EVALUATION OF A POWER UNIT COMMITMENT PLANNING USING A KNOWLEDGE BASED SYSTEM FEATURING FUZZY KNOWLEDGE REPRESENTATION

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ABSTRACT : The optimal operational planning of an electric power system is based upon a priority list of all units participating to the power production. The elaboration of the units priority list is a critical task and is based on both, objective criteria (units' condition, load demand, etc.) and the operators' experience. The fuzzy approach applied to this category of problems gives more reliable results compared to conventional methods.

The objective of this paper is to demonstrate the use of a fuzzy relational database model for manipulating the data required for the priority classification of the units for optimal power unit commitment planning. The priority classification list is formed incorporating criteria like operational cost, safety requirements, environmental impacts, operation condition history, maintenance scheduling and alternative supply availability. Fuzzy linguistic terms for their definitions along with fuzzy inference allow the operators expertise to be exploited.

The proposed database undertakes the representation and handling of the above fuzzy information and additionally permits the user to specify the precision with which the conditions involved in a query are satisfied.

In order to illustrate the behavior of the model a case study is given for the autonomous power system of the Crete Island.

KEYWORDS: Fuzzy priority classification, fuzzy relational database, optimal power unit commitment planning.

1. INTRODUCTION

The daily scheduling of an autonomous electric power system is a rather complicated task. In conventional scheduling the optimization problem is the determination of start-up, shut-down and generation level of all units over a specified time period T, while the objective function to be minimized is the total cost, subject to system demand, reserve requirements and individual unit specific constraints [Bakirtzis 1988].

In the operational planning of an electric power system with N units and T periods of planning, the units' combinations are based on a priority list scheme, which formulates the state of the system for each period. The feasible states of the system for each period are those that supply the required load demand and do not violate any of the constraints. The transition from one feasible state at a given period to a state at the next period is defined as a strategy. The possible unit commitment scenarios for the time interval T are the possible paths for the transition from each feasible state of a period to the states of the next period. In [Sergaki 1997] a fuzzy dynamic programming algorithm is described for the determination of the optimal time schedule of a power system interconnected with WECS which considers the wind produced power, the system demand, the reserve requirements and the operational cost as fuzzy quantities. The unit commitment optimization problem suffers from high computational effort if the priority list scheme is obtained performing an exhaustive enumeration of all unit combinations at each period. Heuristic approaches must be applied to reduce the dimensionality of the possible solution space. The priority list for the units used in the fuzzy optimization procedure is obtained by simply ordering them in increasing full-load production cost, considering restrictions of must-run, base-load units [Burns 1975, Wood 1984]. According to this priority list, a unit is set out of operation only if all above units in the list are out of operation. This strict priority ordering does not incorporate time-dependent effects such as the start-up costs, which are a function of the time a unit has been down, the minimum up and down times, the minimum running time requirements as well as non-cost attributes (i.e. safety aspects, environmental impacts and operational condition history).

The methodology proposed here models all the above aspects following a database approach. The power system planners usually use imprecise and vague terms while stating the above criteria for each unit. The method allows a qualitative description of the units' behavior and characteristics by using the fuzzy sets theory. Fuzzy set approach provides more natural means for a planner to express his preferences in a form of a query containing fuzzy terms.

A case study based on the proposed methodology, for the power system of the island of Crete is presented. To evaluate the performance of the proposed methodology the results are compared with those derived by conventional methods.

2. THE FUZZY DATABASE MODEL

In this section, the fuzzy relational database model is introduced, used for the representation and handling of the above described imprecise information. Classical relational databases treat information as records grouped in relations or tables. Vagueness is included in the proposed model either by adding vague information to the database or by making vague queries to the database.

In a fuzzy data model, an attribute value of a tuple can be a possibility distribution. Different data types can appear for attributes with imprecise treatment (criteria used for the priority classification of the units) according to the specific nature of their fuzzy information [Buckles, 1982]. Incomplete information such as "unknown" and "undefined" can also be represented. "Unknown data type" expresses ignorance about the attribute value, but it is possible for the attribute to take any of its domain values. "Undefined data type" expresses that none of its domain values are allowed. Even if "Crisp data type" is represented for an attribute it is handled as a fuzzy value in a query, according to the linguistic labels defined on the attribute by the experts. Attributes with "Label data type" have linguistic labels defined on them. The meaning of a fuzzy value (e.g. "low") is elicited from the user and is represented as a fuzzy set with a trapezoidal membership function. For "Interval data types", the range of the attribute values are input by the user. The membership function of the "Approximate data type" is assumed triangular with membership value 1 for the attribute value over which the approximation is considered. The margin value is a parameter stored in the database. The classification for the data types adopted and the membership functions associated to each data type are shown in Table 1.

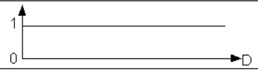
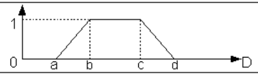
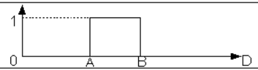
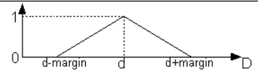
Data Type	Membership function Representation
"UNKNOWN"	
"UNDEFINED"	
"CRISP DATA"	
"LABEL"	
"INTERVAL"	
"APPROXIMATE"	

Table 1: Representation of imprecise data types

The data is structured through the Generalized Fuzzy Relation model, R_{FG}, given by:

$$R_{FG} \in (D_1, C_1) \times \ldots \times (D_n, C_n)$$

where D_j (j=1,2,…,n) is the Fuzzy Domain of the attribute A_j and C_j is a compatibility attribute taking values in [0,1]. The Generalized Fuzzy Relation generalizes the conventional theoretic notion of the relation. A complete tuple ($\tilde{d}_{ij}$, c_{ij}) in the Fuzzy Relation R_{FG} includes the compatibility degree c_{ij} which represents the possibility that $\tilde{d}_{ij} \in R_{FG}$ where $\tilde{d}_{ij}$ represents the domain value for the tuple i and the attribute A_j. The relational algebra must be extended in order to manipulate the defined fuzzy relations. Several definitions for extended operations can be found [Klir 1995]. Here the extended operations are based on the definitions proposed by Zadeh [Zadeh 1965]. Consider two Generalized Fuzzy Relations: (a) R_{FG} with a complete tuple ($\tilde{d}_{ij}$, c_{ij}) with i=1,…, m, m being the cardinality and (b) R'_{FG} with a complete tuple ($\tilde{d}'_{kj}$, c'_{kj}) with $k=1,\ldots,m'$, m' being the cardinality. Then $R_{FG} \cup R'_{FG}$ defines the Generalized Fuzzy Union with a complete tuple ($\tilde{d}''_{\ell j}$, $c''_{\ell j}$), with $\ell=1, \ldots, m''$, m'' being the union cardinality, where $c''_{\ell j}=\max\{c_{\ell j}, c'_{\ell j}\}$. The Generalized Fuzzy Intersection of R_{FG} and R'_{FG} is defined as $R_{FG} \cap R'_{FG}$ with a complete tuple ($\tilde{d}''_{\ell j}$, $c''_{\ell j}$), with $\ell=1,\ldots,m''$, m'' being the intersection cardinality, where $c''_{\ell j}=\min\{c_{\ell j}, c'_{\ell j}\}$. The Generalized Fuzzy Difference of R_{FG} and R'_{FG} is defined as $R_{FG} - R'_{FG}$ with a complete tuple ($\tilde{d}''_{\ell j}$, $c''_{\ell j}$), with $\ell=1,\ldots,m''$, m'' being the difference cardinality, where $c''_{\ell j}=\min\{c_{\ell j},(1-c'_{\ell j})\}$. The Generalized Fuzzy Cartesian product $R_{FG} \times R'_{FG}$ of R_{FG} and R'_{FG} is defined as the Cartesian product of the $(D_j, C_j) \times (D'_{j'}, C'_{j'})$. The Generalized Fuzzy Projection from R_{FG} onto X, where $X=\{(D_s, C_{s'}) : s \in S,\ s' \in S';\ S, S' \subseteq \{1,\ldots,n\}\}$ is a subset of (D_j, C_j), is defined as $P_G(R_{FG};X) \in (D_s, C_{s'})$. The Generalized Fuzzy Selection carried out on R_{FG} by the condition induced by a generalized fuzzy comparison operator $\Theta_{Gj}(A_j, \tilde{a})$ and a compatibility threshold ϑ_j on the attribute A_j with $\tilde{a} \in D$ be a constant is defined as $S_G(R_{FG}; \Theta_{Gj}(A_j, \tilde{a}) \geq \vartheta_j) \in (D_j, C'_j)$ with a complete tuple ($\tilde{d}_{i'j}$, $c'_{i'j}$), with $i'=1,\ldots,m'$, m' being the selection cardinality and $c'_{i'j} = \Theta_{Gj}(\tilde{d}_{i'j}, \tilde{a}) \geq \vartheta_j$. The generalized fuzzy comparison operator $\Theta_{Gj}(\tilde{d}, \tilde{d}') \in [0,1]$ is an extended comparison operator, such as “greater or equal”, “equal to” etc, defined to operate on fuzzy information $\tilde{d}, \tilde{d}' \in D$.

Applying a vague query on the fuzzy relation R_{FG}, a new relation is obtained that adds to every tuple, for every value of the attribute involved, a new compatibility degree according to the condition imposed in the query. The tuples of the derived relation will be selected according to the compatibility threshold established in the query. The established threshold controls the precision with which the condition of the query is satisfied. This threshold is in the interval [0,1] and can be represented through linguistic labels, which have subjective meaning; for example, the threshold label “high” can be established as the one that accepts all tuples whose compatibility degree is greater or equal to 0.8. When a query consists of simple conditions connected with conjunction operator, the intersection of the relations obtained from every condition is computed. The value of the compatibility attribute of every tuple of the intersection is updated to the minimum of those in the respective initial simple conditions. For simple conditions connected with disjunctive operator the union of the relations obtained for every condition is computed and the compatibility attribute is updated with the maximum value. For a negated simple condition, the compatibility attribute value is updated with the complement to 1 of the present value in every tuple.

3. IMPLEMENTATION OF FUZZY RELATIONAL DATABASE APPROACH

This section introduces the organization of the imprecise information in the Fuzzy Relational Database. According to the proposed methodology the priority classification of the units is formed incorporating the following criteria: operational cost, safety requirements, environmental impacts, operation condition history and alternative supply availability, which are attributes with imprecise treatment. The Fuzzy Relational Database model has been developed with Microsoft Access package and organizes all the information concerning the imprecise nature of these attributes using tables or relations. The organisation of the tables is shown schematically in Figure 1. A more detailed description of each table follows.

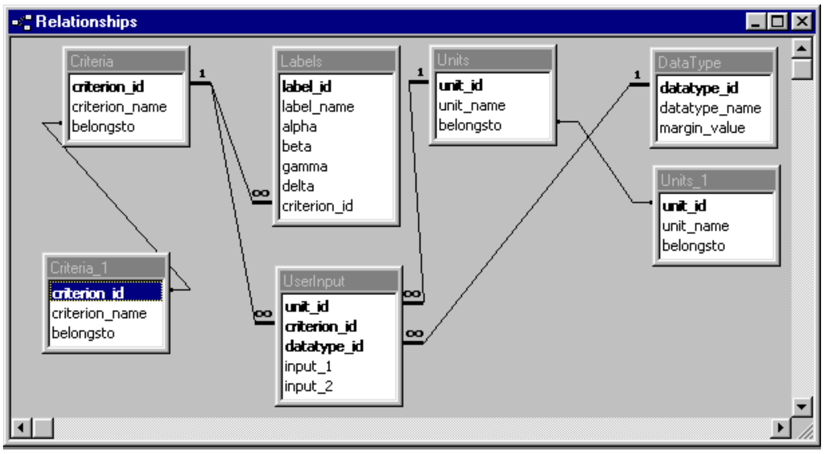


Figure 1: Fuzzy Relational Database organization

The “UserInput” table contains the user description of the system according to the criteria inputs. The “data_typeid” attribute contains information about the data type of the criterion value given by the user, according to the classification established in the “DataType” table. The “input_1” and “input_2” attributes represent the criterion input data. For the “Interval” data type both attributes are used. For all other possible data types shown in Table 1, the data is represented using only the input_1 attribute. The “margin_value” attribute of the “DataType” table contains information concerning the “Approximate” data type. The “criterion_id” attribute associates a numeric identifier to each criterion. The “Labels” table contains the parameters that determine the membership functions corresponding to the trapezoidal type linguistic labels defined for the criteria. The label definitions used for operational cost, safety requirements, environmental impacts, operation condition history and alternative supply availability criteria are illustrated in Figure 2.

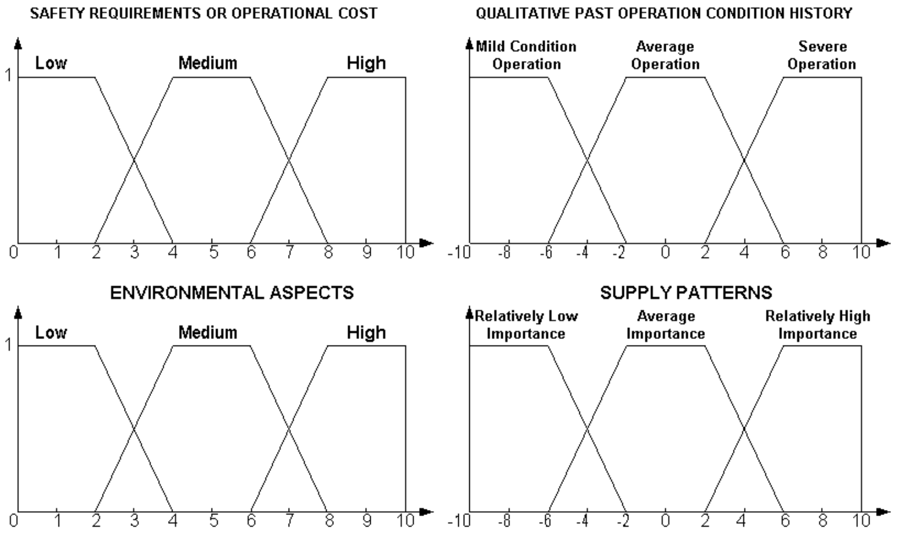


Figure 2: Labels definitions

For the “UserInput” table an interface has been developed which takes the user inputs for every unit and criterion and calculates the corresponding compatibility degrees associated with the labels defined on the criterion, by using the customised modules. The resulting “Results” table involves the “unit_name”, “criterion_name”, “label_name” and “mfValue” attributes. Microsoft Access represents a query using the SQL formalism. The queries are applied on the “Results” table. The WHERE clause specifies conditions which the records of the table ought to follow. Applying a query containing fuzzy terms, the SQL formula calculates a new compatibility degree to every tuple, for every value of the criterion involved, according to the compatibility threshold and the fuzzy comparison operator in the query. The established threshold controls the precision with which the condition of the query is satisfied and can be represented through linguistic labels. When a query consists of simple conditions connected with conjunctive or disjunctive operators, the intersection or the union of the relations obtained from every condition is performed. An example of a query with two simple conditions connected with conjunction follows:

Query: Give me the name and the satisfaction degree of the conditions for those units whose “OperationCost” criterion is “medium” (degree ≥ 0.6) and “EnvirImpacts” criterion is “high” (degree ≥ 0.8)

The SQL query is given as :

```
SELECT Results.unit_name, min(Results.mfValue) AS MINVALUED
FROM Results INNER JOIN Results AS T1 ON Results.unit_name=T1.unit_name
WHERE (Results.criterion_name="OperationCost" AND Results.label_name="medium" AND Results.mfValue>=0.6
AND T1.criterion_name="EnvirImpacts" AND T1.label_name="high" AND T1.mfValue>=0.8) OR
(Results.criterion_name="EnvirImpacts" AND Results.label_name="high" AND Results.mfValue>=0.8 AND
T1.criterion_name="OperationCost" AND T1.label_name="medium" AND T1.mfValue>=0.6)
GROUP BY Results.unit_name;
```

When a unit commitment scheduling is performed the operator forms a query containing fuzzy terms expressing his preferences about the systems condition. The result is a list containing the units and their respective matching degree, stating how well a unit meets the conditions specified in the query.

The proposed methodology was applied to the electric power system of the island of Crete. The conventional power station consists of 6 steam turbines, 4 diesel units and 8 gas turbines. To evaluate the performance of the proposed methodology, a fuzzy priority classification resulting from the proposed model and a priority classification based on the full-load production cost were used for the optimal commitment scheduling. It was observed that the resulting production cost was lower for the fuzzy priority classification approach. Also the unit priority list resulting from the proposed model was closer to the operators estimation.

4. CONCLUSIONS

The aforementioned proposed methodology determines a unit priority list scheme by taking into account both non-cost attributes and time-dependent effects along with cost attributes. Results from the present study reveal the fact that the proposed model provides more natural means for a planner to describe the units behavior and characteristics and to express his planning preferences. The proposed fuzzy relational database model features great flexibility in the handling and the evaluation of fuzzy information and in controlling the degree to satisfy the individual conditions of a query. The comparison of the proposed methodology with the conventional one processes the superiority of the former.

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