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Study of Permanent Magnet Direct Current Motor Design Expert System

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Abstract. In this paper, to apply the expert system technology to the design of permanent magnet direct current motor design, a novel expression form for rules, which is easy to read and use, and the corresponding grammar of knowledge base is defined firstly. Secondly, the inference mechanism is developed. Thirdly, to improve the design efficiency, a new kind of control strategy for regulating design, i.e. the best regulation control strategy, is proposed. Finally, the permanent magnet direct current motor design expert system is developed.

Keywords: electrical machine, expert system, the best regulation control strategy

1. Introduction

In order to develop the electrical machine design expert system (EMDES) quickly, most of the existing EMDES adopt artificial intelligence language, such as Lisp, Turbo Prolog, and etc., since in this case there is no need to develop the inference mechanism. However, the form of rules expressed by Lisp is very complicated, and that expressed by Turbo Prolog can not separate the knowledge base and inference mechanism although it is easier to read.

The design of electrical machines is a process in which the knowledge of regulation is used to change the design from the initial state to the final state according to performance requirements. If the design and the regulation of design correspond to the nodes and the extension of nodes in graph theory respectively, the design process of electrical machines is a problem of searching the object node in graph theory. To speak strictly, the feasible design can be found only if all the nodes have been searched before the feasible design are found. Since the search space is large, this method can not meet the requirements of the EMDES for its lower efficiency. To improve the search efficiency, the existing EMDES adopt heuristic search methods in which the meta-knowledge control strategy (MKCS) is the most widely used. This strategy improves the design efficiency by extending the nodes at the more promising direction according to the information of current design and expertise of electrical machine design, but it has the following shortcomings. One is that the existed feasible design may not be found because the search space is reduced artificially. The other is that the regulation of design is not towards the most promising direction since the knowledge is not fully utilized.

To solve the above problems, following investigations have been done in this paper. A kind of expression form of rules which is easy to read and use, the structure of corresponding knowledge-base and inference mechanism are developed. The best control strategy is proposed which selects the most promising method for the extension of new nodes after the evaluation of all possible extension method, thus the object design can be found in the shortest path. Based on the studies above, an EMDES for permanent magnet direct current motor is developed, and the design results testify the validity of the proposed methods.

2. The Knowledge-based System

2.1. Expression form of rules

Unlike the expression form of rules in the expert system with Lisp and Turbo Prolog, a new expression form of rules is defined in this paper which is not dependent on any AI language.

The expression form of rules is

IF $W_1(x)$

Then $W_2(x)$

2.2. Structure of knowledge-base

Knowledge-base consists of rule base and parameter base. Parameter base is collection of the name and data type of all the variables in the rule base which contains multiple rule groups categorized by problem domain. As the rule base is large, it is divided into several independent rule files, and each file includes one or more rule groups, each of which contains one or more rules.

The frame structure is adopted to administrate the rule-base. The name of the first-class frame is the rule-base, while its slot values are the second-class frame. The name of the second-class frame is the rule file, while its slot values are the third-class frame. The name of the third-class frame is the number of rule-group, while its slot values are the forth-class frame. The name of the forth-class frame is the number of rules, while its slot values are the rules. In inference process, the inference mechanism determines which frame is to be called and finds the suitable rules according to the current status of the design.

2.3. Grammatical rules of knowledge-base

The grammatical rules of knowledge base are defined for the inference mechanism to utilize the knowledge base conveniently. The extension name of the rule-base file is "KB", while that of the parameter-base file is PAM. The grammatical rules of knowledge-base are as follows.

(1) The definition of parameter and parameter group

The parameter group, which is in the form of data-file, is used to define the name and data type of the parameter. Its construction is as follows.

PARM1.name, PARM1.type

PARM2.name, PARM2.type

……

end

The definition sequence of parameter corresponds to that of the parameter in the input and output files of the performance calculation program. The last statement of parameter group is "end".

(2)The definition of rule-base

(a)Definition of rule-group

The format of rule-group is " rulegroup: number".

It is used to declare the sequence of the rule-group in rule-file, i.e., the name of the rule-group.

(b)Definition of rule-name

The format of rule-name is "rule: number".

It is used to declare the sequence of the rule in rule-group, i.e., the name of the rule.

(c)Definition of rule

The format of rule is :

if $premise_1, premis_2, \ldots\ldots, premise_m$

then $action_1, action_2, \ldots\ldots, action_n$

where $premise_i$ is the i*th* premise, and the relationship between premises is "and"; $action_j$ is the j*th* action.

(d)Call Statement of Executable file

It is uesd to call the executable files, for example:

if $x<y$

then system("input.dat", "*a, b, c*", "modu", "out.dat", "*e, f*")

The meaning of statement "*system*" is that the value of parameters *a*, *b*, *c* will be written into the data file from the dynamic data base and then the executable file *modu.exe* will be called which inputs the data needed in the calculation from *input.dat* and writes the output data "*e*", "*f*" into the data file *out.dat* after the calculation. At last, "*e*", "*f*" will be sent to the dynamic data base from *out.dat*.

(e)End Statement

The format of end statement is : end

3. Inference mechanism

The developed inference submodule is a function, which can be called by other program, and its input parameters are rule names and rule sequence numbers. When the function is called, inference mechanism will inference according to the rules of the given rule group in the given rule file.

4. The best regulation control strategy

4.1. The best regulation control strategy

In the best regulation control strategy (BRCS), heuristic information is expressed by valuation function *f(n),* which is the sum of *g(n)* and *h(n)*. *g(n)* is the most promising value of getting from the initial node to the current node, while *h(n)* is that of getting from the current node to the goal node, so that it is the promising value of the shortest path through the current node. Firstly we calculate the valuation function of current nodes to be extended, among which we find the node with the maximum function value. By extending from this node, i.e. the most promising node, the searching process will be led to the goal state more quickly. Instead of extending from all the paths before estimation, BRCS estimates the promising values of the paths to be extended, and extends from the path with maximum promising value. The detailed content of BRCS is as follows.

(1) Set the searching graph G which includes only the initial node *s*. Put node *s* to the OPEN list which includes the nodes to be extended.

(2) Set the CLOSED list which includes the nodes which have already been extended. The initial state of CLOSED list is empty.

(3) if OPEN is empty, quit.

(4) Select the first node in OPEN list and put it in CLOSED list. It is assumed to be node *n*.

(5) If node *n* is the goal node, the solution exists and quit.

(6) Estimate the promising value of all the paths for node *n* to be extended. Extend node *n* on the most promising path and obtain the follow-up node *m*. Put node *m* to graph G.

(7) Set a pointer from *m* to *n*. Put *m* to OPEN list.

(8) Go to step 3.

In electrical machine design, there are many regulation methods. In this paper, all the feasible regulation methods are evaluated according to the expertise knowledge using fuzzy evaluation theory, and evaluation value of all the methods are obtained. The sum of evaluation value and regulation depth is evaluation function *f(n)*.

$$f(n)=h(n)+g(n)=-d(n)+w(n) \quad (1)$$

where *d(n)* is the regulation depth and *w(n)* is the evaluation value of regulation method. The new design obtained after regulating with the maximum evaluation value is the most promising design. It should be noted that sometimes there is only one regulation method with the maximum evaluation value, but sometime there are several ones, that is to say that more than one new design may exist with the same adjusting depth.

4.2. Evaluation of regulation methods

There are many manifestations for the unqualified electrical machine design, such as that efficiency and speed can not meet the requirements. All the manifestations of design compose the fault set, while all the feasible regulation methods of design compose the method set. According to performance calculation, comprehensive evaluation is performed on the possibility of all the regulation method in the method set to regulate the current unqualified design, from which the method with the maximum possibility is selected to regulate the current design.

(1) The fault set

Fault set includes all the manifestations of unqualified design, and it can be expressed in matrix form:

$$U=\{u_1,u_2,\cdots\cdots, u_n\} \quad (2)$$

where u_i corresponds to the *ith* fault, and value of u_i is the state of the corresponding fault in current design. The conventional determination of u_i is that if the *ith* fault appears the value of u_i is 1, otherwise it is zero. Although this approach is widely used in the fuzzy comprehensive evaluation, it has significant disadvantage that it only shows if the corresponding fault exists or not. In fact, when the fault exists, the corresponding parameter may not be the same, so is the regulation method. To solve this problem, the concept of membership degree is introduced in this paper based on the method of fuzzy set theory. In EMDES, membership degree indicates the degree for the existing of corresponding fault. The value of membership degree is between 0 and 1. If corresponding fault does not exist, the value is 0. The bigger membership degree is, the larger the deviation of corresponding performance or parameter from the allowable range is.

In electrical machine design, the constraints of performances or parameters can be divided into three categories, i.e. $x>a_1$, $x<a_2$ and $a_1<x<a_2$. The value of u_i is the value of fuzzy evaluation function for the corresponding performances. The expression form of fuzzy evaluation function varies with the constraint form. For the sake of simplicity, the third category of constraint is converted to $x>a_1$ and $x<a_2$, i.e. the combination of the first and second category constraint. The expression forms of fuzzy evaluation function for the two constraints are as follows.

(a)The fault of $x>a_2$

For the fault of $x>a_2$, the corresponding fuzzy evaluation function is sigmoid-right distribution function, and the expression is

$$\mu(x)=\begin{cases} 0 \ (x \le a_2) \\ \frac{1}{2}+\frac{1}{2}\sin\frac{\pi}{a_2'-a_2}(x-\frac{a_2+a_2'}{2}) \ (a_2 < x \le a_2') \\ 1 \ (x > a_2') \end{cases} \quad (3)$$

where the values of a_2 and a_2' depend on the characteristics of corresponding performance.

(b)The fault of $x<a_1$

For the fault of $x<a_1$, the corresponding fuzzy evaluation function is sigmoid-left distribution, and the expression is

$$\mu(x)=\begin{cases} 1 \ (x \le a_1') \\ \frac{1}{2}+\frac{1}{2}\sin\frac{\pi}{a_1'-a_1}(x-\frac{a_1+a_1'}{2}) \ (a_1' < x \le a_1) \\ 0 \ (x > a_1) \end{cases} \quad (4)$$

where the value of a_1 and a_1' depend on the characteristics of corresponding performance.

Fuzzy evaluation function is a part of knowledge base, from which inference mechanism infers to acquire the value of u_i.

(2) Determination of the weight set

Each element of fault set has different effects on the evaluation result. According to the importance of each element, the weight set is established with corresponding weight for each element.

$$C=\{c_1, c_2, \cdots\cdots, c_n\} \quad (5)$$

The determination criterion of weight is that the higher weight will be assigned to the element which has greater influence on the subsequent regulation. In EMDES, the operation point of permanent magnet, current density and pole-arc coefficient have great effects on the design, so they will be given higher weights.

(3)Method Set

Method set includes all the regulation methods for the design of permanent magnet dc motors.

$$V=\{v_1,v_2,...,v_m\} \quad (6)$$

(4)Fuzzy Comprehensive Evaluation

All the regulation methods are evaluated according to the *ith* fault. If only the *ith* fault exists, the promising value of all the regulation methods compose the matrix R_i'.

$$R_i'=\{r_{i1}',r_{i2}',\ldots,r_{im}'\} \tag{7}$$

where the promising value r_{ij}' of the j*th* regulation method is acquired by the inference on the evaluation knowledge-base. Considering the state of fault, the evaluation matrix is

$$R_i=R_i'\cdot u_i=\{r_{i1},r_{i2},\ldots,r_{im}\} \tag{8}$$

After evaluating all the faults, fuzzy comprehensive evaluation matrix R is obtained.

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \tag{9}$$

Combined with weight set, the evaluation result is as follows:

$$B=C\cdot R=\{b_1,b_2,\ldots,b_n\} \quad)$$

where b_j corresponds to the j*th* regulation method and is selected as the promising value of current regulation method.

5. Expert system for permanent magnet dc motors

Based on above studies, two expert systems on the basis of the MKCS and BRCS are developed respectively. With the two expert systems above, a permanent magnet dc motor is designed, and the design results are shown in Table 1.

The expert system for permanent magnet dc motors with BRCS has more human-like decision style than that of MKCS. In expert system with BRCS, the time to generate the feasible solution is shorter than that of MKCS because of the more reasonable regulation method.

It can be seen that the permanent magnet dc motor design expert system based on BRCS adopts the most promising regulation method to decrease the time of analysis and calculation, so that the design will be led to the goal state more quickly.

Table 1. Design results

Configuration parameter	Efficiency (%)	Rated speed (r/min)	Change rate of speed (%)	EMF of commutation (V)	Times of regulation
MKCS	86.3	2954	10.5	0.94	56
BRCS	86.6	2965	9.47	0.675	33

6. Conclusion

Being based on the above studies, following conclusions can be drawn.

- On the basis of the existing expression form of rules in EMDES, a new kind of expression form of rules that is easy to read and write is defined to overcome the disadvantage of the existing ones. A set of completed grammar rules for knowledge-base is established. Frame configuration is adopted to administrate large knowledge-base conveniently.
- According to the defined expression form of knowledge, a flexible inference mechanism of high efficiency is developed.
- The BRCS is proposed to find the feasible solution along the shortest path if it exists, so the search process will be led to the goal state more quickly.

7. References

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