An SVM-T3SD Policy Driven Method for IT Infrastructure Selection in Smart Grid

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Abstract—**This paper presents a decision-maker expert system, referred to as SVM-T3SD (Support Vector Machines for Tricotyledon Theory of System Design) to select a proper IT infrastructure for a Smart Grid. The proposed SVM-T3SD is a policy-driven decision making method combining the SVM, Fuzzy and T3SD concepts. The practical data are taken from the Greater Tehran Electrical Distribution Company (GTEDC) and three alternative IT infrastructures – Spread Spectrum (SS), Distribution Line Carrier (DLC) and Leased Line (LL) – are considered in this study. Conclusively, it is revealed that the method is as effective as previously proposed methods, yet more efficient, due to employing fewer rules to construct the expert system rule-base.**

Keywords-Smart Grid; IT Infrastructure; Decision Making; Policy Driven; Support Vector Machines; Fuzzy; Tricotyledon Theory of System Design; System Theory.

I. INTRODUCTION

Smart Grid is a power system which relies extensively on its Information Technology (IT) infrastructure [1]-[3]. Migration to Smart Grids requires a reliable and optimized IT infrastructure. Its selection is the core issue for designing a Smart Grid, because the most challenging parts of the Smart Grid are mostly the distribution automation systems, which drastically depend on IT systems.

Different enterprises around the world spend every year approximately US $10 trillion on IT-enabling projects, which shows how significant and important research of IT systems development is [4]. Despite recent important improvements, the majority of these IT projects still do not meet functional requirements, cost estimations, or schedule estimations [5]. This fact shows how important is a reliable and efficient IT infrastructure selection in the Smart Grid for a complex enterprise. However, many failures in the IT systems of energy utilities result from unsystematic design, ad hoc designs and the application of heuristic rules [1]-[8]. These methods are not only highly suspect of not being optimal, but also, as stated in [9] "lead to serious errors and biased decisions, because they employ heuristics or 'rules of thumb' for decision making".

In a utility company, the operational and functional needs of the utility sub-systems are dictated by its corporate policy. Consequently, stakeholders must ensure that the IT systems which are developed are aligned with the corporate policy of the utility. Literature [10]-[11] shows that the alignment of the IT system with the enterprise corporate policy reduces the risk for IT projects to fail. Therefore, the design decision method must be highly sensitive to the enterprise corporate policy, i.e. it should be Policy-Driven [2].

Despite the extensive literature on optimization of financial cost functions, [12]-[18], there are only very few works considering quantitative performance approaches in IT and power systems, especially as a trade off with cost. In [2], Fereidunian, *et al.,* presented a performance/cost trade off method. Despite this work, there is still a research gap in the field of performance/cost trade off implementation studies in both power and IT systems design literature. The work in [2] has applied figures of merit (FoM) and scoring functions (SF) to quantify the system quality attributes, obtaining significant results.

This paper is a continuation of the IT infrastructure designs research in [1], [2], [19], and [20], which, to the best of our knowledge, are the first implementation of the established, but young [21], general systems design methodology to Smart Grid systems. The contribution of this paper is the introduction of a new decision making method, called SVM-T3SD, which couples together the Support Vector Machine (SVM) method together with fuzzy and T3SD methods. We compare the new method with the weight-based approach in [2] and with the Fuzzy-T3SD method [20]. We show how the new method makes the same decisions using fewer rules. Thus, it facilitates the capture of human expert judgments for decision making. Moreover, T3SD theory unifies different FoMs, which simplifies the SVM classification process.

The remainder of this paper is organized as follows: a brief introduction to SVM is given in section II; the SVM-T3SD design decision method is described in section III; Section IV discusses the implementation process of the proposed method by analyzing a practical example, presenting implementation results for three application scenarios; finally, discussion and conclusion can respectively be found in sections V and VI.

II. Background

This section introduces the basic concepts of support vector machines (SVM). A more detailed discussion can be found in [21], [22].

SVM is a non-probabilistic binary classifier, categorized under supervised learning methods used for data analysis and pattern recognition via classification and regression analysis.

Using a training data set, SVM constructs a set of hyperplanes which separate the hyperspace into two different sub-spaces. The hyperplanes are actually derived from the training set data points which were closest to the boundaries of the two classes, referred to as support vectors. The training set is indicated as:

$$\text{Training data set } = \{(x_i, c_i) | x_i \in \mathbb{R}^p, c_i \in \{-1, 1\}\}_{i=1}^{n} \quad (1)$$

where x_i is a p-dimensional real vector and c_i is the class it belongs to: class -1 or class 1. The aim is to find the maximum margin hyperplane which separates the two classes in the hyperspace by employing (2):

$$\text{w} . \text{x} - \text{b} = 0 \quad (2)$$

where w is the slope and b is the intercept of the hyperplane.

Afterwards, for any new data fed to the machine, the class to which the data belongs is determined. This decision is made by using the data in the boundary's equation. If the result is negative the data belongs to class -1; if it is positive the data belongs to class 1.

We choose 3 levels of quantization, because it gives a good trade-off between accuracy and complexity. Thus, 3 classes must be defined to fill out our needs. Although SVM is regarded as a binary classifier, some methods are suggested to do multiclass classification with it. Two main multiclass SVM methods can be used:

One-against-all classification, in which there is only one binary SVM for each class to separate members of that class from members of other classes.

Pair-wise classification, in which there is one binary SVM for each pair of classes to separate members of one class from members of the other.

In this paper we select the One-Against-All (OAA) method. The initial formulation of the one-against-all method required unanimity among all SVMs: a data point would be classified under a certain class if and only if it was accepted as a member of that class and rejected by all other classes.

More details on SVM's classification method utilized to construct such expert system can be found in [23].

III. Methodology

A. Problem Statement

IT selection decisions as sub-problems of Smart Grid. The main problem targeted by this research consists in selecting an IT infrastructure for one of the Smart Grid functions. Here we consider the Feeder Reconfiguration Function of Utility Management Automation System, as in [24].

As shown in Fig. 1, the Smart Grid includes an IT infrastructure which, if selected correctly, can complete the architecture of the Smart Grid to implement a feeder reconfiguration function system.

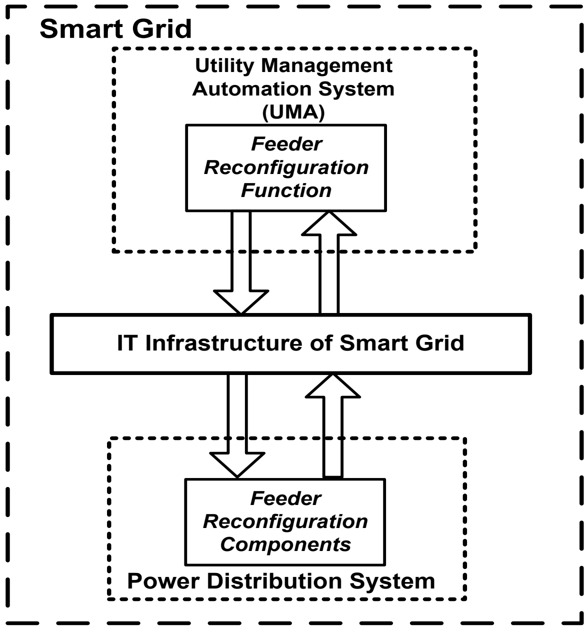

Figure 1. Architecture of IT Infrastructure in Smart Grid for Feeder Reconfiguration Function

B. Method Overview

To solve the problem, this paper introduces a design decision model for selecting an efficient IT infrastructure for a Smart Grid according to the policy of the utility. Fig. 2 illustrates our presented design decision model, in which design inputs and design concepts can be introduced by requirement analysis [2]. A simple classification of system requirements include: performance requirements, cost requirements and trade-off (policy) requirements [2], [25].

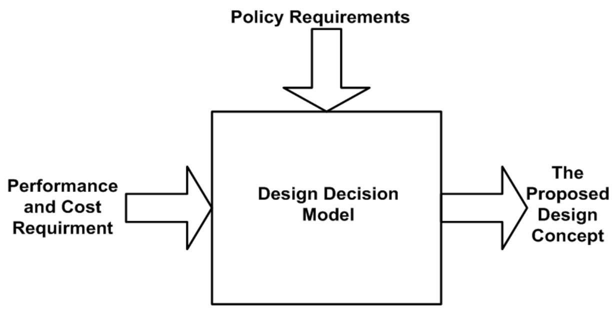

Figure 2. Block Diagram of Design Decision Model

C. SVM-T3SD System Design Method

The proposed design decision model is based on the model-based Tricotyledon of system design (T3SD). In Fig. 3, the proposed SVM-T3SD design decision model is shown. After the analysis of the requirements, two sets of Figures of Merit (FoMs) and their scoring functions are determined for the performance and cost requirements of the system [25]. As in [2], the system design concepts (the IT infrastructure alternatives) are explored by investigating the technologies that are available to build the system [2]. The Standard Scoring Functions (SSFs) are used to grade the FoMs and to build a unified scaling system for FoMs, thus mapping the FoMs space to a normalized space. Consequently, this method leads to different types of FoMs with different dimensions. This property of the T3SD theory that unifies and normalizes the FoMs simplifies the decision making process.

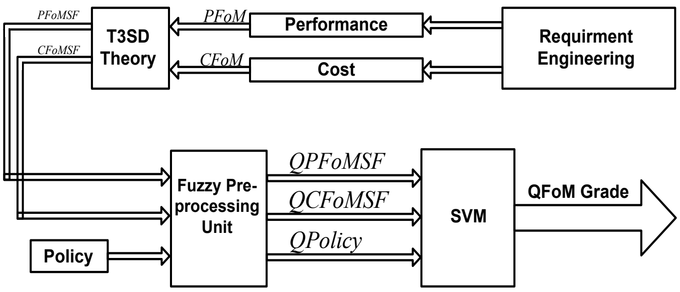

Figure 3. The Proposed SVM-T3SD Method for selection of IT Infrastructure

To avoid the complexity drawn from wide diversity inside this normalized space, we make use of a fuzzy pre-processing unit for the inputs of the system to divide this space into 3 main categories with fuzzy labels. As it is proven in [26], although it costs a little more computation, the introduction of fuzzy class label is eventually worth for better choices, with a large margin. Therefore, 3 linguistic labels are proposed for each input. The proposed fuzzy pre-processing unit is made of 3 Gaussian membership functions as shown in Fig. 4.

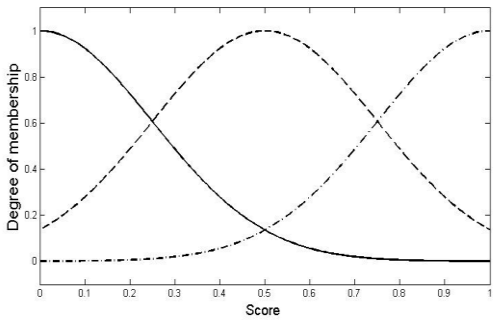

Figure 4. Proposed Membership Functions for SVM-T3SD Method

After pre-processing, data is fed to the SVM expert system. For more information on selection of the best SSFs see [25], [27] and [28].

In this paper, SVM is proposed as an expert system to select the proper IT infrastructure. Since the T3SD theory applies normalization and unification pre-processing on the inputs, SVM classification techniques can be simply applied; however, the scored inputs need to be quantized. For our approach, three levels of quantization are considered to describe the proposed system's functionality: Unusable (U), Moderate (M), and Excellent (E). Afterwards, the training set, extracted from judgments of the utility Experts, is used to train the SVM Expert System.

IV. Implementation, Results and Discussions

This paper focuses on the IT infrastructure selection for the Utility Management Automation (UMA) system, as one of the functions of the Smart Grid [24]-[30]. We consider judgments obtained from the Greater Tehran Electrical Distribution Company (GTEDC)'s experts.

Marihart [31] has enumerated 14 different design concepts for the IT infrastructures. In this paper, due to the engineering practice of the GTEDC, we consider three different design concepts: Spread Spectrum (SS), Distribution Line Carrier (DLC) and Leased Line (LL) [1], [2], [19].

A. Figures of merit

These three design concepts are being evaluated from the cost and performance perspectives as follows:

1) Performance Figures of Merit (PFoM)

According to the functional requirements of the UMA-FRF system, three PFoMs are considered:

a) Minimum number of disconnected customers: best modeled with customer average interruption duration index (CAIDI) [32], [33].

b) Minimum recovery time: best modeled with average service unavailability index (ASUI) [1], [2], [19], [32] and [33].

c) System reliability in sense of digital communication: best modeled with Bit Error Rate (BER) [1], [2] [19] and [34].

Fig. 5 shows the SSFs calculated for the aforementioned PFoMs which are later used to obtain the Membership Function (MF) of the fuzzy pre-processing unit mentioned in [1], [2] and [19].

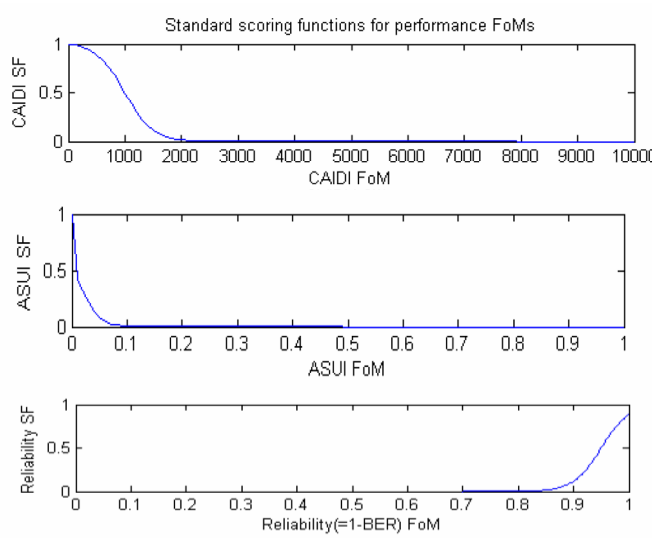

Figure 5. PFOMs' SSFs

2) Cost Figures of Merit (CFoM): As the functional requirements of the system lead into defining PFoMs, the technological requirements are the reason for the cost. In other words, the technological requirements specified for the system of interest lead to defining CFoMs. In this particular case study, no system design cost is considered since cost is the focus of other sub-projects.

We consider the two following CFoMs:

1) Cost due to the system engineering, procurement and construction (EPC): This is the amount of money spent on the construction stage and subsystems procurement which are calculated individually and then normalized to consider relative costs as in [1], [2], [19] and [35].

2) Cost of operation and maintenance (O&M): This is the amount of money spent due to the maintenance cost and is then normalized to consider relative costs as in [1], [2], [19] and [35].

Fig. 6 shows the SSFs calculated for the aforementioned CFoMs which are later used to obtain the Membership Function (MF) of the fuzzy pre-processing unit mentioned in [1], [2] and [19].

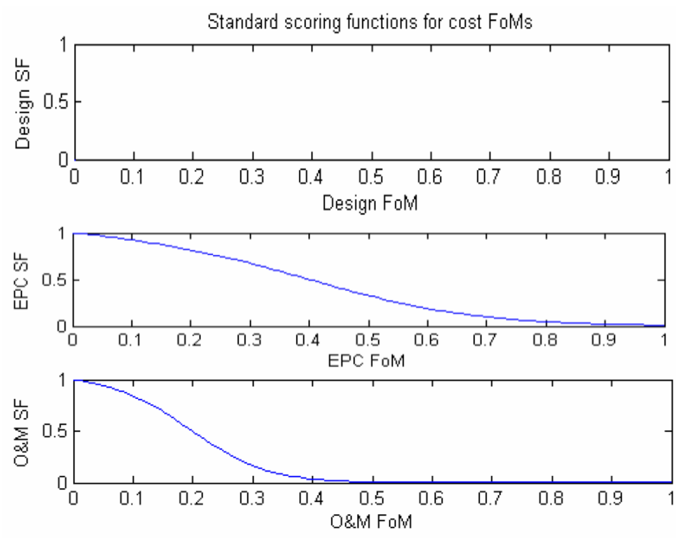

Figure 6. CFoMs SSFs

B. *Policies for trade-off analysis*

We develop three policies to design the decision method. These policies are: payment method, possession condition, and cost-performance trend.

The utility may adopt different payment strategies for its new IT infrastructure. For example, the utility may prefer to pay once or over time. This policy issue is represented by a SVM variable with three linguistic values: pay-once-policy, moderate-payment-policy and pay-gradually-policy.

IT infrastructure's possession condition is an important policy issue, because it expresses how the IT infrastructure can be controlled by the utility. This policy issue is illustrated by a SVM variable with three linguistic values: non-possession (leasing), moderate possession and full possession.

The utility performance and cost policies trends show the relative importance of cost and performance compared to each other. This policy issue is illustrated by the SVM variable, with three linguistic values: cost oriented, cost-performance equilibrium and performance oriented.

C. *Implemented Scenarios*

As mentioned before, we consider three policies. These policies are quantized into three linguistic levels after passing the pre-processing unit as shown in Table I. Consequently, 27 different policy combinations are available. We selected three of them as policies of the proposed SVM-T3SD design method. The developed scenarios reflect the prospective policy of the company.

TABLE I. CHARACTERISTICS OF POLICIES

Policy	Performance	Type of Possession	Type of Payment
1	M	M	O
2	M	M	M
3	M	F	G

Levels of Performance: Poor, Moderate, and Excellent;
Types of Possession: Full, Moderate, and Non;
Types of Payment: At once, Moderate, and Gradually.

1) Unbiased Policy: The utility prefers moderate payment, moderate possession of technology and cost-performance equilibrium.

2) Full Possession Policy: The utility prefers moderate payment, full possession of technology and cost-performance equilibrium.

3) Pay-once and Full Possession Policy: The utility prefers pay-once-policy, full possession of technology and cost-performance equilibrium.

The three scenarios are implemented using the SVM-T3SD method. Results are presented in Table II.

TABLE II. RESULTS: IMPELEMENTED POLICIES IN SVM-FUZZY-T3SD

Alternatives	DLC	LL	SS	NA
CAIDI	0.5	0.5	0.5	0.0154
ASUI	0.465	0.465	0.465	0.4102
Reliability	0.0016	0.881	0.881	0.0869
EPC	0.4004	0.9477	0.3855	1
O&M	0.8	0.71	0.7981	1
Scenario 1	Unusable	Excellent	Good	Unusable
Scenario 2	Unusable	Good	Good	Unusable
Scenario 3	Unusable	Good	Good	Unusable

As shown in Table II, the first scenario represents an un-biased policy according to which payment, possession and cost-performance equilibrium all are in moderate states. In this scenario LL is proposed as the selected IT infrastructure.

The second scenario represents a full possession policy, with the other policies in moderate state. The SVM-T3SD method determines that LL and SS are better matched to the policy compared to DLC and NA.

Finally, the third scenario represents pay-once and full possession policies. This scenario, as scenario 2, shows that LL and SS are better matched to the policy compared to DLC and NA.

The proposed SVM-T3SD design decision method successfully can include more scenarios compared to the method in [2], where the policies are introduced as weights. On the other hand, with the SVM-T3SD method, the policy can manipulate every FoM. Finally, decision making parameters in [2] are defined as scalar weights, while SVM-T3SD receives them as training set. The comparison between the design decision method in [2] and the SVM-T3SD design decision method are illustrated in Table III.

TABLE III. COMPARING POLICY-DRIVEN DECISION MAKING

	Ref. [2]	**SVM-Fuzzy-T3SD**
Scenario numbers limitation	1 scenario	Unlimited
Policies enter as:	Weight	Input
Policies enter at:	Highest level	Whole system
Complexity of policy	Scalar weight	Training set

The Fuzzy-T3SD expert system's decision making process proposed in [20] is based on human experts' judgments - regarded as IF THEN rules - to be taught to the expert system. These IF THEN rules should cover all possible states so that the expert system can perform in high reliability. However, SVM-T3SD requires much fewer rules to achieve just as fine decisions as Fuzzy-T3SD makes, since as stated in section II, SVM doesn't require all data to build the expert system and it only needs those data laying on the boundaries. This is very important in situations where only few vital rules are available.

V. CONCLUSION

The SVM-T3SD expert system was suggested to drive policy-driven decision making. This expert system selects the IT infrastructure for one of the Smart Grid functions using a combination of SVM, Fuzzy and T3SD. Three scenarios were considered to examine the SVM-T3SD expert system. Results show that decisions are equal to other methods [2], [20], showing that although all of these methods are effective, but SVM-T3SD expert system is more efficient since fewer rules are necessary in its decision making process.

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