Neural Network Based Overcurrent Voltage Controlled Protection System in Large Electrical Networks

Yasser G. Mostafa*, and M. Shafik Aly**

Abstract--**Generation stations are considered extremely vital part of power system. Overcurrent voltage controlled relays are extensively used as backup protection of generators. Coordination between generator overcurrent voltage controlled relays and transmission line directional overcurrent relays represents a tedious task in power system protection as it depends heavily on network topology and system parameters. Mis-coordination is normally practiced in this situation. In this paper an intelligent modular protection system is proposed for relays parameter setting to assure proper coordination between such relays. The proposed system is based on artificial neural networks. The developed system interacts dynamically with protected network taking into consideration different loading and operating schemes. The system is applied and tested on large unified electrical power network. Good results are obtained to assure precise coordination in different fault type, location and network topologies.**

***Index Terms*-- Intelligent systems, neural networks, overcurrent protection, and protective relaying.**

I. INTRODUCTION

THE function of generator backup protection is to disconnect the generator if a system fault has not been cleared by other protective devices after a sufficient time delay has elapsed. This function serves to protect the power system components against excessive damage and to prevent the generator and its auxiliaries from exceeding their thermal limitations. Users and system designers are reluctant to use any relay that operates solely on overcurrent for fear that it might trip off the generator when the demand on it is the greatest. The use of ordinary time overcurrent relays presents a serious difficulty in attempting to determine the proper current and time settings.

Reference [1] presents different types of protective relays which are used to provide the function of generator backup protection. The use of voltage controlled over current protection relays become popular for back up protection especially in large generators. These relays are not responding only to current measured but also to the voltage measured on the generator terminals. Great difficulty is raised to coordinate between voltage controlled over current relays and directional over current relays which are normally installed to protect transmission lines.

Different methods to perform coordination between overcurrent voltage controlled relays (51V) and directional overcurrent relays (67) are introduced in Reference [2].

First introduced method was the simplified method where it is assumed that if the voltage on relay 51V is below certain level of nominal voltage, forcing the 51V tap to certain percentage of the normal setting. This assumption represents the maximum and the worst case, as the (51V) relay will appear to trip faster than actual situation especially in the cases of low fault currents which are normally happen far from the generator. This leads to mis-coordination between both relays. A typical tripping curve of 51V in such method is shown in Fig. 1.

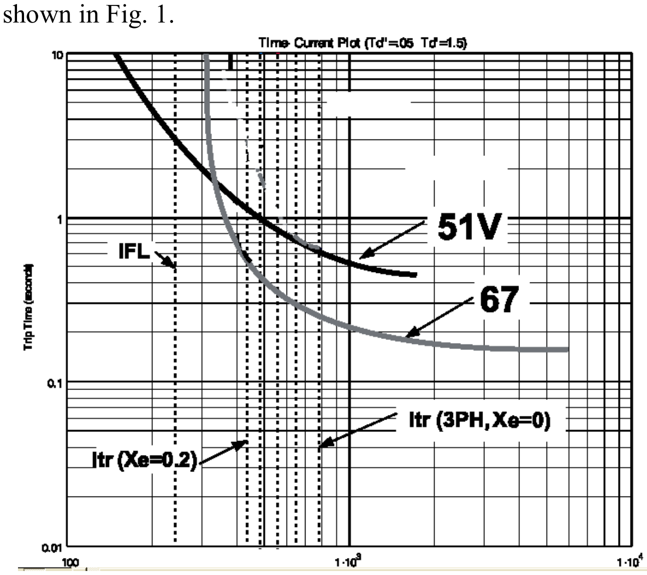

Figure 1. A Typical 51V Coordination Plot Using the Simplified Method

Second introduced method is voltage restrained overcurrent relay type. This method is also developed to make the operating characteristics function of voltage as well as current. As the magnitude of the voltage applied to the relay voltage coil decreases from rated value, the time current characteristic is modified so that the relay becomes more sensitive due to the measured voltage on relay terminals. This method gives better tripping time control compared with the simplified method, but On the other hand proper coordination between relays in this case is very tedious task. Table I and Fig. 2 Illustrate the restraining characteristics in this case

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TABLE I. PERFORMANCE OF VOLTAGE RESTRAINED OVERCURRENT RELAY AT DIFFERENT VOLTAGE VALUES

Percent Rated Volts	Pickup, Percent Tap Setting
100 %	100 %
78 %	78 %
48 %	52 %
0	25 %

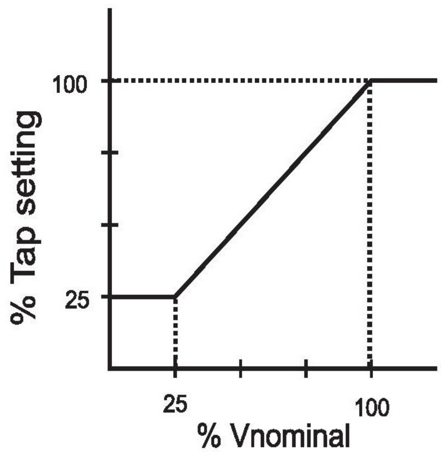

Figure 2. 51/27R Characteristic curve

Third introduced method is the integration time calculation method, where the current waveform is sampled periodically to monitor the applied current. Integration of the current is performed by sampling the applied signal and periodically updating the travel register. Each time a ¼ cycle's worth of new data is accumulated, a one cycle Discrete Fourier Transform, or DFT, is performed using the new data and the previous ¾ cycle's data. From the DFT, the magnitude of the applied current is determined. The current magnitude is compared to the pickup setting for the 51V relay. If the current is over the pickup setting, a Multiple Of Pickup, or MOP, is determined. The MOP is applied to the timing equation along with the curve constants and the update time interval to determine an incremental change. Larger MOPs result in greater incremental changes and therefore, faster trips. The incremental change is normalized to 1 or 100% and represents the percentage of travel occurred in one time interval. This process is continued until the travel value reaches one. This indicates the timing has reached a trip value and a trip output is issued. If the MOP drops back below the pickup prior to trip, the travel register is decreased according to the reset characteristic selected by the user. This method has a very accurate tripping scheme for 51V relay, but the problem is generated from the mis-coordination between the overcurrent voltage controlled relay, and the transmission line directional overcurrent relay. Flow chart of this method is shown in Fig.3.

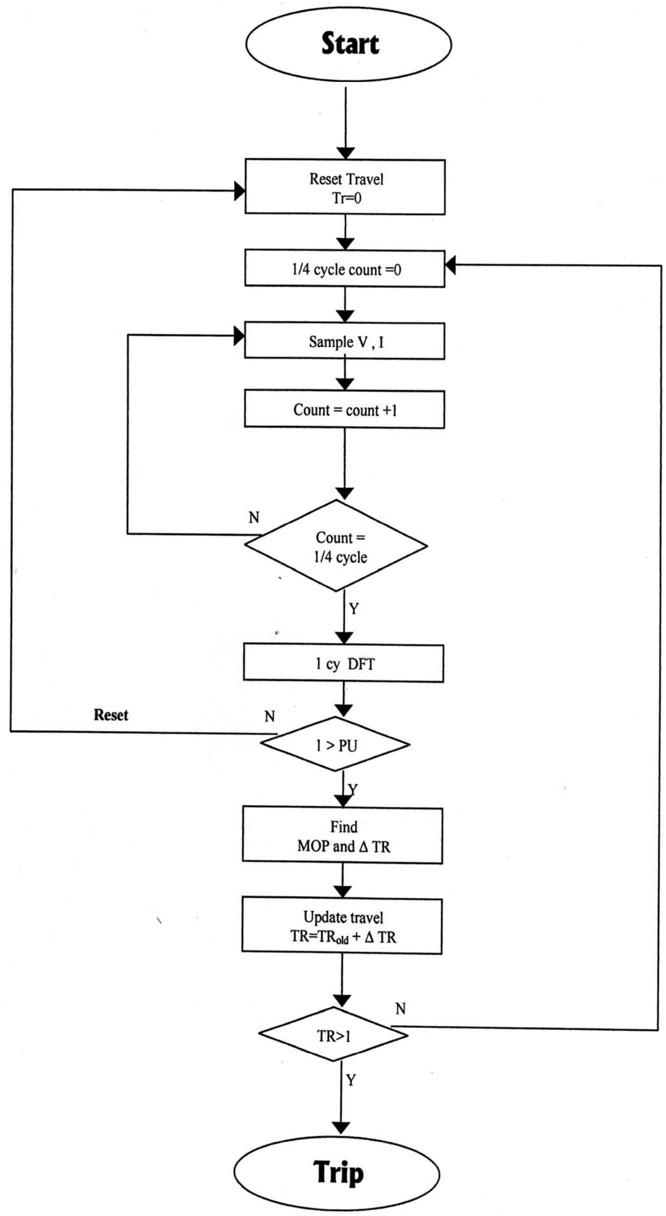

Figure 3. Flow Chart of an Integrating O/C Relay Algorithm

In this paper; new modular protection system is developed to set the parameters of both overcurrent voltage controlled relay (51V) and transmission line directional overcurrent relay (67). The developed system has modular structure and it consists of three different modules. Block diagram of proposed protection system is indicated in Fig. 5.

A. Simulation Module

The simulation of the electrical power network was developed with the aid of ETAP software which is a very powerful tool for power system analysis [3]. Analysis of the performance of electrical network at different loading and fault conditions is performed. Data is collected and then transferred to data handling module.

B. Data Handling Module

This process is very important to analyze, collect and index all needed parameters during each case study in the proper format to supply the developed neural network module. This process is done through data file exporting and arrangement in a simple format suitable for neural network developed technique.

The study is performed on different power stations in different locations, loading conditions and different network topologies. This helps to handle and analyze a wide range of data output and gives better understanding during comparing results for each situation. Using these data, optimum values for relay 51V setting can be calculated based on a suitable proposed backup period.

C. Relays Setting Module

The output from the data handling module is the input to MATLAB software [4] for the training process of neural network. Optimum value for relay 51V setting is the target output from this training. Off line training is done through different neural network designs. This variety of results is also to estimate the difference in accuracy in different cases of neural networks designs.

In our proposed network the input vector
$\rho = (D, I_{gen}, V_{gen}, I_{line})$

Where:
D: is distance between Generator and fault ' KM'
I_{gen}: is the current value at generator terminals 'amp'
V_{gen}: is the voltage value at generator terminals 'Volt'
I_{line}: is the current value at transmission line 'amp'

Weights 'W_p' are unity and bias 'b' is zero. The output layer '*a*' is the Time Dial value for relay 51V

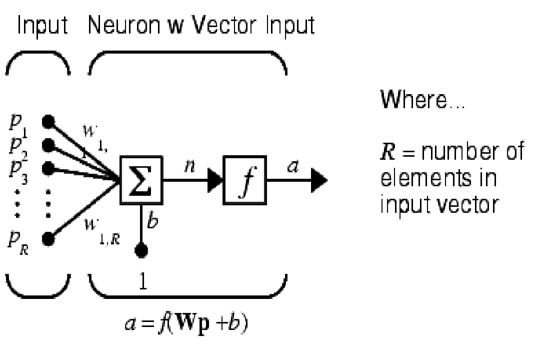

Figure 4. Neural network design

The neural network module is used for off-line training process, it can also be used for on-line relay adjustment which can determine the setting of relay 51V and selects the most suitable coordination curves with a proper predetermined coordination time. The proposed coordination time depends on relay types, relay accuracy and fault currents as well.

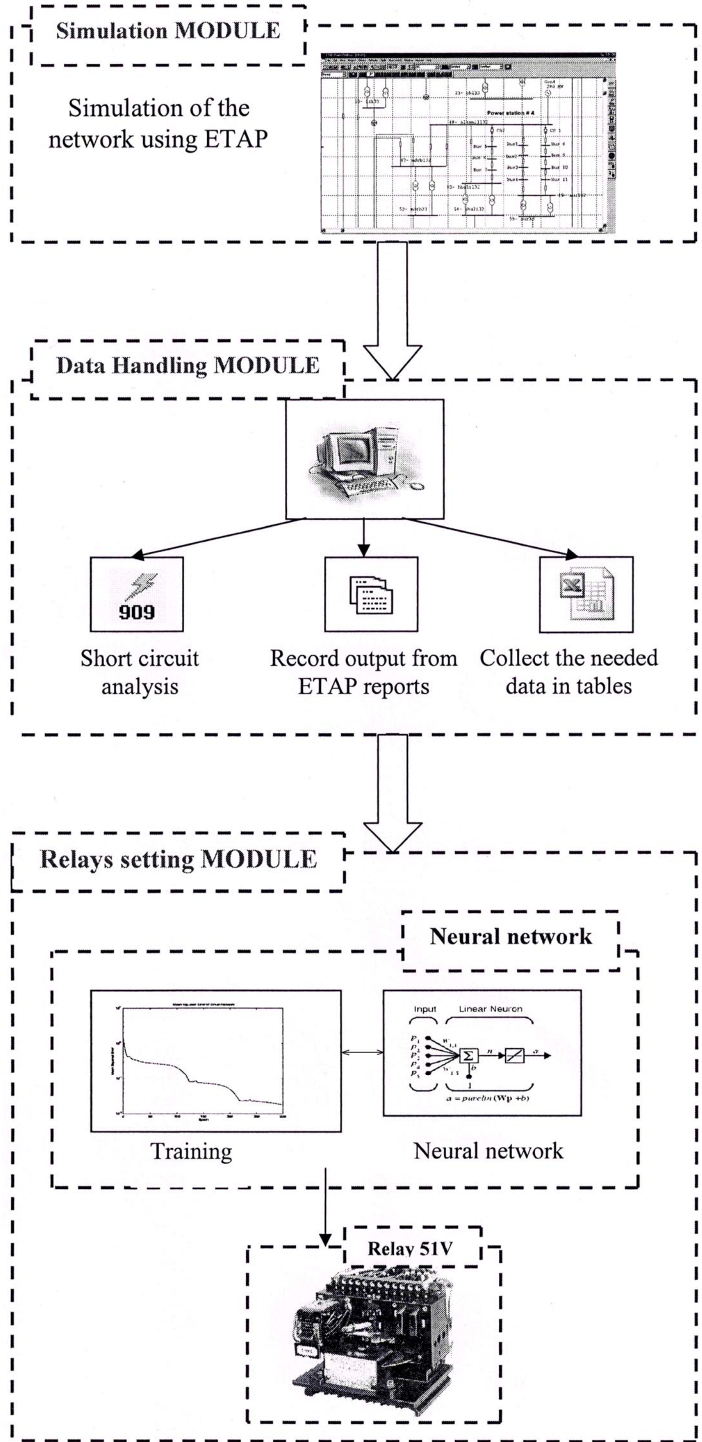

Figure 5. Block diagram of modular structure showing data process flow

II. NETWORK UNDER STUDY

The network under study is shown in Fig. 6, represents an actual large unified network in gulf area. This network under study consists of 10 generating stations and about 33 substations at different voltage levels. Number of busses is 100 buses, and 182 branches and installed capacity is about 3,223.5 MVA.

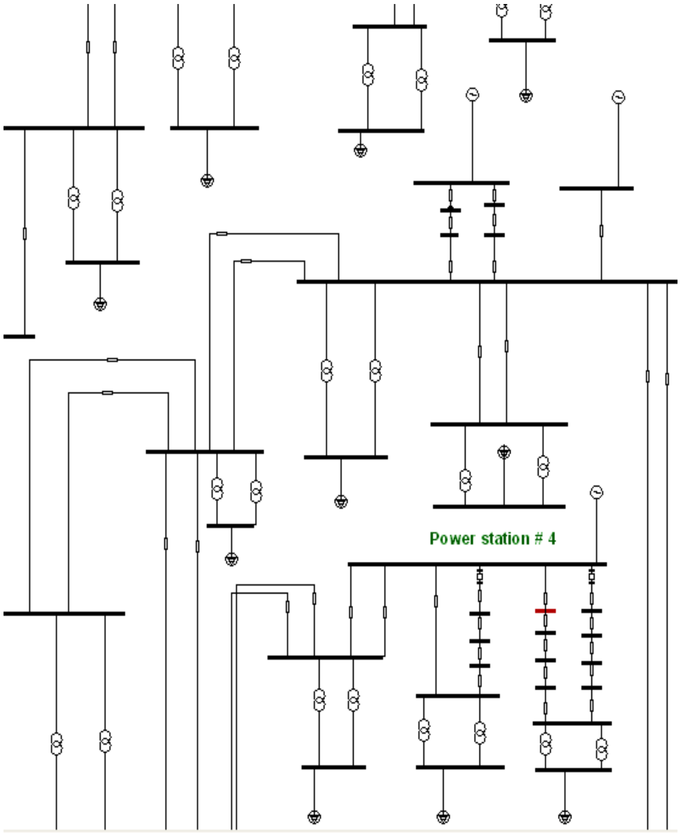

Figure 6. Single line diagram for a depicted part of the network

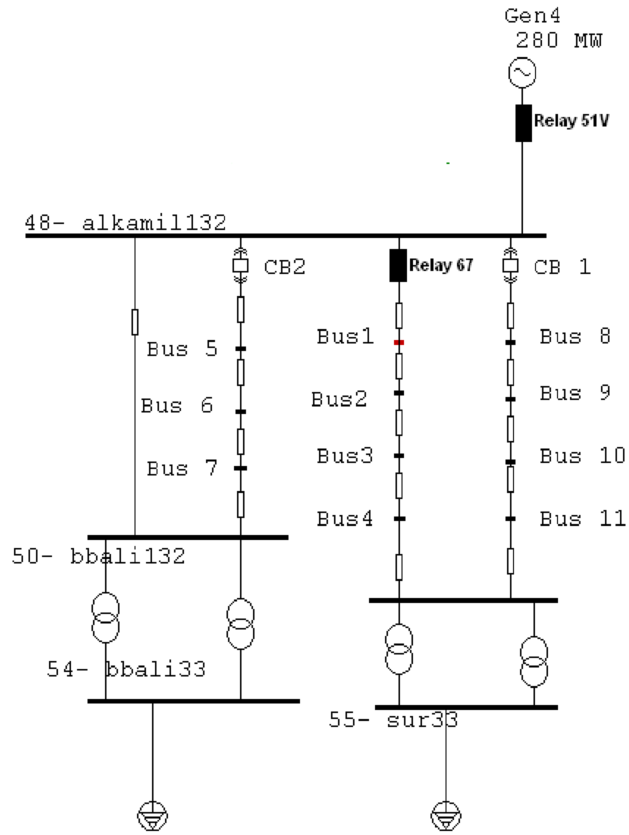

Figure 8. Close look for PowerStation # 4

The percentage of power contribution for each generating station compared to the total installed capacity is shown in the Pie chart of Fig.7.

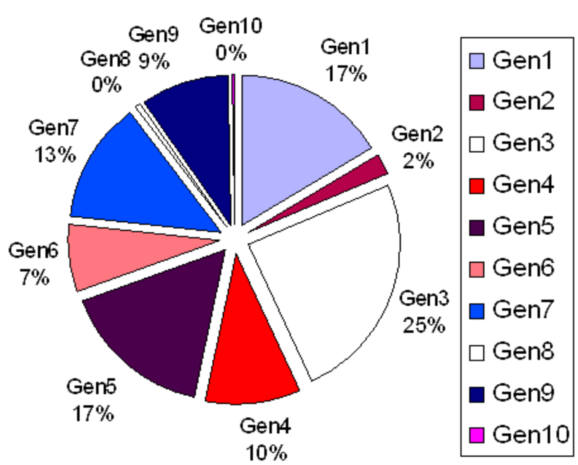

Figure 7. Pie chart showing the power contribution for each generator

Study was done on 4 different generators in different locations of the network. The aim of this variety is to handle and analyze a wide range of data output and gives better understanding during comparing results for each situation. Fig. 8 shows a depicted part of the network understudy where coordination between over current voltage controlled relay 51V and directional over current relay 67 is required.

For faults near the generator terminals, the relay 51V can be set to provide backup protection for the generator. Whereas for remote faults, the line impedance causes the resulting voltage drop and effective tap on the 51V relay to increase. The trip time becomes longer and therefore can not be practical to perform safe backup protection for the generator. Even if the relay is set to lower limit to decrease the tripping time, in this case mis-coordination may happen and the backup relay (51V) can trip before the relay 67 which is not practical as shown in Fig.1.

Assumptions used during calculations:

- All loads are proposed as static load
- Only loads data available was considered, no load estimation was carried out.
- Short circuit calculation was done based on IEC 909 standards
- Generation stations are presented by one integral unit (including the step- up transformers)

III. RESULTS ANALYSIS

In this study, three methods are tested on Gen4.

A. Simplified Method Test Results:

A simulation for the power station#4 with fault on bus 4 is shown in Fig 9.

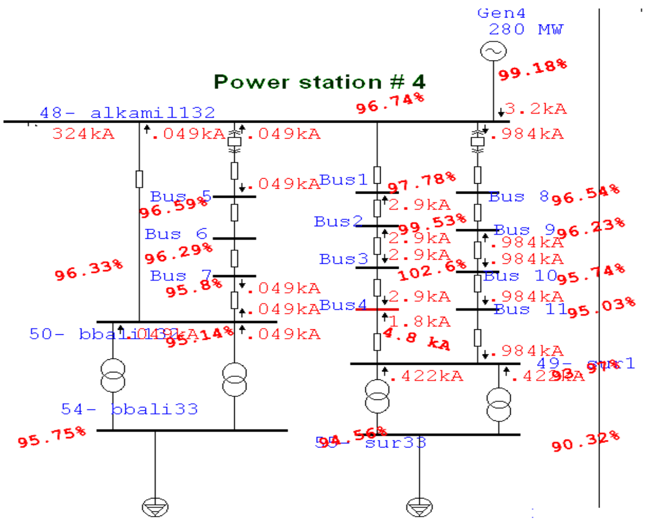

Figure 9. Gen 4 after applying short circuit analysis

Table II shows power system simulation results as obtained from ETAP and the setting of both relays for simplified method.

TABLE II. VALUES FOR CURRENTS AND VOLTAGES OBTAINED FROM ETAP VERSUS CORRESPONDING TRIPPING TIMES [5]

fault at Bus #	Dist. From Gen	I_G	V_G	T.D 51V	51V trip time	I_L	T.D 67	67 trip time
1	5 KM	8.6	25%	20	0.92	10.6	15	0.84
2	13 KM	5.8	25%	20	1.05	6.8	15	0.99
3	31 KM	4.1	25%	20	1.20	4.4	15	1.23
4	49 KM	3.2	25%	20	1.33	2.9	15	1.58
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Fig 10 shows (67) and (51V) relays coordination curves for different fault current values using simplified method of coordination. The tripping curves indicate mis-coordination occurrence at low fault currents.

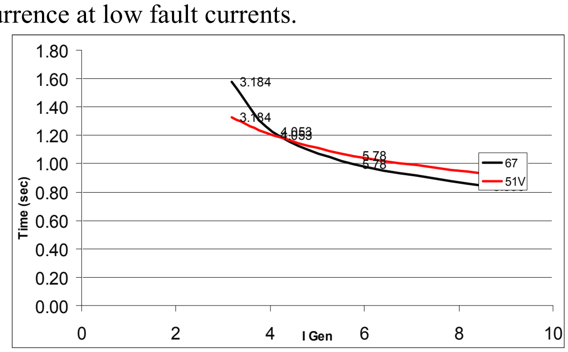

Figure 10. Tripping time versus current (miscoordination occurs at low fault current)

B. *Voltage Restraining Method:*

In this case, tripping time for relay 51V depends on both the voltage and current values that are measured on (51V) relay terminals.

Table III shows power system simulation results as obtained from ETAP and the setting of both relays for voltage restraining method.

TABLE III. VALUES FOR CURRENTS AND VOLTAGES OBTAINED FROM ETAP VERSUS CORRESPONDING TRIPPING TIMES [5]

fault at Bus #	Dist. From Gen	I_G	V_G	T.D 51V	51V trip time	I_L	T.D 67	67 trip time
1	5 KM	8.6	33%	20	1.01	10.6	15	0.84
2	13 KM	5.8	54%	20	1.45	6.9	15	0.99
3	31 KM	4.1	68%	20	2.05	4.4	15	1.23
4	49 KM	3.2	75%	20	2.73	2.3	15	1.58
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Good coordination at faults near generator (max fault currents) is illustrated in Fig 11 shows. Long back up time for remote faults (low fault currents) represents thermal and dynamic stress on generator in this case.

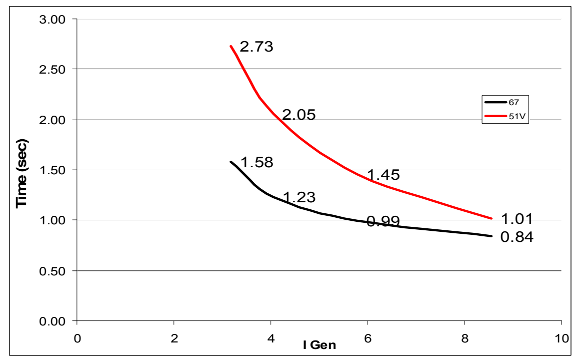

Figure 11. Tripping time versus current (too much backup period at low fault currents)

C. *Developed Neural Network Method*

In this case the relay (67) setting parameters are set based on results obtained by simulation module in each network topology. On the other hand the relay 51V is operated on a flexible setting basis.

As shown below in table # IV, setting for relay 51V is adjusted according to each case, not fixed as the previous 2 methods.

TABLE IV. VALUES FOR CURRENTS AND VOLTAGES OBTAINED FROM ETAP VERSUS CORRESPONDING TRIPPING TIMES [5]

fault at Bus #	Dist. From Gen	I_G	V_G	T.D 51V	51V trip time	I_L	T.D 67	67 trip time
1	5 KM	8.6	33%	20	0.99	10.6	15	0.84
2	13 KM	5.8	54%	15	1.14	6.9	15	0.99
3	31 KM	4.1	68%	13	1.38	4.4	15	1.23
4	49 KM	3.2	75%	12	1.73	2.3	15	1.58
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.

This setting for the relay 51V is determined according to the neural network output module. In this application accurate results are obtained by using a standard feed forward neural network (FFNN) that consists of 2 layers and a *Purelin* Transfer Function.

Fig. 12 shows that the proper coordination time is obtained whatever fault current values. Also acceptable and controlled coordination time is obtained which is normally between 0.1 and 0.2 Seconds. This coordination time can be defined based on fault currents, relay types and accuracies as well.

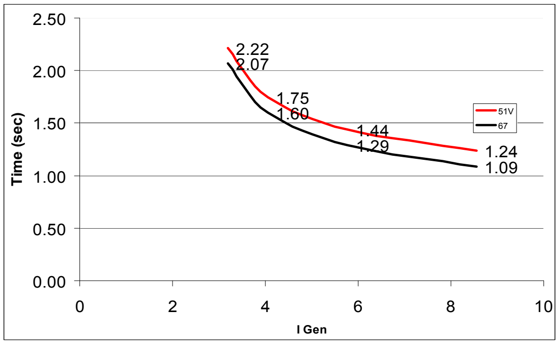

Figure 12. Tripping time versus current (fixed backup period= 0.15 sec throughout all current ranges)

IV. CONCLUSION

Overcurrent voltage controlled relay coordination with normal directional overcurrent relays represents tedious task in power system operation. Miscoordination is normally practiced in this situation. Neural network system interfaced with power system transient analysis simulation program is designed to assure good coordination between both relays. Different network topology, fault types, loading condition, earthing system methods are considered in this intelligent system. The proposed system is applied and tested on one of the gulf areas unified network, good results are obtained.

V. REFERENCES

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VI. BIOGRAPHIES

Yasser G. Mostafa was born in Cairo/Egypt on March 21, 1965. He received B.Sc. and M.Sc. from Ain Shams University, Cairo, Egypt in 1987 and 1993 respectively. His Ph.D. degree in Electrical Engineering was from Ain Shams University in 1997.

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