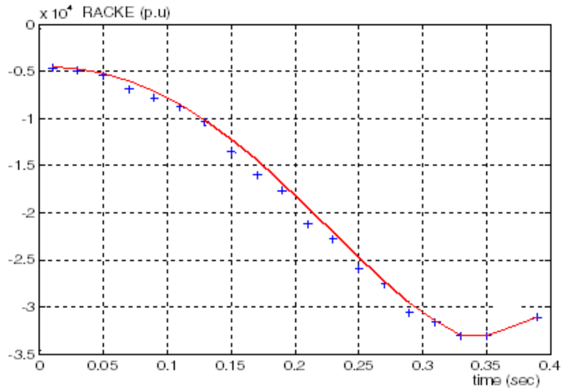

Figure 8a. RACKE against Tc for critical Ge.
+++ Output of MATLAB ---- Output of ANN

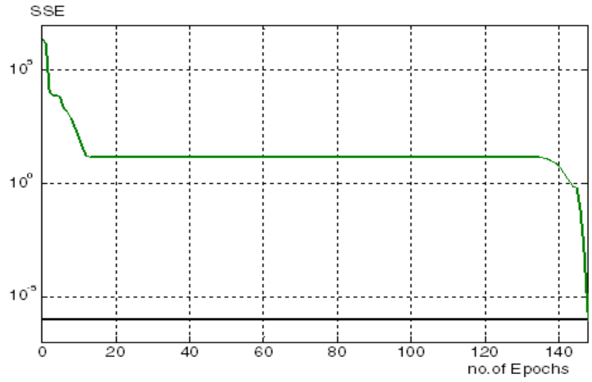

Figure 8b. SSE of critical Gen at Tc=0.27sec

Table.8. classification of transient stability with ANN (PNN) method

T(SEC.)	RACKE	Assessment
0.01	-.024	Stable
0.03	-.444	Stable
0.05	-.698	Stable
0.07	-.967	Stable
0.09	-1.233	Stable
0.11	-1.421	Stable
0.13	-1.805	Stable
0.15	-2.056	Stable
0.17	-2.266	Stable
0.19	-2.326	Stable
0.21	-1.649	Stable
0.23	-1.233	Stable
0.25	-.987	Stable
0.27	-.444	Stable
0.29	.313	Unstable
0.31	1.124	Unstable
0.33	1.432	Unstable
0.35	1.657	Unstable

Table 9. classification of transient stability with ANN(PNN) method

$T_{(SEC.)}$	$\delta_{2\ (deg.)}$	$\delta_{3\ (deg.)}$	Assessment
0.01	19.94	18.30	stable
0.03	22.50	18.74	stable
0.05	27.26	19.32	stable
0.07	29.3	19.55	stable
0.09	34.20	20.06	stable
0.11	37.01	20.34	stable
0.13	43.34	20.91	stable
0.15	49.78	21.23	stable
0.17	54.68	21.79	stable
0.19	64.78	22.34	stable
0.21	68.21	22.63	stable
0.23	73.50	22.93	stable
0.25	78.44	23.14	stable
0.27	83.93	23.37	stable
0.29	106.9	23.91	unstable
0.31	120.9	23.67	unstable
0.33	131.8	22.87	unstable
0.35	140.2	20.54	unstable

CONCLUSIONS

A complete model for transient stability study of multi-machine power system was developed using MATLAB commands to suit the changes in the original power system network due to fault or corrective action . A model of an ANN for checking and control of power system voltage stability and transient stability margin change has been developed .The proposed ANN tries to enhance the voltage stability and transient stability margin utilizing generator excitation and clearing time setting as controllers for various loading conditions and fault location for 9-busses IEEE power system .

The following conclusions can be summarized:

1) All machines in the system swing at critical clearing time that fact is concluded through the results and the graphs that obtained using MATLAB model simulation, multi-machine system have been used to show this effect .
2) The RACKE method achieve considerable reduction in computing time compared with the SBS method. Because this methods do not require the solution of system equation beyond fault clearing time.
3) ANN methods depended Try & Error to determine the hidden layer parameters [(η) learning rate, (α)Moment factor ,no. of neurons]
4) Features (accuracy, elapsed time) of neural network (PNN) method that used for testing system is efficient method for classifying the power system stability.
5) The MATLAB program had fast and high accuracy to mathematical analysis and professionally dealing with matrices.
6) The result of this study explain that Neural Network is efficient to analysis transient stability of power system and classification.

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Appendix I (generator data)

Generator no.	1	2	3
Rated MVA	247.5	192.0	128.0
Kv	16.5	18.0	13.8
H(s)	23.64	6.4	3.01
Power factor	1.0	0.85	0.85
Type	Hydro	Steam	Steam
Speed	180 r/min	3600 r/min	3600 r/m
x_d	0.146	0.896	1.313
$x`_d$	0.061	0.120	0.181
x_q	0.097	0.865	1.258
$x`_q$	0.097	0.197	0.25
$x_{1(leakage)}$	0.034	0.052	0.074
T_{do}	8.96	6.00	5.89
$T`_{qo}$	0	0.535	0.600
Stored energy at rated speed	2364 MWs	640 MWs	301 MWs
Note:Reactance values are in pu on a 100 MVA base.All time constant are in sec.			

Pre-fault network: $YRpf =$
$$\begin{bmatrix} 0.85 - j2.99 & 0.29 + j1.51 & 0.21 + j1.23 \\ 0.29 + j1.51 & 0.42 - j2.72 & 0.21 + j1.09 \\ 0.21 + j1.23 & 0.21 + j1.09 & 0.28 - j2.37 \end{bmatrix}$$
During-fault network:
$$YRdf = \begin{bmatrix} 0.657 - j3.816 & 0 + j0 & 0.070 + j0.631 \\ 0 + j0 & 0 - j5.486 & 0 + j0 \\ 0.070 + j0.631 & 0 + j0 & 0.174 - j2.796 \end{bmatrix}$$

After fault network:

$$Y_{Raf} = \begin{bmatrix} 1.14 - j2.30 & 0.13 + j0.71 & 0.18 + j1.06 \\ 0.13 + j0.71 & 0.38 - j2.02 & 0.19 + j1.21 \\ 0.18 + j1.10 & 0.19 + j1.21 & 0.27 - j2.35 \end{bmatrix}$$