論 文
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기존 전산 프로그램 연계에 의한 신뢰도 제어 운전 지원을 위한 전문가 시스템

An Expert System for Operational Aids of Security Control by Incorporation with Conventional Program Packages

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요 약

전력 계통의 신뢰도 제어는 계통 운전 상태에 대한 안전성 평가와 이에 기초한 계통 운전 안전을 위한 제반 조치 및 제어를 하는 것이며 광범위한 분야를 포함한다. 계통의 운전상태는 통상 평상상태(normal state), 경계상태 (alert state), 비상상태(emergency state)로 구분하며 비상상태시에는 고장 파급 방지를 위한 제반 조치 즉 고장점 제거 및 과부하 해소 등의 대책이 필요하며 경계상태에서 계통의 위험요소를 항상파악하여 사고를 미연에 방지할 수 있도록 대책을 세우도록 한다. 그리고 평상상태에서는 일상적인 시나리오에 따라 위험요소 존재여부를 감시한다. 따라서 계통 신뢰도 제어에는 계통 상태 판정 또는 대책의 결정에 경험 지식의 적용이 상당한 효과를 거둘 수 있는 분야로 알려져 있다. 본 연구에서는 신뢰도 제어 관점에서 계통상태를 정성적 분석을 통하여 보편적으로 적용할 수 있는 경험율을 찾아내고 이에 적합한 지식 베이스를 구축함으로써 경험율을 효율적으로 이용할 수 있는 전문가 시스템을 개발하고 기존 전산 프로그램과의 연계 방안을 제시한다.

Abstract- The security control can be defined as all control actions and counter-measures to return the operating state of the system to a normal state. In an emergency state, fault clearing and/or overload suppression is enabled as a security control in order to prevent the extension of the fault. In the alert state, counter-measures should be set up in advance for the dangerous points of the system operation in order to protect the system from expected accidents. In the normal state, the routine scenario is conducted to analyze system state. In the decision-making of the classification of system states, the heuristic and experienced knowledge can be well applied and thus application of expert system to this area attains considerable achievements. In this study, it is attempted to extract empirical rules through heuristic analysis and establish the knowledge base. Finally, the incorporation method with the conventional program packages is proposed. The expert system is designed to select an appropriate method and to perform the corresponding package. The input data can be automatically set up by using the data base. The computation results can be automatically added to the data base.

1. Introduction

The increase of complexity and diversity in electric power system operation requires sophisticated and experienced operators in each minutely divided areas. Recently, much efforts have been paid to the development of expert systems which can take the place of the operating experts. [1, 2, 4-7] This study is aimed to establish an expert system which gives operational aids in the security control of power systems.

A system operator can be called as an expert when he has the following abilities ;

1) deductive analyisis and reasoning in problem-solving by using operating data for the previous cases similar to the present situation.
2) essential decision-making by the rough calculation and empirical judgment.
3) In a case where accurate calculation is required, selecting efficient calculation methods, performing the corresponding program packages and analyzing the results.

Many authors of recent papers have been devoted to the development of an expert system which can cover the first and second abilities. [2, 5] However, this study is focused on the covering of the third ability besides the first two for the utilization of computational tools. The operating states of system are usually classified into normal states, alert states and emergency states. [7]

The security control can be defined as all control actions and counter-measures to return the operating state of the system to a normal state. In an emergency state, fault clearing and/or overload suppression is enabled as an security control in order to prevent from extension of fault. In the alert state, counter-measures should be set up in advance for the dangerous points of the system operation in order to prevent from expected accidents. In the normal state, the routine scenario is conducted to analyze system state. In the decision making of the classification of system states, the heuristic and experienced knowledge can be well applied and thus application of expert system to this area attains considerable achievements[2, 5]

In this study, it is attempted to extract empirical rules through heuristic analysis and establish the knowledge base. Finally, the incorporation method with the conventional program package is proposed. The expert system is designed to select an appropriate method and perform the corresponding package. The input data can be automatically set up by using the data base. The computation results can be automatically added to the data base.

The proposed system is tested to the 14-bus IEEE sample systems and the results show the effectiveness of the expert system application.

2. Expert System for Security Control

The security control can be classified into two categories : security assessment and security control. The security assessment includes the on-line security monitoring and testing of the robustness of the system through the contingency analysis.

The security control includes the preventive control and restorative control. However, this study is restricted to only the security assessment since the security control deals with various topics.

2.1 Security Monitoring

Security monitoring is to detect the abnormal point of the system by testing the on-line data of the operating state of the system, which performs checking whether line flows exceed its capacity or whether bus voltages get out of normal range. The security monitoring can be easily implemented to the expert system since it requires simple upper and lower limit checking. If any of the line flows or bus voltages gets out of normal, then the alarm signal is issued with the line or bus number.

2.2 Robustness Test by Contingency Analysis

The Power System must Secure the Robustness to

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supply electricity without any trouble for the case of various contingencies such as line outages due to lightening, sudden generator outages etc. Consequently, the robustness test requires checking system state under each of various contingencies. Moreover, system state under a certain contingency must be evaluated by some computation tool or experience. Conventionally, the system state under contingency is evaluated by the computation program package, so called, contingency analysis program package. However, it requires excessive computation time due to too many possible contingencies. This study is aimed to extract heuristic rules to evaluate the system state under contingency. Implementing the heuristic rules can afford the expert system to save remarkable computation time. However, in case where the heuristic rules do not apply, it is necessary to incorporate with the computation software packages. In this syudy, it is attempted to develop an expert system which has the following functions;

1) evaluating the system state under contingency by heuristic rules.
2) incorporating with computation software packages if necessary.
3) determining the application boundary of heuristic rules by self-learning.

The incorporation with computation software packages can be accomplished by using an interface of the computation software package. The computation package interface performs the following functions.

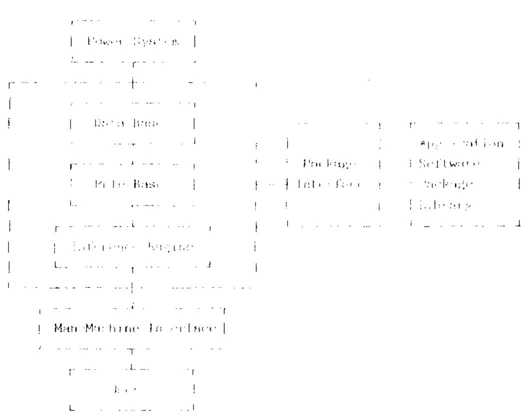

Fig. 1 Expert system configuration

- set up the input data file.
- access to the object module of computation package
- access to the output file .of computation package and updating data base.

This software interface can be simply designed with the software programming. The expert sytem configuration is given in Fig. 1.

3. Knowledge Base and Inference Engine

The core part of the expert system is the inference engine and knowledge base. In this stydy, an efficient data expression method is proposed to represent topological data of system configuration and system parameters, and it is attempted to extract effective heuristic rules.

3.1 Data Base

Data Base for the power system consists of operating state data, system parameters and topological data of system configuration with the on-off data of the circuit breakers. The data for system elements such as transmission lines, generators, loads etc. is represented by the form of frame. Each slot of the frame stores one attribution of the elements with an appropriate name. The element data frame has the following form.

element(Element Name, [data("Name", Value, Unit), data("Name", Value, Unit)]).

On the other hand, bus data can be represented by a set of attached elements, for which another form of frames is defined as a "component" frame. Each slot of the frame represents an attached element and its operation state.

component(Component Name, "bus type", [element list]).

Examples

```
element(line(3), [data("bus_to_bus", 1, 3,_),
          data("impedance", 0.014, 0.058,
          "pu"),
          data("Yc", 0.0, 0.00084, "pu"]),
  element (generator(2), [data("Terminal_
          Voltage", 1.05, , "pu")]
          data("output_power", 150.0,_, "MW")
```

data("Max. output", 200.0, , "MW")])

component(Bus(5), "Generator Bus", [line(1), Line(2), generator(5)])

With use of the element and component, the system or subsystem of network can be simply represented by the following system frame.

system("system name", [element or component list])

Example

system("whole system", [bus(1), bus(2), bus(3), bus(4), line(8), line(10)])

3. 2 Rule Base

In the security control, it is required to test the robustness of the system against possible contingencies. In this study, several heuristic rules for the robustness test are suggested.

Suppose all bus voltages are within the allowable tolerance and the total load of the system is less than the specified load, say, 50% of the total generation capacity. Then, the system maintains the robustness for the all possible contingencies unless the distribution of load is severely biased.

Rule 1

conditions ;

1) Are all bus voltages within the allowable tolerance?

2) Are all loading factors of lines less than some specified value, say, 50% ?

3) Is the total load of the system less than 50% of total system generation capacity ?

clauses : If all the above conditions are satisfied, the system is robust against all contingencies.

Consider the line flows around a bus as shown in Fig. 2. If one of the four lines has specially great flow, the following rule can be applied for the robustness test.

Rule 2

Condition ;

$$Pk > \sum_{\substack{i=1 \\ i \neq k}}^{4} (Pri - Pi) + (P_{GI}^{max} - P_G)$$

$(k=1, 2, 3, 4)$

where Pri, Pi ; line capacity and line flow for line i

P_{GI}^{max} P_G ; generator capacity and output

clause ; If the condition does not hold for any k, then the system is weak or vulnerable for the contingency outage of line k

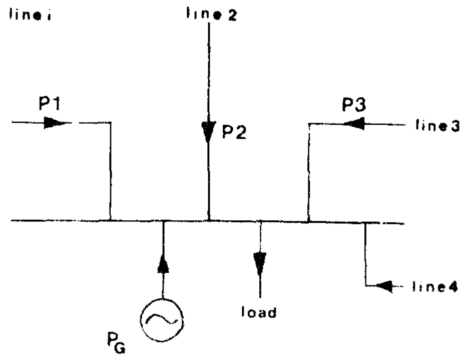

Fig. 2 Line flow scheme

For a certain line outage contingency, the line flows can be roughly evaluated by the assumption of proportional changes.

Consider the contingency outage at line 3 in Fig. 2. The simplest counter-measure against this outage is to cover the line flow $P3$ by increasing the generator output if possible. If it fails, then we have to consider line flow changes in other 3 lines. These line flows can be roughly evaluated with the proportional change assumption ;

$$\Delta Pe1 = [P3 - (P_G^{max} - P_G)] \times \frac{P1}{P1+P2+P4}$$

$$Pe'1 = P1 + \Delta Pe1$$

$$\Delta Pe2 = [P3 - (P_G^{max} - P_G)] \times \frac{P2}{P1+P2+P4}$$

$$Pe'2 = P2 + \Delta Pe2$$

$$\Delta Pe4 = [P3 - (P_G^{max} - P_G)] \times \frac{P4}{P1+P2+P4}$$

$$Pe'4 = P4 + \Delta Pe4$$

Then, the system robustness test can be performed with the use of the above roughly evaluated line flows. Hower, the errors involved in the rough calculation must be taken into account in decision-making. This can be done with the introduction of marginal factors α and β, and the robustness is checked as follows;

Rule 3

If $\Delta Pek \geq \alpha[Prk - Pk]$, then line k is vulnerable for the contingency under consideration, or contingency outage of line 3 in Fig. 2 ($\alpha \geq 1.0$).

Rule 4

If $\Delta Pek \leq \beta[Prk - Pk]$, then line k is robust against the contingency under consideration ($0 \leq \beta \leq 1.0$).

The marginal factors should be determined by the statistics. If they are chosen with sufficient margin, then the reliability of the rules is increased, but the number of cases for which the rules are not applied is also increased, and vice versa. In this study, a learning system is introduced to attempted to determine these marginal factors with the initial learning set.

On the other hand, the above rules do not apply if the rough calculation ΔPek holds that

$$\beta(Prk - Pk) < \Delta P_{ek} < \alpha(Prk - Pk)$$

In this case, it is necessary to calculate accurate power flows of line k in order to test the vulnerability of line k, which requires the incorporation with computation software package.

4. Incorporation with the Computation Software Package

The languages for the expert system are developd for the treatment of letter information, while they are not suitable for computation purposes. Consequently, it is necessary for the expert system to incorporate with the conventional software packages for computation. The expert system has a function to perform an object module program if provided, for example, function "system" in prolog. In this study, an incorporation interface with computation packages is developed with the use of file management techniques. The incorporation interface has the following functions; establishing data base for input data form of software packages, setting up input data files and updating of expert system data base.

4.1 Data Base of Software Input Data Form

By analyzing the computation software package, the expert system is provided with the input data and the corresponding format and then it establishes data base of input data form with the use of the ordered list expression.

4.2 Setting Up of Input Data File

This function is supported by the data searching and the writting_ in_ file functions. Both functions are implemented with the corresponding rule base. The data searching function searches required data and format among the whole space of expert data base. If the data and format are found, the writting_ in_ file function writes the data in the input file in accordance with the corresponding format.

4.3 Execution of Software Package

The expert system gets directly access to the object module of the software package and the input data file and executes the program. The computation results are stored in the output file.

4.4 Updating of Expert System Data Base

Expert system gets access to the output file and searches available data to update the data base with the use of data searching rules and updating rules.

In this study, the line flow calculation, when accurate calculation required, is performed with the incorporation with the contingency analysis program package written in FORTRAN.

5. Test Result

An expert system is established for the power system security control on the basis of the above discussions, and tested for the IEEE 14-bus sample system, shown in Fig. 3.

In order to test the proposed heuristic rules, the results by heuristic rules are compared with those by accurate calculation. The rough calculation of line flows is tested for various contingency cases.

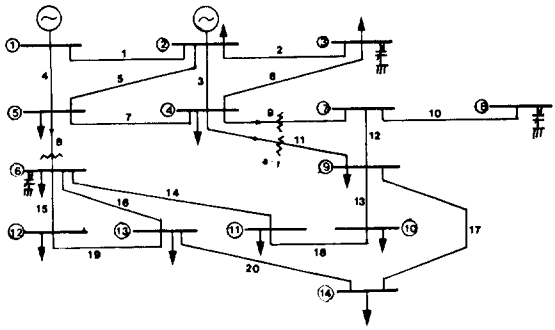

Fig. 3 IEEE 14-bus sample system

Table 1 Test results with the use of proportional change

Contingency line outage		application line		rate line power	Rough Calculation	Load Flow	normal line flow
5	4	1	5	1.271	0.452	0.563	0.748
		2	4	0.955	0.845	0.895	0.563
		2	5	0.703	0.25	0.123	0.414
		4	3	0.394	0.116	0.080	0.232
		4	7	0.476	0.139	0.183	0.280
		4	9	0.268	0.079	0.104	0.158
		5	6	0.681	0.56	0.552	0.401
4	9	2	4	0.955	0.510	0.556	0.563
		4	3	0.394	0.254	0.235	0.232
		4	7	0.476	0.306	0.384	0.280
		5	4	1.052	0.561	0.570	0.619
		7	9	0.486	0.390	0.394	0.287
		9	10	0.096	0.037	0.023	0.057
		9	14	0.166	0.063	0.077	0.099
6	11	5	6	0.115	0.359	0.363	0.401
		6	12	0.129	0.085	0.082	0.076
		6	13	0.295	0.193	0.196	0.174
		11	10	0.054	-0.036	-0.035	0.033
9	14	4	9	0.268	0.128	0.144	0.158
		7	9	0.486	0.231	0.260	0.287
		9	10	0.096	0.069	0.115	0.057
		13	14	0.089	0.151	0.153	0.052
12	13	6	12	0.129	0.062	0.061	0.074
		6	13	0.295	0.186	0.187	0.174
		13	14	0.088	0.049	0.050	0.052

Table 2 Robustness test for different operating conditions.
No. of test cases = 84
A = No. of correct decision
B = No. of incorrect decision
C = No. of unapplicable cases

normal line power / rate line power		50 %			60 %			85 %		
α	β	A	B	C	A	B	C	A	B	C
1.2	0.8	76	3	5	71	8	5	39	33	12
	0.7	74	2	8	63	7	14	37	32	15
	0.6	73	2	9	58	7	19	31	31	22
	0.5	64	2	18	52	7	25	27	30	27
1.3	0.8	76	3	5	71	8	5	37	31	16
	0.7	74	2	8	63	7	14	35	30	19
	0.6	73	2	9	58	7	19	29	29	26
	0.5	64	2	18	52	7	25	25	28	31
1.4	0.8	76	3	5	70	5	9	34	27	23
	0.7	74	2	8	62	4	18	32	26	26
	0.6	73	2	9	57	4	23	26	25	33
	0.5	64	2	18	51	4	29	22	24	38
1.5	0.8	76	3	5	70	4	10	34	27	23
	0.7	74	2	8	62	3	19	32	26	26
	0.6	73	2	9	57	3	24	26	25	33
	0.5	64	2	18	51	3	30	22	24	38
2.0	0.8	74	3	7	70	4	10	31	24	29
	0.7	72	2	10	62	3	13	29	23	32
	0.6	71	2	11	57	3	24	23	22	39
	0.5	62	2	20	51	3	30	13	21	44
3.0	0.8	73	3	8	68	4	12	25	16	43
	0.7	71	2	11	60	3	21	23	15	46
	0.6	70	2	12	55	3	26	17	14	53
	0.5	61	2	21	49	3	32	13	13	58

Typical samples of test results are listed in Table 1. The line flow is tested for the adjacent lines to the contingency line, since the flows of these lines can be severely affected by the contingency. This result shows that the rough calculation with the use of proportional change assumption can provide with useful information for the robustness test of system against contingencies. However, considerable errors can be efficiently covered by using the marginal factors α and β.

Table 2 shows the results of the system robustness test for different operating conditions with various marginal factors. Here it is noted that the reliability of the test can be increased by taking greater α and smaller β. However, the number of unapplicable cases rapidly increases. Consequently, the marginal factors must be selected to make compromise between reliability and applicability. On the other hand, the operating condition of system should be taken into consideration. In this study, a self-learning system is under research to determine the maginal factors.

6. Conclusions

This study proposed an expert system for the security control of the power system with the extraction of heuristic rules and the incorporation method with computation software packages. The developed expert system is tested for the 14-bus sample systems, the results of which show the applicability and effectiveness of expert system application to the power system security control. The features of the proposed expert system are follows :

a) A systematical data expression method is proposed for easy handling of the topological data of system configuration.

b) Heuristic rules are extracted in the practical operational sense, which can afford to save remarkable computation time in the system robustness test.

c) An efficient method is proposed to incorporate the expert system with the computation software packages.

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