Automation of Contingency Analysis for Special Protection Systems in Taiwan Power System

Shih-En Chien, I-Ta Cheng, Yi-Ting Chou and Chih-Wen Liu

Abstract-- **Taiwan Power Company (TPC) has implemented an event-based special protection system (SPS) against extreme contingencies. The decision making mechanism of the event-based SPS is based on look-up tables. A huge number of contingency analyses are required for constructing and updating the look-up tables. In this paper, automation techniques are developed to increase the analysis efficiency for speeding up preparing a look-up table. Contingency selection algorithms including both the depth-first algorithm and breadth-first algorithm are used to search for contingency cases automatically. A preprocess interface is designed to provide a friendly user-machine interface between the power system raw data and simulation software. And a computer program is developed to integrate the search algorithm and preprocess interface for fulfilling the automation of contingency analysis for SPS. The techniques realized with programs demonstrate a great time-saving advantage compared to traditional man-made work. The automation of contingency analysis for SPS does not only speed up the simulation process but also improve the efficiency, which is well demonstrated in the paper.**

Index Terms—**power system protection, power system faults, automation.**

I. INTRODUCTION

In the latest five years, there have been several severe power blackouts experienced in Taiwan. These power events include the 729 incident which happened in July 29 1999, the 921 incident in September 21 1999 and the 410 incident in April 10 2004. These power contingencies have caused paramount economic loss in Taiwan. So how to avoid blackouts or lower the occurring probability of blackouts surely is the most important issue of power companies and the government. After the 729 incident [1]-[2], Taiwan Power Company (TPC) immediately investigated the cause and found that insufficient power infrastructure was one of the major causes. In order to avoid similar power contingency from happening, TPC decided to strengthen the power system protection except implementing the power infrastructure establishment. Evaluating the feasibility of many power system protection strategies, TPC finally adopted the special protection systems (SPS) to improve the defense ability of Taiwan power system to disturbances or contingencies.

A SPS is designed to detect abnormal system conditions and take predetermined corrective actions (other than the isolation of faulted elements) to preserve system integrity and provide acceptable system performance [3]. Fig. 1 illustrates the general structure of SPS.

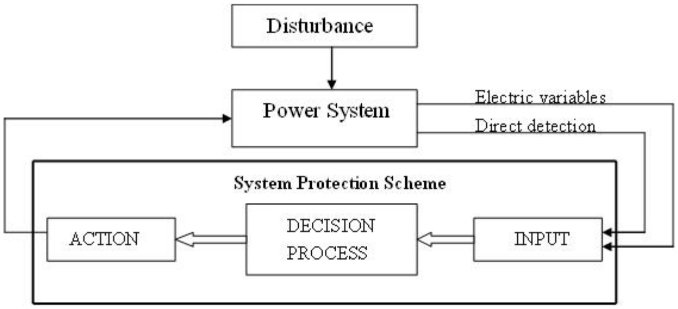

Fig. 1. General structure of a special protection system [3]

There are many ways to categorize SPS, including input signal types, the level of influence to the power system, the action time length, contingency types responded by the SPS, etc. The most commonly used one is by input signal types comprising the response signal and event signal. Thus SPS can be categorized into the response-based and event-based SPS. For the response-based SPS, electric variables such as the bus voltage or frequency are measured and sent to the SPS to execute state estimation or other calculations. Then we match the calculation results with the normal values. If it is not normal, we take predetermined corrective actions. TPC has designed an event-based SPS through the help of Powertech Labs Inc. of Canada [4]. When an event happens, this event-based SPS will directly detect and judge the event to figure out whether the control signal needs to be sent to trigger one control action. The manner of judgment is based on a look-up table which relates an event with its control action. Because there are too many types of events, and load conditions also influence which control action will be taken, the event-based

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SPS requires a lot of look-up tables for search. To make a look-up table, the power system contingency analysis should be completed. Enumerating the power system contingencies and the complex simulation steps is the bottleneck to the analysis efficiency. For more than two decades, contingency analysis has received considerable attention [5]-[13]. The contingency analysis is a classification issue oriented to providing an assessment of the security level of the current power system state, regarding the occurrence of a possible contingency. This task may be approached by both functional methods, characterizing the severity of each contingency by a numerical value, and graphical methods, permitting the contingency evaluation in a visual way. Usually contingency analysis can be divided into three parts: contingency definition, selection, and evaluation. Contingency definition is the least time-consuming part. The purpose of contingency selection is to identify severe contingencies from a list of possible contingencies for further detailed evaluation once the preventive and corrective measures have been identified. The applied traditional contingency selection methods are generally based on the solution of a power flow problem for each contingency. Thus, the process requires a redundant computational cost. A real time contingency analysis becomes impossible when a minimally real power network is considered. The selection method currently used by TPC also belongs to the traditional group. And they use PSS/E (Power System Simulator for Engineering) [14] to automatically provide the power flow solution for each contingency. Of the recent substantial body of work found in the literature on contingency selection methods, one is called “the ranking method”, involve using a performance index as scalar function to describe the effects of an outage on the whole network. For another set of method, known as “the screening method”, the most severe cases are identified with top priority in the contingency list for more detailed ac analysis. At the same time, the non-critical cases are removed from the list. This paper aims at presenting an automatic contingency analysis for SPS incorporating a new selection method easier than ranking methods or screening methods with a graphical contingency evaluation method which is based on a friendly human-machine interface. And the application of this automatic analysis tool has shown satisfactory results. The automatic technique addressed by this paper can be divided into the following three parts:

(1) Use the searching algorithm to implement the automatic selection scheme for power system contingencies.

(2) Address a concept of the preprocess interface. This interface is the base for interaction, operation and data transfer between users and the machine.

(3) Develop a computer program to integrate the searching algorithm and the preprocess interface for fulfilling the automation of contingency analysis for SPS.

II. SELECTION SCHEME FOR POWER SYSTEM CONTINGENCIES

To explain the selection scheme, take a leaf as an example. The study system can be regarded as a leaf. The power transmission network that represents the contingency search space is like the nerves spreading in the leaf. If one or more transmission trunk lines can be found in the study system, the buses passed by these transmission trunk lines are similar to nerve branching points and form a set of pivot buses. The transmission lines linked with pivot buses spread all over the study system, composing a search space. So the number of pivot buses determines the size of search space that it is the basis for selection of contingencies.

The following describes the selection principles according to different types of contingencies.

N-1: All the transmission lines linked with pivot buses are selected as contingencies. If there are transmission lines which have the same sending and receiving end, only one transmission line would be selected because they have the same effects to the study system.

N-2: In the power transmission system of Taiwan, there are two common types of loop structures, as Fig. 2 shows. For type one, two loop lines share the same electric power tower. If the tower collapses, the two loop lines will all be in fault. For type two, the loop connection between the three buses is like a triangle. If any two loop lines of the triangle cause outage, the link between one bus and the others will be cut so that it may cause an acute influence on power transfer. Because the occurrence possibility of these N-2 contingencies is much larger than other types, and the impact on the power system is also more significant, any transmission line set in type one and type two is selected as N-2 contingencies.

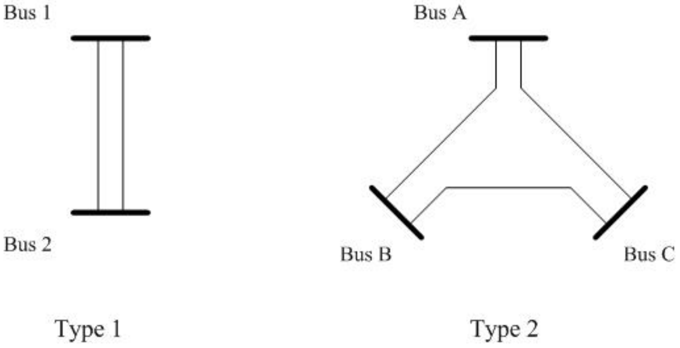


Fig. 2. Selecting principles for N-2 contingency cases

N-3: In terms of the power transmission system plan guidelines of TPC [15], the power supply reliability requirements for important areas, such as leading lines of nuclear power plants and extra high voltage (EHV) trunk lines, must satisfy N-2 criterion. The areas demanding better power quality or higher power supply reliability, such like science parks, can take N-2, underground or higher criteria to supply power after receiving the approbation of the administration organization. Because SPS is for acute power contingencies, it is necessary to take contingencies of N-3 or more serious criteria into consideration. Because of the very low probability of N-3 contingencies happening in different transmission lines in real world, reasonable criteria selection is to combine N-2 with N-1 into N-3 contingency cases.

For selecting other types of contingencies, the selection principles of N-1, N-2 and N-3 contingency types can be applied as basis for extension.

The contingency selection scheme comprises trunk line searching, determination of pivot buses and contingency selection. Because this scheme comprises definite steps, it is appropriate to illustrate the scheme by computer algorithm. The process of contingency selection coincides with the concept of finding a solution through the search in artificial intelligence field. Therefore this paper utilizes search techniques to develop a new selection method for contingencies.

The elasticity of contingency selection is limited by search space which indicates the transmission lines in the study system. Thus, the first job is to define the study system by study objectives. Often the study system can be divided according to voltage levels or districts. Fig. 3 shows the two characteristics of the divisions in the study system.
Firstly, different voltage levels are separated by transformers. Secondly, there are often tie lines between districts for power supply transfer. However, due to the prevention of excessive fault currents or the disallowance of power system relaying, these tie lines are normally open.

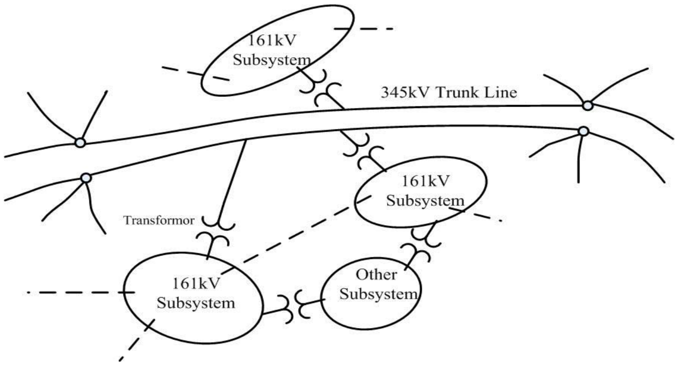


Fig. 3. Demonstration for two characteristics of division of the study system

In the above, two physical characteristics become the boundary conditions between the districts, being utilized by the computer program for automatic contingency selection in order to make sure that the contingencies are automatically selected by the computer program.

This paper uses depth-first search algorithm to implement the computer program for main trunk search. One advantage is that it can quickly find a path between the appointed starting bus and ending bus. Fig. 4 demonstrates the search process. The main trunk searched is assumed from bus OMEI (2001) to bus TUNSIO (610).

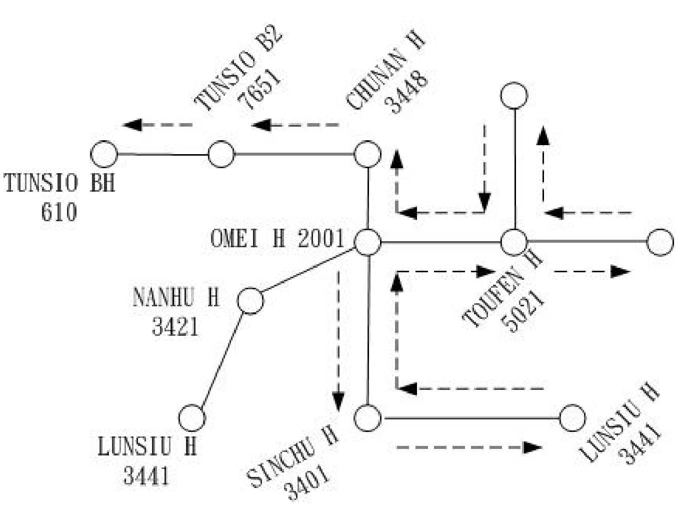


Fig. 4. Searching process for the main trunk search

The search process begins at bus OMEI (2001), passes bus SINCHU (3401) and goes forward till it meets bus LUNSIU (3441) where there is no other lines linked to. Now we go back to bus SINCHU (3401), finding there is no other routes except the original one. Again, we go back to bus OMEI (2001) and try to find another route leading to bus TOUFEN (5021). Such search process continues until finding the path targeted, which is resulted to OMEI (2001)-CHUNAN (3448)-TUNSIO (7651)-TUNSIO (610). In fact, there is always a path between any two buses under boundary condition. The searching program does not set the searching cost conditions; meanwhile, the structure for the power transmission system is similar to a net. Therefore, it is impossible to complete an enumerating search; also, the efficiency of the main trunk search is enhanced largely.

Fig. 5 is the flow chart of the depth-first algorithm. The algorithm begins at loading the files depicting the power system parameters; then, we take the transmission line constants out and store them into the database, as a search space. Next, we use the match and stack structure to implement the depth- first algorithm in order to complete the main trunk search.

In the contingency selection principles for N-2 contingencies, there are two types taken in consideration. For type one, it is easy to use the depth-first searching algorithm to search the transmission lines linked to the pivot buses. As for type two, the breadth-first searching algorithm is also needed besides the depth-first search algorithm. The purpose of using the breadth-first searching algorithm is to quickly find the transmission lines linked to the starting and ending buses so that the number of passed buses can be minimized. If there is a transmission line linked with the pivot bus but not the ending bus, which is found in each time of the search process, we should check if the next transmission line is linked to the ending bus.

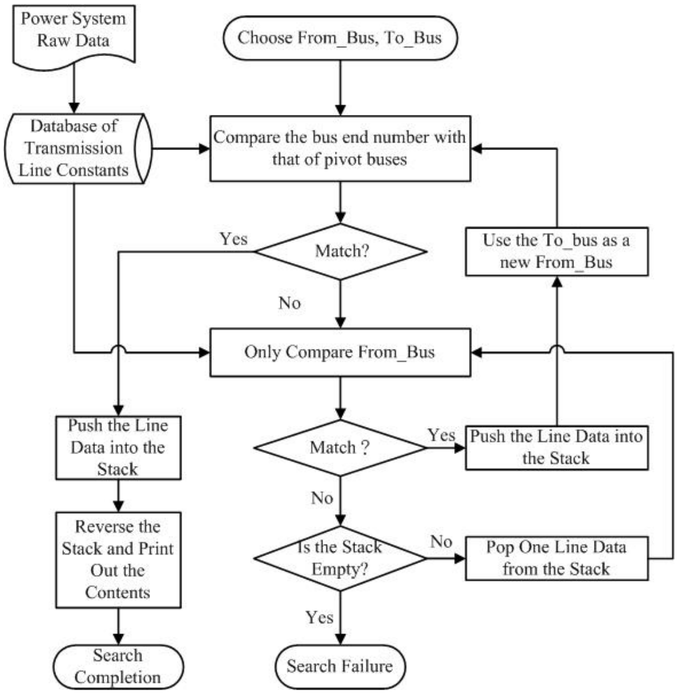


Fig. 5. Flow chart for the depth-first algorithm

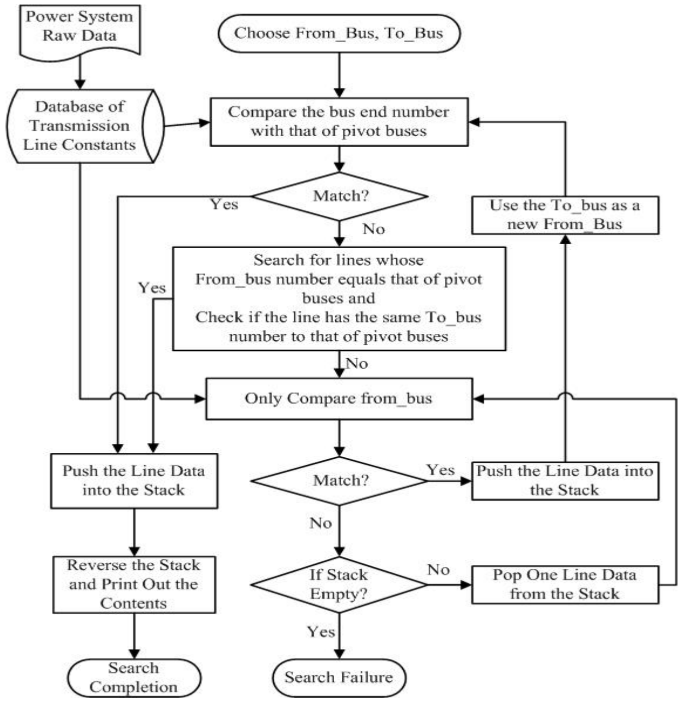


Fig. 6 Flow chart for the breadth-first algorithm

If not, we then go back to the last bus. The left search steps are the same to those of the depth-first algorithm. Fig. 6 shows a flow chart of the breadth-first algorithm. The major difference between the depth-first and the breadth- first algorithms is that the former looks for the transmission lines linked to the pivot buses layer by layer, while the latter checks if the found transmission line leads to the ending bus. That is, the breadth-first algorithm can lower the number of transmission lines searched. Commanding both the starting and ending buses are the same, we applied the computer algorithm to find out the wanted path where the search encounters at three connection points. Starting from one bus, passing two buses and finally returning to the starting bus can make such a path like a triangle. This path coincides with the type two loop structure of Fig. 2. By using the characteristics of the triangle path, the search program firstly executes the main trunk search; then, the breadth-first search for every pivot bus on the main trunk. At last, we find the triangle path starting from the pivot bus and pick out any two transmission lines from the triangle path in order to get three cases of N-2 contingencies.

For different study objectives, the computer algorithm for the main trunk search can be revised to meet the requirements by using techniques such as multi-path, repeating search for pivot buses, addition of restriction conditions, etc.

III. PREPROCESS INTERFACE

The simulation software of PSS/E is a common tool for many major power utilities in the world including TPC to conduct power flow calculations and transient simulations. However, the usage of this software is complicated, and the manual operation costs much time that it may cause fatigue to the user and error to the simulation results. Therefore, using so called "Batch" commands to make the simulation run automatically is a better choice. But writing the batch files for mass simulation is also not easy. This section would introduce an integrated interface for producing the batch files automatically to promote the efficiency in mass simulation. Fig. 7 shows how the interface relates to PSS/E. The role of the preprocess interface is to provide a friendly user-machine interface between the power system raw data and simulation software. The interface lets the commands provided by PSS/E transfer to batch files automatically, and starts the PSS/E to execute the contingency evaluation. Users do not have to handle with the complicated process indicated by the grey area in the Fig. 7; on the other hand, users can concentrate on the verification and analysis of the power system raw data, gatherings and statistics of simulation results.

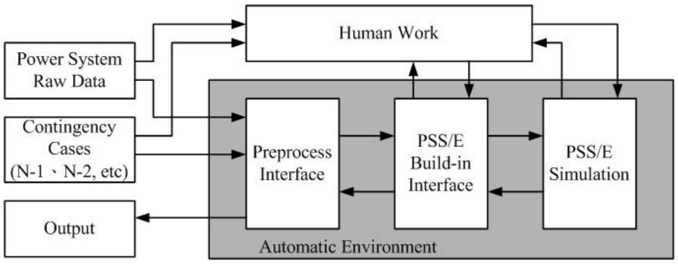
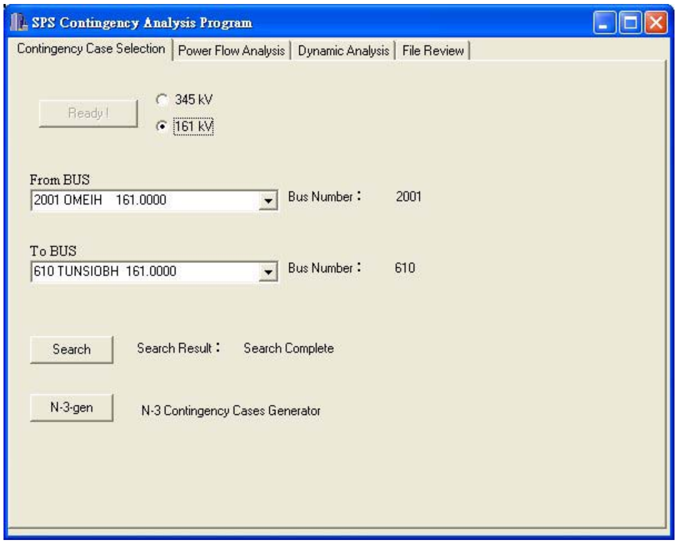


Fig. 7. Demonstration of how the preprocess interface relates to PSS/E

IV. DEVELOPMENT OF COMPUTER PROGRAMS FOR AUTOMATION OF CONTINGENCY ANALYSIS

This paper uses C++ Builder to develop a program to implement both the search algorithm and the preprocess interface. The function of this program includes the contingency selection and automatic simulations for PSS/E. Fig. 8 and Fig. 9 are pictures of this program.



○ 345 kV
● 161 kV

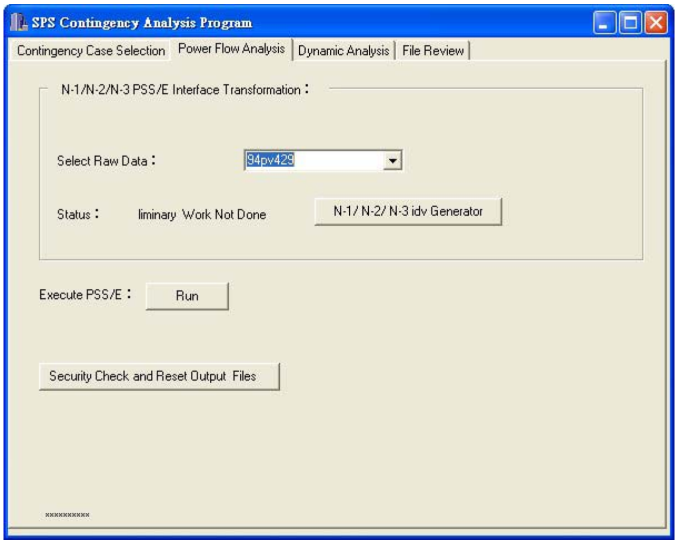
From BUS: 2001 OMEIH 161.0000 Bus Number : 2001

To BUS: 610 TUNSIOBH 161.0000 Bus Number : 610

Search Result : Search Complete

N-3 Contingency Cases Generator

Fig. 8. The picture of the function of the contingency selection



N-1/N-2/N-3 PSS/E Interface Transformation :

Select Raw Data : 94pv429

Status : liminary Work Not Done

Execute PSS/E :

xxxxxxxxxx

Fig. 9. The picture of the function of the contingency evaluation

V. SIMULATION RESULTS

The Hsinchu Science Park is a significant electronic industry area in Taiwan. SPS is considered a good solution for improving the power system reliability of this area. So this paper takes this area as an example to evaluate the performance of the automatic analysis program.

A. *Main trunk search*

Given the system raw data provided by TPC, the electric power of Hsinchu Science Park is mainly supplied by OMEI EHV substation and TUNSIO power plant. We define the area is under the power supply of OMEI EHV substation and take TUNSIO EHV substation as the study system for contingency analysis. This study system involves thirteen buses as shown by Fig. 10.

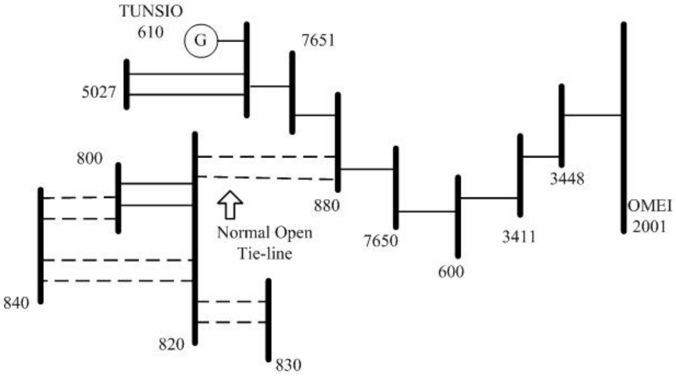


Fig. 10. Demonstration for the main trunk search process from bus OMEI to bus TUNSIO

B. *N-1 contingencies selection*

We found 31 N-1 contingencies by manual work but 47 by automatic search. What makes the difference of the search results between the manual work and the automatic search? By manual work, some less important cases will be ignored according to the experiences of the user. But the automatic search program does not consider other restriction conditions also not neglect the normal open transmission lines.

C. *N-2 contingencies selection*

We found 9 N-2 contingency cases by manual work but 18 by automatic search. From section two, we know there are two types in N-2 contingency selection principles. It is simple to find out type one of N-2 contingencies by manual work; though it is very difficult for type two. The user often overlooks cases for type two by manual work. On the contrary, the automatic search program can overcome such problems.

D. *Simulation performance evaluation*

The performance evaluation of the computer program has a great relation to the computer hardware used. The computer hardware used in this study is as follows.

The brand of CPU: AMD Athlon 64.

CPU frequency: 1.8GHz.

Memory size: 1G bits.

With the computer hardware mentioned above, the automatic analysis program can accomplish about 1183 cases for steady state power flow analysis per hour. During the simulation period of the steady state power flow analysis, the automatic analysis program can produce the result files of power flow analysis. The files depict whether the bus voltage, transmission line current and transformer loading go beyond the limit of related security criteria. The file production can decrease the simulation efficiency especially when the number of the simulation is massive. By evaluating the performance conservatively from the above information, the program can still accomplish at least 1000 cases even if the number of simulation is massive. If we run the simulation manually, at most 90 cases can be handled per hour. The user may feel tired that error increases when the simulation loading is heavy. If the contingency number required for simulation for a SPS is 240 thousands, 10 days is needed for just one computer to automatically accomplish the mass simulation but 111 days by labor work for one user without rest.

In this paper, the application of the searching algorithms has shown satisfactory results in contingency selection. Since a visited transmission line may be marked to prevent infinite searching in the searching mechanism [16], missing critical buses is possible especially for branches of a main path. For more discreet considerations, the searching program can be easily modified to meet any solid requirements, even though the basic searching function has acceptable performance already.

VI. CONCLUSIONS

Using SPS to overcome the disturbances triggered by contingencies for the maintenance the system integrity is a very common method in nowadays. There has been a large amount of operation experience for many years in the major power companies around the world. In Taiwan, there have been several SPSs installed for preventing blackouts. For event-based SPSs, some reasons, such as change of settings of power system facilities, change of load, seasonal electric power adjustments, joining of independent power plants (IPP), etc. can prompt the look-up tables to be updated. The complicated steps for making or updating the look-up tables tell the importance and necessity of automatic techniques for mass simulation. This paper has presented an automatic analysis program for helping design the look-up tables for event-based SPSs. The performance shows the program presented can enhance the contingency analysis process through automation, drastically reducing the cost time when manually carrying out part of the task, as well as improve performance by removing human error from part of the process.

VII. ACKNOWLEDGEMENT

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IX. BIOGRAPHIES

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