APPLICATION OF THE EXPERT SYSTEM FOR THE SELECTION OF CAPACITOR FUSES

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Summary: An expert system application is tried to design shunt capacitor banks in order to correct power factor and to select line fuses for the capacitor bank protection. The programming language of the expert system is the PROLOG, and it runs on the personal computer. It is shown that the expert system aids and is useful to design shunt capacitor banks and to select line fuses quite well.

1. Introduction

The power factor improved by shunt capacitors connected in parallel with electrical distribution lines reduces the size of each components in distribution system, so that electric utilities in our country provide to reduce the rate of customer charge and urge for consumers to install capacitor banks at their electrical receiving system.

The combinations of a load-breaking switch and a current limiting fuse (clf) are often installed in sereis to control and protect capacitor bank curcuit.

Clfs applying to line fuses provide backup protection against ruptures of shunt capacitor tanks.

This paper reports the application of expert system to design shunt capacitor banks and to select applicable line fuses to the shunt capacitor banks installed at consumer's electrical receiving-end.

The commercial expert system tool that belongs to DECsystem-10 PROLOG is used for expert system construction. The programming language of the expert system is the Prolog, and the system is used on the personal computer which has 640kB memory capacity. It is recognized that the expert system aids to design shunt capacitor banks and to select suitable line fuses quite well within short executive time.

2. The Expert System in Prolog

Prolog programming consists of three types of clauses of facts, rules and questions. Facts called data express the objects and their relationships and always unconditionally true. Rules express true relationships between facts depending upon a given condition. Question looks like a expression of fact, except the special symbol of a question mark and a hyphon, gives answers of Prolog that consists of a set of objects satisfying the questions. A question except a question mark and a hyphon is called a goal.

Informations in an expet system can take the form of facts and rules. Facts and rules are contained as the knowledge base in an expert system, the expert system uses these facts and rules as the basis for decision making.

2.1 Knowledge Acquisition

The knowledge base which is the collection of domain knowledges is acquired from a domain expert who solves more efficiently problems in a particular field. It may also get expertise from various sources as stating later.

2.2 Inference Execution

Each clause of rule consists of a head and a body. They are connected by the symbol ":-". The clause of a rule has the form as follows

```
conclusion:-condition_1,condition_2,
        ...,condition_n.              (1)
```

A set of conditions on the right-hand side of the rule is the body of a clause, can be tested for their truth value. The conclusion on the left-hand side of the rule is the head of a clause is true if its conditions can be proved true. Each term of above clause(1) is called a predicate.
A condition is compared with the conclusions of the stored clauses. When it finds a match, it tries to prove the goal by considering the conditions of the matched conclusion as subgoals. When all subgoals are shown to be true, the goal itself is proved.
These inference proceedings are rigidly controlled by the interpreter, which has the principal mechanims of backtrack, pattern matching called unification, syllogistic inference and a scheduler.

3. Data Base Representation

The main data structures of this expert system can be represented in the form of list structures. The values of elements of a list are mostly obtained by the manufacture's catalogues. The list is an ordered sequence of

```
rating_lf(pt_t_uco_1,[rated_volt('7.2'),
  rated_current(3),
  rated_breaking_current(63),
  reted_min_breaking_crrnt(27),
  fusing_current_7200s(28),
  fusing_current_60s(29),
  fusing_current_100ms(71),
  fusing_current_2ms(1800),
  breaking_current_13ms(342)]).
```

Fig.1 An example of data for a line fuse

elements of capacitors and clfs data, so that facts are organized to be able to get necessary informations on relations between data.
As shown in fig.1, in the example of this data structure, rating_lf is the name of data kind, pt_t_uco_1 is the name of data, the elements in the list are names of ratings and of fusing and breaking charateritics about a clf, the value in each parentheses of elements is the voltage or current value of ratings and of fusing and breaking charateritics.

4. Rule Base Representation

Knowledge in this expert system originates from many sources, such as electrical regulations, research papers, case studies, reports, manufacture's manuals, empirical data, books, and domain expert experiences. Knowledges that includes procedures, intuitive method and strategeies for problem solving are necessary for the expert system to build into a computer program.

4.1 Rule Base of Design Capacitor Bank

One of necessary informations for the design of shunt capacitor bank is total capacity of the capacitor bank in full load at the consumer's receiving-end. And other required informations are original and desired improving power factor. The total capacity of capacitor bank is calculated by using the following well known formula

$$Q = P\{\sqrt{(100/Pf\_b)^2 - 1} - \sqrt{(100/Pf\_a)^2 - 1}\} \quad (2)$$

where
Q = total capacity of the capacitor bank (kVA)
P = consumer's recieving power capacity (kW)
Pf_b = original receiving-end power factor at full load (%)
Pf_a = desired improving receiving-end power factor at full load (%).

P, Pf_b and Pf_a are not provided as data base in the expert systen, so that the expert system asks for the user to supply these informations. The values of P, Pf_b and Pf_a are input to the running expert system from the computer terminal.

When the receiving power is greater than 500kVA, the total capacity of capacitor bank is divided into a few banks in practice, so that the necessary capacity of capacitor bank is timely ajusted to meet the changing demand of reactive power as close as possible. In our country, individual divbided capacitor bank is usually used in a series reactor, the capacity of series reactor is 6% of the capacity of the individual capacitor.

The devided capacitor bank and its series reactor are selected from the manufacturer's cataloged capacity to meet just or just over the calculated capacity.

4.2 Rule Base of Selection CLFs

The applicable clf to capacitor curcuit is selected from one of clfs passed all selecting rules with aim of short circuit protection of capacitor banks and series reactors.

Selecting rules are as follows,

(1) the rated voltage Vr of clf equals or is larger than the circuit voltage Vl_1, and Vr is equals or smaller than the voltage of 1.2 times Vl_1.

$$Vl\_1 \leqq Vr \leqq 1.2 \times Vl\_1 \quad (3)$$

(2) the rated frequency of clf equals the circuit frequency.

(3) the clf is able to carry the current of 1.5 times the circuit full load current, that is, the rated current of clf Inf is greater than the current of 1.5 times the capacitor rated current or capacitor curcuit current Inc.

$$1.5 \times Inc \leqq Inf \quad (4)$$

(4) the rated breaking current of clf Il is greater than the short circuit current Is.

$$Is < Il \quad (5)$$

(5) the overcurrent of the circuit to be less than the minimum breaking current of clf Imb is breaked by the series switchgear such as load breaking switch. That is, an intersection point of the operating time-current characteristics of clf and the series switchgear is greater than the minimum breaking current of clf.

$$Imb < If \text{ and } If = Is \text{ at } Tf=Ts \quad (6)$$

(6) the minimum pre-arcing current of clf Immf is greater than the current of 2 times the curcuit current.

$$2 \times Inc < Immf \quad (7)$$

(7) the current of 10 times the curcuit current is greater than the 60s pre-arcing current of clf If_60.

$$10 \times Inc > If\_60 \quad (8)$$

(8_1) in the case of no series reactor, clf does not melt by flowing the over current of 70 times the curcuit crrent during 2ms and can repeat it 100 times. That is, the over current is smaller than the current of S-factor times the 2ms pre-arcing current.

$$70 \times Inc < S \times If\_2m \quad (9)$$

(8_2) in the case of installation of series reactor, clf does not melt by flowing the current of 5 times the curcuit crrent during 100ms and repeating it 100 times. the over current is smaller than the current of S-factor times the 100ms pre-arcing current.

$$5 \times Inc < S \times If\_0.1 \quad (10)$$

(9) the maximum Juele-integral of 10% breaking probability of capacitor bank during 13ms is greater than the maximum Juele-integral of 13ms operating current of clf.

$$(If\_13m)^2 < (Ic\_13m)^2 \quad (11)$$

If_13m is operating current of clf at 13ms, Ic_13m is current on the characteristics of 10% breaking probability of capacitor at 13ms.

(10) operating time-current characteristics of clf is under 10% breaking probability characteristics of capacitor bank.

$$Ifi < Ici \text{ at } Tfi = Tci \quad (12)$$

Tfi, Ifi are time and current of the clf at the 'i'th point on the operating time-current characteristics of clf, Tci, Ici are time and current of the capacitor at the 'i'th point on the 10% breaking probability characteristics of capacitor.

Rule (1) is expressed in a program as shown in fig.2. When a capacitor rated voltage Vnc and a clf rated voltage are given, the condition of 'float' calculates $Vnc\_12 = 1.2 \times Vnc$, next condition of 'ge' decides $Vnc \leqq Vnf$, and the last condition decides $Vnf \leqq 1.2 \times Vnc$. If every condition is true, the conclusion is true.

```
rated_voltage_clf(Vnc,Vcf):-
   float(*,'1.2',Vnc,Vnc_12),ge(Vnf,Vnc),
   ge(Vnc_12,Vnf).
```

Fig.2 A program of rule(1) of the clf selecting rules.

5. Support Facilities

In the expert system, general problem-solving knowledge is organized by separation from the knowledge about the problem domain.

5.1 Data Base Processing

The data base processing is composed of capacitor data base processing and clf data base processing. After menu selection, the data base processing asks for the user to input pertinent data in conversing with the expert system and stores data in the data base base during the expert system executing. Other data base manipulations are executed by the editor and thebuilt-in clauses in Prolog.

5.2 Explanation of Results

Explanation facility explains how the system arrived at its conclusions or answers. Users tend to have more faith in the results, more confidence in the system by the explanation of process getting at its answer.

The successful way leading to the conclusion is explained after the complation of clf selection. The expert system indicates the specified conditions of power factor correcting curcuit and the designed capacitor bank. The comparison is displayed between the specified selecting rules of clf and the characteristics of selected clf, then time-current characteristic is displayed between the clf and the capacitor bank on graph or by the values.

5.3 Support Facilities of Tool

Main components of this expert system support environment are knowledge base debugging aids, input/output facilities and knowledge base editor. This expert system tool has usual facilities such as normal display, windows, a mouse pointing device and manipulating fundamental mathematical formula. The editor of expert system tool includes lots of predicates of various functions and common programming languages such as writing, reading, displaying, delating, copying, etc.

6. An Example of the Expert System Execution

As shown in fig.3(a), the expert system may start after inputting quesion of goal 'run.' in the interpreter. Information under ▒ means user input.

The user selects next processing from the contents of menu as shown in fig.3(b). Here user selects item 3 for design a capacitor bank circuit and selection clfs to achieve the power-factor correction for a system.

The running expert system communicates with the user and asks for the user to input the suitable informations about capacitor banks circuit design and switching controllers of capacitor bank.

After the user inputs the required information as shown in fig.4, the expert system shows the

|?-run.

(a) the expert system starts running

1 data base processing of clfs
2 data base processing of capacitors
3 design of capacitor banks curcuit
and selection of clfs
4 finish

(b) processing menu

Fig.3 The expert system starts running and the processing menu

Input according to the following request;
Circuit voltage(kV) = 6.6
Consumer's recieving power capacity (kVA) = 1500
Original receiving-end power factor at full load(%) = 75
Desired improving receiving-end power factor at full load(%) = 95

Fig.4 An example of system requests for capacitor banks

given data about capacitor bank circuit and calculated results on the display.

Afterwards the expert system arrives at the conclusion of capacitor bank circuit design as shown in table 1.

Next, the system goes to the selection of applicable clf to the above designed capacitor curcuit by the user picking the item of selection clf processing from the second menu omitted as next action.

The capacities of capacitor bank and reactor are shown about the object selected from the designed capacitor bank as shown in table 1. The method of selection clf executes the elimination of the clf data base which does not meet each step of the selecting rule as shown in fig.5(a). The passed data names are shown on the display.

During the executing, the user gives appropriate informations such as short circuit current of capacitor bank circuit, breaking capacity of load-switch, S-factor of clfs for the requirement of the expert sysem. The expert system decides the clfs which passed the all selecting rule to be applicable as shown in fig.5(b). After the selection of clf is completed, the expert system shows data for the selected capacitor bank and clf on the display.

As final process, the expert system goes to

Table 1 Number of divided bank, calculated one capacitor bank capacity, designed capacitor bank capacity and series reactor capacity to design number

design number	number of dividing	calculated capacity(kVA)	recommending capacity(kVA)	reactor capacity(kVA)
1	6	138.0	150	9.0
2	5	166.0	200	12.0
3	4	207.0	250	15.0
4	3	277.0	300	18.0
5	2	415.0	500	30.0
6	1	830.0	1000	60.0

the indication of the comparison between the specified conditions of power factor correcting curcuit and the designed one capacitor bank and its circuit. The

[data passed 1st rule] pt_t_uco_1, pt_t_uco_2, pt_t_uco_3, pt_t_uco_4, pt_t_uco_5, pt_t_uco_6, pt_t_uco_7, [data passed 3rd rule] pt_t_uco_4, pt_t_uco_5, pt_t_uco_6, pt_t_uco_7,

(a) data names of clfs passed 1st, 3rd rule

[data passed 9th rule] pt_t_uco_4, pt_t_uco_5,

(b) clfs passed all rules

Fig.5 Selecting execution of clf

confirmation of appropriate clf selection is the comparison between the all specified selecting rules of clf and the characteristics of selected clf, then operating time-current characteristic curve of the clf between 10% breaking probability characteristics of the capacitor bank on graph or by the values.
Lastly, the user picks the next action or the finish processing. We obtained the selected clf to agree entirely with the manufacture's data.

7. Conclusion

It was proved that the developed expert system aided electrical designing engineer in his designing job of pawer-factor correcting circuit.
The developed expert system is quite simple and remains many problems to improve its performing better, but we can suggest that the developed expert system is available and useful for diagnosis of distribution circuits.
The tool was chosen because it was efficient one available that ran on our personal computer.

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