

Power customer satisfaction and profitability analysis using multi-criteria decision making methods

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ABSTRACT

Nowadays, the consumer demands for electrical energy are increasingly growing, because this energy is present in all fields of human activity. Any company producing and distributing electric power sets two main objectives, namely: customer satisfaction and profit making. The aim of this paper is to investigate appropriate tools (multi-criteria decision making methods) aiding decision makers to achieve these goals. The criteria adopted revolve around quality of service and include: cost, reliability, availability, maintainability and power quality. However, the alternatives are technical and organizational measures often taken in planning and operation phases of electrical power systems. Three methods are used, namely: the analytic hierarchy process (AHP), the cost benefit analysis (CBA) and the economic criteria inspired from game theory (ECIGT). The first method highlights the impact of the experts' views in the formalism of the final decision of the manager and it is viewed as a transparent decision process. As for the ECIGT, it provides several scenarios to define a strategy according to the decision maker's behavior. One of its important finding resides in the possibility of evaluating the reactions of the customers towards the decisions taken by the system manager. Consequently, it allows the analysis of the enterprise profitability. However, the CBA method is efficiently integrated into these two complex methods decision making. The application developed in this paper shows that RAM (reliability, availability and maintainability) criteria are significant stakes in the performance of a business and are an important asset for new projects justification.

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1. Introduction

Distributors of electrical energy are often working to meet a balance between the requirements' satisfaction of the end users of the power system and the containment of the generated costs. This issue requires the knowledge of useful criteria aiding to lead to an appropriate management without prejudicial constraints. In several cases, the decisions taken by managers are resulted from the ultimate reflections of a group of experts who associates weights to the importance of both suitable criteria and suggested alternatives. In both competitive and monopoly markets, customer satisfaction is a prerequisite and a critical business objective. In a liberal environment, the customer has free choice to provide the best services and in this case the non-competitive company risks losing much of the market, consequently it reduces its profitability. In the case of a monopoly market, the consumer dissatisfaction can lead to a conflict of interest which undoubtedly will have adverse

consequences for both parties. This paradigm is addressed in the context of multi-criteria decision making. The aim of this paper is to investigate mechanisms leading to simultaneously analyse customer satisfaction and enterprise profitability in both monopoly and liberal environments. It provides decision makers with scientific tools aiding them to choose the best alternative from one sample to meet the fixed goals, objectives, desires values and so. Compared to this issue, three multi-criteria decision making methods are introduced, insuring the development of mathematical models taking into account the psychological side of both decision makers and customers, namely: the analytic hierarchy process (AHP), the cost benefit analysis (CBA) and the economic criteria inspired from game theory (ECIGT). The AHP method is a transparent process that remains very useful for a company insuring a public service. It is also a measurement theory that prioritizes the hierarchy and consistency of judgmental data provided by a group of decision makers. As for the ECIGT approach, it presents a certain virtue, like the ability to simulate different possible states of the manager (optimistic, pessimistic, prudent or gambler) and allows to understand the reactions of consumers (not satisfied, satisfied or quite satisfied) in relation to the attitude of the decision maker.

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This method is widely used in the resolution of problems posed in an uncertain future. The third proposed method; CBA is an appropriate tool for costs assessment and efficiently integrated into AHP and ECIGT decision making methods cited above. To achieve the objectives set, five criteria were selected namely: the cost, the reliability, the availability and the maintainability of the network, as well as the power quality. These criteria highlight, with a high fidelity and in a simultaneous manner, the consumer's and the company's interests. The consumer seeks a product with both high availability and quality encompassed in terms of quality of service. However, the enterprise privileges profitability, which is heavily reliant to the cost of the services, to the system reliability and to the applicability of the needed maintenance actions, which in turn should be performed easily and leading to efficient results. A general decision making process can be divided into eight steps such as: problem definition, requirements determination, goals establishment, alternatives identification, criteria definition, decisions making tool selection, alternatives against criteria evaluation and finally solutions against problem statement validation. The developments expressed in the present paper follow these requirements where steps order is quite respected, considering a part of the distribution network of Bejaia city (Algeria) as a practical case. After analyzing the current state of the network which is considered poor in terms of quality of service, decision-makers had to take technical and organizational measures to improve the supply of electric energy. Experts' opinions and consumers' reactions were supported with great interest to avoid inconvenience leading to conflicts. For purposes of simulations, a software program was developed to implement the mathematical models developed for each method. The obtained results provide decision-makers with a range of choices enabling them to target a well-defined goal and take appropriate actions according to the means of the power supply company. The rest of the paper is organized as follows: Section 2 sets the decision methodology overview. Section 3 develops briefly the three used multi-criteria decision making methods, easily applicable to electric power system. The criteria and the alternatives useful in the case study application are presented in Section 4. The description of the system under study is dressed in Section 5; however, Section 6 is devoted to the application and where the results are discussed. Finally, the conclusions of the research are presented in Section 7.

2. Decision methodology overview

Electric utilities need to provide energy delivery services at the lowest cost. The customer satisfaction has become a critical business objective. Combined to the enterprise profitability, it is directly related to reliability, availability and maintainability of the network, as well as to the power quality. The association of these criteria to the strategies developed by the company to attain the fixed objectives and goals constitute the multi-criteria decision making paradigm. To analyse customer satisfaction and enterprise profitability, three methods are developed, namely: the analytic hierarchy process (AHP), the cost benefit analysis (CBA) and the economic criteria inspired from game theory (ECIGT). Regarding customer's wants treatment on manufacturer products, Yang [1] relates reliability to customer satisfaction and presents reliability and quality techniques as important parameters for improving customer satisfaction. Considering Kano model, the author described the relationships between customer satisfaction and customers' wants. Bollen et al. [2] have introduced the customer dissatisfaction index (CDI) defined as the probability that the supply for a given customer is of insufficient reliability. Elliot and Serna [3] stated that utilities are facing new challenges to managing customer satisfaction. They have discussed key elements summarized as follows: the first order drivers are service, price and reliability and

the second perception drivers are customer responsiveness, company reputation, and outage frequency and duration. Once the managers understand these drivers, the next step is to assess opportunities for improvement. To evaluate the satisfaction of users of the electric power, in a recent publication, Guo and Niu [4] developed a method based on decision tree, where the analysis is conducted by choosing 20 customer questionnaires. To highlight the importance of the AHP method, a review of a total of 150 AHP application papers is provided by Omkarprasad and Sushil [5] as an informative summary kit for researchers and practitioners. However, AHP has recently been applied to solve problems concerning electric power systems. It has been used by Negim et al. [6] as an expert system to identify the vulnerability of special protection schemes (SPS), and by Malik and Sumaoy [7] for impact evaluation and logical prioritization of demand side resources to planning criteria. ANP and AHP processes were jointly used by Chen et al. [8] for the strategic selection of a feeder management system applied to the power industry in china. The development with practical application given in the present paper has proven that AHP method makes the selection process very transparent with a great benefit to a company assuring public services. The approximated values of weights representing the degrees of importance of criteria and alternatives are validated by the results obtained using the CBA method. To investigate the behaviors of the decision-makers in an uncertain future and to highlight the reactions of the customers, we have introduced some economic criteria inspired from game theory. According to this issue, Voropai and Ivanova [9,10] have conducted some investigations in relation to both game theory and the problem of expansion planning of power systems. It is stated that if the power supply company invests in the installation, the investment project may call for a multi-criteria assessment. For an independent investor, one should allow for an incentive for the behavior of the other concerned subjects and the problem can be associated with the game statement. The AHP, the CBA and the ECIGT methods were adopted in the present paper because customer satisfaction refers to customers' mental state after comparing the products and services received with their expectations.

3. Decision making tools

3.1. Analytic hierarchy process

The decision method decomposes a complex multi-criteria decision problem into a hierarchy. AHP is also a measurement theory that prioritizes the hierarchy and consistency of judgmental data provided by a group of decision makers. AHP incorporates the evaluations of all decision makers into a final decision, without having to elicit their utility functions on subjective and objective criteria, by pair-wise comparisons of the alternatives. Five selection criteria C_j (for $j = 1-5$) are considered to be relevant and are respectively: the cost, the reliability, the availability, the maintainability and the power quality. Four alternatives are selected denoted by A_i (for $i = 1-4$) highlighting technical and organizational measures taken during planning and operation phases of the power system. Steps to general use of the AHP method are summarized in Ref. [11] and its application to power customer satisfaction and enterprise profitability is described as follows:

- (1) Model the problem as a hierarchy containing the decision goal (customer satisfaction and enterprise profitability), the alternatives (technical and organizational measures) for reaching it, and the criteria for evaluating the alternatives (cost, reliability indices, and power quality).
- (2) Establish priorities among the elements of the hierarchy by making a series of judgments based on pair-wise comparisons of the elements.

- (3) Synthesize these judgments to yield a set of overall priorities for the hierarchy.
- (4) Check the consistency of the judgments.
- (5) Come to a final decision based on the results of this process.
- (6) Analyze the sensitivity to changes in judgment to study the margin of stability and the decision.

In the matrix QJ representing a quantified judgment on a pair of elements q_{ij} , given by Eq. (1), the problem becomes one of assigning to the n elements e_1, e_2, \dots, e_n a set of numerical weights W_1, W_2, \dots, W_n that reflects the recorded judgments. If QJ is a consistency matrix, the relation between weights W_i and judgments q_{ij} is simply given by $q_{ij} = W_j/W_i$ (for $i, j = 1, 2, \dots, n$). The largest eigenvalue λ_{\max} and the eigenvector X can be calculated using Eqs. (2) and (3) respectively. The consistency ratio (CRI) is given according to the size of the matrix QJ and the consistency index (CI) is assessed using Eq. (4).

$$QJ = [q_{ij}] = \begin{bmatrix} 1 & q_{12} & \dots & q_{1n} \\ \frac{1}{q_{12}} & 1 & \dots & q_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{q_{1n}} & \frac{1}{q_{2n}} & \dots & 1 \end{bmatrix} \quad (1)$$

$$\lambda_{\max} = \sum_{j=1}^n q_{ij} \frac{W_j}{W_i} \quad (2)$$

$$(QJ - \lambda_{\max} I)X = 0 \quad (3)$$

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (4)$$

In the AHP, pair-wise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding consistency ratio (CR) is less than 10%.

3.2. Economic criteria inspired from game theory

Usually, game theory is applied when several players are competing. Compared with electricity grids, there are several companies in a competitive environment. To solve the issue on the basis of game theory, a game matrix is constructed where rows correspond to scenarios of customer satisfaction and reactions of the customers to the future investment, however, the columns correspond to the strategies developed by the decision makers. The elements of the game matrix designate the costs of the given alternatives. The economic criteria used in the present paper are the Laplace–Bayes criterion, the Wald or max–min criterion, the Savage or min–max Regret criterion and the Hurwitz criteria. For electrical networks restructuring, these criteria were briefly introduced by Neimane [12], and explained as follows.

Under the Bayes–Laplace criterion (Z_{BL}), a probability or a weight is associated to each scenario i . The cost associated to scenario i for a strategy j is V_{ij} and the probability of each scenario is Q_j . The advantage of this criterion is that each scenario is taken into account and the importance of the scenario is reflected through its probability of occurrence, however it may lead to a risky decision.

The Laplace's criterion (Z_L) can be based on the statement that the probabilities are unknown and there are no sufficient reasons to consider them to be different. In many cases such assumption can turn out to be groundless. The optimal solution is the one minimizing the arithmetical mean of costs over n scenarios. The min–max decision rule (Z_{mM}) is to seek decision-makers action, which minimizes the maximum potential loss. A decision-maker who

uses the min–max criterion acts extremely conservatively. He seeks the actions that achieve the best outcome under the worst scenario. Adopting the Wald (max–min) criterion (Z_{Mm}) corresponds to a prudent attitude of a decision maker. It will seek to identify for every possible strategy, a scenario that would lead to worse outcomes. Afterwards, he will try to cover himself by adopting a strategy that is likely to provide the least bad possible result, if the evolution of competition (scenarios) is detrimental to the company.

Hurwitz proposes a criterion (Z_H) which consists to calculate for each strategy a weighted average of the worst and the best of its potential outcomes and chooses the one for which the solution is the largest. According to this criterion the best strategy is the one minimizing the linear combination of minimal and maximal costs. The five described economic criteria are formulated in the following equations, respectively.

$$Z_{BL} = \min_i \sum_j Q_j V_{ij} \quad (5)$$

$$Z_L = \min_i \frac{1}{n} \sum_j V_{ij} \quad (6)$$

$$Z_{mM} = \min_i \max_j V_{ij} \quad (7)$$

$$Z_{Mm} = \max_i \min_j V_{ij} \quad (8)$$

$$Z_H = \min_i [\alpha \cdot \max_j (V_{ij}) + (1 - \alpha) \cdot \min_j (V_{ij})] \quad (9)$$

where $0 \leq \alpha \leq 1$ is a parameter indicating planers attitude towards the risk. The value $\alpha = 1$ reduces the Hurwitz' criterion to min–max criterion described above and corresponds to an extremely pessimistic decision-maker. The value $\alpha = 0$ corresponds to an extreme optimism.

3.3. Cost benefit analysis

The cost benefit analysis (CBA) is efficiently integrated into complex methods decision making such as: AHP and ECIGT. A balance is achieved by minimizing the total cost (TOC) gathering all costs in three terms given by the following expression:

$$\begin{aligned} \text{Total cost (TOC)} &= \text{Utility cost (UC)} \\ &+ \text{Customer interruption cost (CIC)} \\ &+ \text{Losses cost (LC)} \end{aligned}$$

The sub-criteria derived from the total cost are defined as follows: for an item k , with a unit capital cost I_k , the updated annual cost is $I_{ak} = I_k \gamma^n (\gamma - 1) / \gamma^{n-1}$. The utility cost for k' items over the period $T = [t_1, t_2]$ of planning updated is:

$$UC_t = \sum_{t=t_1}^{t_2} \sum_{k=1}^{K'} I_{ak}(t) \gamma^{-t} \quad (10)$$

The customer interruption cost (CIC) is used as a substitute in the assessment of reliability-worth in electric power systems [13]. Numerous studies have been conducted to provide estimates of CICs and a wide range of methodologies has evolved. A power network should supply its customers with minimal outages and maximal power quality. This is evaluated using the current total harmonic distortion (ITHD) index which determines the degree to which harmonics distort the sinusoidal wave form of the current in the network and based on expected energy not supplied (EENS) index assessment [14]. The customer interruption cost can be

given by the following expression: $CIC = L(K_p \cdot EFLC^2 + K_w \cdot EDLC)$ or $CIC = L \cdot K_p \cdot EFLC^2 + K_w \cdot EENS$. It is a quadratic function of failures number and the updated value is assessed as follows:

$$CIC_t = K_w \sum_{t=t_1}^{t_2} EENS \cdot \gamma^{-t} + K_p \sum_{t=t_1}^{t_2} L \cdot EFLC^2 \cdot \gamma^{-t} \quad (11)$$

This valorization directs the investments in priority on the most disturbed zones. The losses cost depends on the maximum losses which appear in overhead transmission lines, underground cables and sub-stations. If the dissipated active power in a section k is P_{max} , the annual cost of losses is given by the following expression: $R_k = (K_p + K_w \cdot \theta \cdot T_a) P_{max} \cdot v$, and the total updated losses cost for k' sections, is given as:

$$LC_t = \sum_{t=t_1}^{t_2} \sum_{k=1}^{k'} R_k \cdot \gamma^{-t} \quad (12)$$

where $\gamma^n(\gamma - 1)/\gamma^{n-1}$ is the capital recovery factor (CRF) with $\gamma = i + 1$ and i , the worth rate characterizing the financial policy of the company. The parameters K_w , K_p , θ , v , T_a and n are the tariff of kilowatt-hour (kW h), the tariff of kilowatt (kW), the ratio defining the use of the network, the demand variation factor, the annual use duration of the network and the year of use, respectively.

Finally, the optimum reliability level is determined by minimizing the expected cost as:

$$ECOST_t = UC_t + LC_t + CIC_t \quad (13)$$

Compared to the formulation of the ECOST given in Ref. [15], the formula given by Eq. (13) includes the cost of the loss of quality.

4. Criteria definition and alternatives identification

4.1. Criteria definition

Deregulation of electric power industry has motivated electricity customers to pay more attention in evaluating both the direct cost of electric service and the monetary value of the reliable electric service [16]. To evaluate the service reliability value, three cost sub-criteria quantifying utility cost (UC), customer interruption cost (CIC) and losses cost (LC) were developed in Section 3 of the present paper in the cost–benefit analysis context. The primary objective of an energy producer and distributor is to acquire quality product that satisfies user needs (customer) with measurable improvements to mission capability and operational support in at a fair and reasonable price. Reliability (R), availability (A) and maintainability (M) are addressed as essential elements of mission capability. These elements are three related characteristics of a system and its operational support. From technical point of view they are defined as follows.

Reliability is the probability of an item to perform a required function under stated conditions for a specified period of time. It is further divided into mission reliability and logistics reliability. Analysis of recurrence data from repairable systems and analysis of lifetime data for components and non-repairable units require different statistical models and methods of analysis [17]. However, in all cases, reliability should be defined with respect to a well-defined mission and condition of use. In addition to consider it as a probability, in the case of electric power system, reliability can be treated on the basis of a well-known indices, namely: expected frequency of load curtailment (EFLC (fault/yr)), expected duration of load curtailment (EDLC (h/yr)), expected duration of a curtailment (EDC (hrs)) and expected energy not supplied (EENS (kWh/yr)) [18], expressed by the following equations, respectively:

$$EFLC = \sum_{k=1}^n \lambda_k \quad (14)$$

$$EDLC = \sum_{k=1}^n \lambda_k T_k \quad (15)$$

$$EENS = L \cdot EDLC \quad (16)$$

where λ_k , T_k are the failure rate and the failure duration of an item k , respectively and L is the load. Availability, as measured by the user, is a function of how often failures occur and corrective maintenance is required, how quickly indicated failures can be isolated and repaired, how quickly preventive maintenance tasks can be performed, and how long logistics support delays contribute to down time. Maintainability is the ability of an item to be retained in, or restored to, a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair. Therefore, in practice, before recording a maintenance action, it is useful to ensure its applicability which is the resultant of ease of implementation and effectiveness of its results. Achieving power quality of power systems affects all connected electrical and electronic equipment. It is a measure of deviations in voltage and frequency of the particular supply system. In recent years, there has been a considerable increase in nonlinear loads; in particular distributed loads, such as computers, TV monitors and lighting. These draw harmonic currents which, when distorted, have detrimental effects including interference, loss of reliability, increased operating costs, equipment overheating, motor failures, capacitor failure and inaccurate power metering. It has been discovered that the 85% of power supply malfunctions attributed to poor power quality are caused by voltage sag or interruptions of less than a second duration [19]. Recently, new technologies like custom power devices based on power electronic concepts have been developed to provide protection against power quality problems.

4.2. Alternatives identification and development

Based on the level of performances of the electric power system at the actual state, when the fixed objectives are not satisfied; technical and organizational measures should be taken to ensure its improvement; they are translated as follows:

- Intensification of the maintenance operations, to reduce the number of failures.
- Reorganization of the networks for more flexibility in failure conditions, by building more high voltage/medium voltage (HV/MV) stations, so that lengths of outgoing MV transmission lines will be decreased.
- Automation of networks by adding remote control switches on outgoing MV lines to better control restoration of supply and to limit the interruption duration, and the geographical area affected by failures.
- Realization of work under voltage and automation of failure research by installing fault detectors.
- Load transfer between feeders, undergrounding circuits and replacement of aging equipment [20].

These actions are grouped in four alternatives, as follows:

- Alternative 1 (A_1): Corresponds to the actual state of the electric power system under study.
- Alternative 2 (A_2): Faults detectors are installed at each sub-station; consequently the time to fault research is reduced.

- Alternative 3 (A_3): To alternative 2 (A_2), are added remote control switches on outgoing MV lines to reduce the number of customers concerned by a failure.
- Alternative 4 (A_4): Some overhead circuits are undergrounded and sections of the aging cables are replaced by new ones (are concerned the sections with a number of joints exceeding the threshold value).

5. Electric power system under study

It has been frequently observed that a major part of service interruptions experienced by individual customer, has its origin in the distribution system failures. Therefore a particular interest is given to this part of the network.

The voltage level of the studied distribution system (Bejaia city, Algeria) is medium and about 30,000 V. Each feeder is made up of serial-connected components and consists on a succession of underground and overhead circuits. As shown in Fig. 1, the whole system is in a bridge structure, where the main components are: two HV/MV transformers Tr_1 and Tr_2 with circuit-breakers CB_{HV} and CB_{MV} at the both sides. The key component is the switchgear S_w connecting the MV bare buses. The MV geographical distribution part is partitioned in ten (10) feeders. In normal operating conditions, the feeder structure is radial. If a fault occurs on a feeder, the defaulting section is isolated and the parts not concerned by the fault are rescued from the source side and also from the opening node (N.O) side which will be closed at the occasion. This gives the advantage of looping circuit and allows minimizing the number of load points (Li) disconnected after fault's appearance. Data are derived from collections that are based on interruption reports obtained from the fields in the last 10 years or so [17].

6. Case study application

6.1. Reliability indices and costs evaluation versus alternatives

The application is done on a part of a real distribution system actually under operation where the main inputs are: First, the network topology (serial configuration for feeder), the lengths of sections, the power values at load points, the evolution of the demand tendency and the fault research method. Second, the reliability

parameters of the components dressed in Table 1. These parameters were obtained using a statistical assessment of data, collected over a period of 17 years. The treatment consisted of the selection of numbers of failures for each element of the network, the durations of failures and the response times after a failure or a maintenance action.

Using Eqs. (14)–(16), we have computed the reliability indices and the results are dressed in Table 2 for the four alternatives A_i , $i = 1-4$.

The first information derived from this evaluation is that it is obvious that some reliability indices, such as the failure frequency are not sensitive to certain alternatives. However, the alternatives 2, 3 and 4 have a very visible influence on the reliability indices linked to down time and to energy not supplied. It is shown that these indices are improved depending on the importance of the engaged alternative.

To evaluate the costs versus alternatives, additional inputs are produced with the specificity of the Algerian case and are given as follows:

- $v = 1.07$, this means that the annual evolution of the electricity demand is around 07%.
- $T = 5$ years, is given with relation to the period of government planning; 5-year program period.
- $K_w = 0.6$ US\$ and $K_p = 0.23$ US\$, these values seem quite lower compared to the international values, because electricity price is still partially supported by the government unless the tendency goes to the enterprises autonomy.
- $\theta = 30\%$, this ratio gives an idea that in Bejaia city, the electric network is not used at its nominal level. This is due to the absence of strong industrial activities, and the city is in developing stage. However, $T_d = 8760$ h, gives the total hours in the year.

From practical point of view, the alternatives are described with the enumeration of items' costs as follows:

- Alternative A_1 is carried without investments;
- Alternative A_2 corresponds to the installation of 205 fault indicators on the system where the unit cost is $I_f = 600$ US\$.
- Alternative A_3 corresponds to A_2 with the addition of five reclosers in line where the unit cost is $I_r = 3500$ US\$.
- Alternative A_4 , as described above, corresponds to undergrounding a length of 2.75 km of cable (70 mm²) and replacing a length of 7.25 km of oldest sections. The cost of the cable is 18,000 US\$ per km.

The costs per unit given in the investment evaluation are taken following international standards, because the equipment used is imported from abroad, consequently it is entirely supported by the enterprise.

The costs given by Eqs. (10)–(13) were assessed using Matlab 6.5 software package. The obtained results for three distinguished values of the worth rate “ i ” are dressed in Table 3.

The cost-benefit analysis aids to evaluate the importances of sub-criteria relative to cost. For example, the CIC is more important

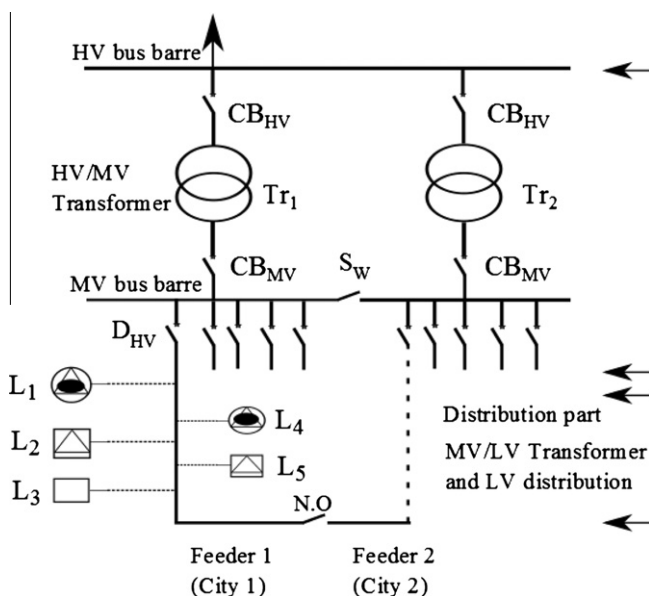


Fig. 1. The electric system under study.

Table 1
System reliability inputs parameters.

System reliability parameters	
t_{gs} : Mean time to travel to a sub-station	15.0 min
t_{rs} : Mean time to repair of an MV/LV sub-station	1200.0 min
t_{rc} : Mean to repair of underground cable	900.0 min
λ_s : Average failure rate of an MV/LV sub-station	0.01(1/yr)
λ_c : Average failure rate of underground cable	0.38 (1/km yr)

Table 2
System reliability indices according to alternatives.

Overall system reliability indices	Alternatives (A_i)			
	A_1	A_2	A_3	A_4
EFLC (fault/yr)	2.716	2.716	2.716	0.464
EDLC (h/yr)	826.6	604.0	322.0	164.0
EENS (kW h/yr)	80320.0	58650.0	31380.0	16020.0
MDF (h)	4.1	2.8	1.8	0.8

Table 3
The matrix of costs (US\$) versus alternatives.

Worth rate values	$i = 0.02$	$i = 0.03$	$i = 0.04$
Alternatives			
A_1	52108	50629	48215
A_2	49671	53683	57655
A_3	33923	38863	43625
A_4	858320	833970	810680

than the LC. It is shown that the costs are highest when using alternative 4. This means that to achieve a high level of performance, it is necessary to go through an important investment which is a necessity especially in the case of aging and overhead networks.

6.2. Analytic hierarchy process implementation

The application of the AHP method follows the sixth steps enumerated in Section 3. This first step is summarized in a flowchart given in Fig. 2.

The second step is the pair-wise comparison of the importance of criteria, this is done by assigning a weight between 1 and 9 [21] and the reciprocal of this value is then assigned to the other criterion in the pair. The first results are given in Table 4, and correspond to the pair-wise comparison of the main criteria with respect to the goal.

Table 5
Pair-wise comparison matrix of the sub-criteria with respect to the cost.

	LC	CIC	UC	Priorities
Losses cost (LC)	1	1/3	1/6	0.0914
Customer interruption cost (CIC)	3	1	1/4	0.2176
Utility cost (UC)	6	4	1	0.6910

Table 6
Pair-wise comparison matrix of the sub-criteria with respect to the reliability.

	Ag	EDLC	EFLC	Priorities
Aging (Ag)	1	1/3	1/5	0.1047
Expected duration load curtailment (EDLC)	3	1	1/3	0.2583
Expected frequency load curtailment (EFLC)	5	3	1	0.6370

The third step is to extract the relative importance implied by the previous comparisons. In the judgment matrix with pair-wise comparisons, the corresponding maximum left eigenvector is approximated by using the geometric mean of each row. Next, the numbers are normalized by dividing them with their sum [22]. To assess the priority vector P_j (eigenvector), the maximum eigenvalue λ_{\max} , the consistency index CI and the consistency ratio CR using Eqs. (1)–(4) respectively, we have developed a program under Matlab 6.5 software package where the algorithm is given as follows:

Step 0: Read the inputs

- The judgment matrix order N .
- The elements of the judgment matrix $q_{ij}, i = 1 : N, j = 1 : N$, the relative consistency index RCI value corresponding to N .

Step 1: Compute the geometric means, $m(i) \leftarrow \left(\prod_{j=1}^N Q(i,j) \right)^{\frac{1}{N}}$ for $i = 1 : N$.

Step 2: Compute the priorities, $P(i) \leftarrow \frac{m(i)}{\sum_{l=1}^N m(l)}$ for $i = 1 : N$.

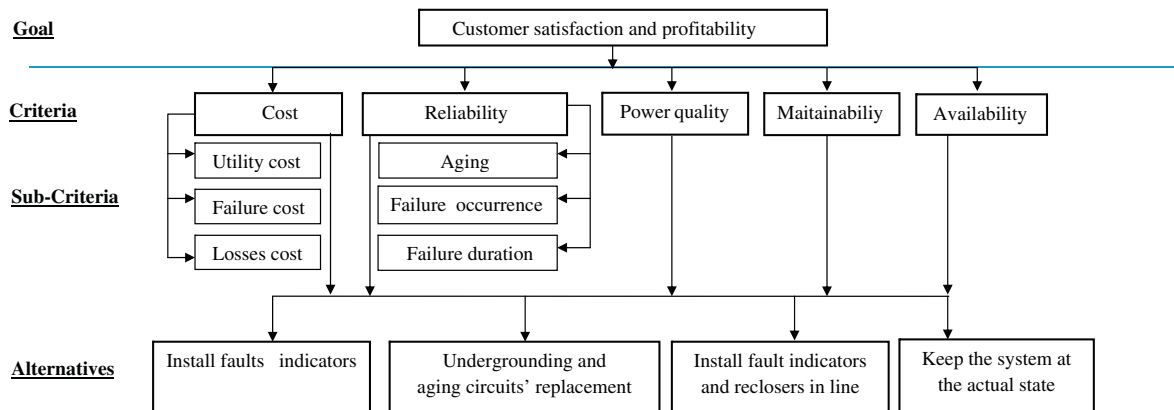


Fig. 2. Decomposition of the problem into hierarchy.

Table 4
Pair-wise comparison matrix of the main criteria with respect to the goal.

	Power quality	Maintainability	Availability	Reliability	Cost	Priorities
Power quality	1	1/4	1/4	1/6	1/8	0.0352
Maintainability	4	1	1/3	1/4	1/7	0.0721
Availability	4	3	1	1/3	1/7	0.1185
Reliability	6	4	3	1	1/2	0.2715
Cost	8	7	7	2	1	0.5027

Table 7

Comparison matrices and local priorities.

P Q	A ₁	A ₂	A ₃	A ₄	Priority	A	A ₁	A ₂	A ₃	A ₄	Priority	M	A ₁	A ₂	A ₃	A ₄	Priority
A ₁	1	1	1/3	1/7	0.0797	A ₁	1	1/3	1/5	1/7	0.0537	A ₁	1	1/5	1/2	2	0.1432
A ₂	1	1	1/2	1/6	0.0917	A ₂	3	1	1/3	1/5	0.1151	A ₂	5	1	1/2	3	0.3543
A ₃	3	2	1	1/5	0.1787	A ₃	5	3	1	1/4	0.2394	A ₃	2	2	1	3	0.3985
A ₄	7	6	5	1	0.6499	A ₄	7	5	4	1	0.5918	A ₄	1/2	1/3	1/3	1	0.1040
$\lambda_{\max} = 4.0649CI = 0.0216CR = 0.0240$						$\lambda_{\max} = 4.1776CI = 0.0592CR = 0.0658$						$\lambda_{\max} = 4.2990CI = 0.0997CR = 0.0110$					
Ag	A ₁	A ₂	A ₃	A ₄	Priority	EDLC	A ₁	A ₂	A ₃	A ₄	Priority	EFLC	A ₁	A ₂	A ₃	A ₄	Priority
A ₁	1	1	1/3	1/6	0.0937	A ₁	1	1/3	1/5	1/7	0.0537	A ₁	1	1	1/3	1/7	0.0756
A ₂	1	1	1/2	1/4	0.1147	A ₂	3	1	1/3	1/5	0.1151	A ₂	1	1	1/3	1/5	0.0756
A ₃	3	2	1	1/3	0.2295	A ₃	5	3	1	1/4	0.2394	A ₃	3	3	1	1/6	0.1790
A ₄	6	4	3	1	0.5621	A ₄	7	5	4	1	0.5918	A ₄	7	7	6	1	0.6698
$\lambda_{\max} = 4.0412CI = 0.0137CR = 0.0153$						$\lambda_{\max} = 4.1776CI = 0.0592CR = 0.0658$						$\lambda_{\max} = 4.1135CI = 0.0378CR = 0.0420$					
LC	A ₁	A ₂	A ₃	A ₄	Priority	CIC	A ₁	A ₂	A ₃	A ₄	Priority	UC	A ₁	A ₂	A ₃	A ₄	Priority
A ₁	1	1	2	1/6	0.1279	A ₁	1	1/3	1/5	1/7	0.0539	A ₁	1	3	5	7	0.5627
A ₂	1	1	2	1/6	0.1279	A ₂	3	1	1/3	1/6	0.1103	A ₂	1/3	1	2	6	0.2487
A ₃	1/2	1/2	1	1/7	0.0733	A ₃	5	3	1	1/3	0.2579	A ₃	1/5	1/2	1	4	0.1398
A ₄	6	6	7	1	0.6709	A ₄	7	6	3	1	0.5779	A ₄	1/7	1/6	1/4	1	0.0488
$\lambda_{\max} = 4.0365CI = 0.0122CR = 0.0135$						$\lambda_{\max} = 4.1256CI = 0.0419CR = 0.0465$						$\lambda_{\max} = 4.1344CI = 0.0448CR = 0.0498$					

Table 8

Final results using synthesis.

Criteria	C	R	A	M	P.Q.	Overall priority
Priorities	0.5027	0.5027	0.5027	0.2715	0.2715	0.2715
Sub-criteria	UC	CIC	LC	Ag	EFLC	EDLC
Priorities	0.6910	0.2176	0.0914	0.1047	0.6370	0.2583
A ₁	0.5627	0.0539	0.1279	0.0937	0.0756	0.0537
A ₂	0.2487	0.1103	0.1279	0.1147	0.0756	0.1151
A ₃	0.1398	0.2579	0.0733	0.2295	0.1790	0.2394
A ₄	0.0488	0.5779	0.6709	0.5621	0.6698	0.5918

Table 9

Synthesizing results for sensitivity analysis.

Criteria	C	R	A	M	P.Q.	Overall priority
Priorities	0.1660	0.1660	0.1660	0.3765	0.3765	0.3765
Sub-criteria	UC	CIC	LC	Ag	EFLC	EDLC
Priorities	0.6910	0.2176	0.0914	0.1047	0.6370	0.2583
A ₁	0.5627	0.0539	0.1279	0.0937	0.0756	0.0537
A ₂	0.2487	0.1103	0.1279	0.1147	0.0756	0.1151
A ₃	0.1398	0.2579	0.0733	0.2295	0.1790	0.2394
A ₄	0.0488	0.5779	0.6709	0.5621	0.6698	0.5918

Step 3: Compute the spectra of the matrix QJ, $SPQJ \leftarrow eig(QJ)$.

Step 4: Determinate the maximum of the eigenvalues of QJ, $\lambda_{\max} \leftarrow \max(SPQJ)$.

Step 5: Compute the consistency index CI, $CI \leftarrow (\lambda_{\max} - N)/(N - 1)$.

Step 6: Compute the consistency rate CR, $CR \leftarrow CI/RCI$.

Step 7: End.

The validity of the obtained results was confirmed by comparing them with those obtained using software developed by Whittaker and Adams [23]. The pair-wise matrices of the sub-criteria with respect to both cost and reliability are given in Tables 5 and 6, respectively.

In the fourth step, is checked the consistency of judgments and all particular results of comparison between the sub-criteria and alternatives are summarized in Table 7.

Column's values "Priority" dressed in Table 7 constitute the elements of Table 8 where the synthesis corresponding to the rankings of the four alternatives against the nine criteria and

Table 10

Example illustrating the expected cost and Laplace's criterion.

Scenarios	Weights	Alternatives (strategies)			
		A ₁	A ₂	A ₃	A ₄
Scenario 1	0.15	52,108	49,671	33,923	858,320
Scenario 2	0.70	50,629	53,683	38,863	833,970
Scenario 3	0.15	49,215	57,555	43,625	810,680
Expected cost	$\sum Q_i V_{ij}$	50,638	53,662	38,800	834,129
Mean	$\frac{1}{n} \sum (V_{ij})$	50,650	53,636	38,803	834,323
Minimum	$\max_i (V_{ij})$	52,108	57,555	43,625	858,320
Minimum	$\min_i (V_{ij})$	49,215	49,671	33,923	810,680

sub-criteria confounded is given. With this synthesis, we come to the final step involving the final decision of this process.

For customer satisfaction, based on alternatives proposed initially, the highest priority is given to alternative A₄. To judge

Table 11

Alternative's costs versus economic criteria inspired from game theory.

Alternatives	Laplace criterion	Wald criterion (Max–min)	Hurwitz criterion	Min–max criterion	Bayes–Laplace criterion
<i>Criteria</i>					
A ₁	50650	49215	50660	52108	51010
A ₂	53640	49671	53610	57555	52640
A ₃	<u>38800</u>	33923	38770	<u>43625</u>	<u>37580</u>
A ₄	834320	<u>810680</u>	<u>834500</u>	858320	840320

the dominance of certain criteria relatively to each other and to decide about objectivity of the choice set, we have introduced the concept of the sensitivity analysis, by modifying the importance values of certain criteria. Proposals are made by assigning greater weights to the quality of power and to reliability compared to the cost, and changes are made for others criteria. Table 8 is reproduced, where changes are apparent in the first line corresponding to the priorities assigned to criteria. The sensitivity analysis results are given in Table 9.

The high score recorded by the alternative 4 was confirmed looking to the scores deduced from the overall priority shown in the right column of Table 9. These scores highlight the effectiveness of the retained alternative on the reliability indices.

6.3. Economic criteria inspired from game theory implementation

On the basis of the assessment of the costs of different alternatives, various economic criteria were considered using the expressions given by the equations noted from 5 to 9. The results of an example illustrating the expected cost assessment considering the Laplace's criterion are given in Table 10. However, the results of the computation for the whole criteria are dressed in Table 11.

The underlined results in Table 11 indicate the costs retained using economic criteria inspired from game theory and consequently highlight their corresponding alternatives following the considered criteria. The probabilities assigned to the worth rate, for the Bayes–Laplace criterion, are respectively 0.15, 0.70, and 0.15. In the field of electrical networks, and under the context of the current economic crisis, it is shown that customer satisfaction also depends on the attitude of the manager and on his vision to the investment policy. It has been proven that high performances of systems lead to customer satisfaction, which in turn encourages consumption and therefore creates wealth. The optimistic option should be supported by the decision-makers to generate growth and the austerity, in turn should be avoided.

7. Discussions and conclusion

It is important for any power enterprise to analyse customer satisfaction. First, they will gather information concerning the trends in market demand for the power service in order to supply a better individualized service. Second, a regular and long-term tracking analysis of customer satisfaction will encourage power enterprises to improve their operations and service. Third, the ultimate goal, to raise profits, will be achieved by cultivating more faithful customers.

For general consumer goods, the effects of actions to enhance performances are immediate. However, in the case of electricity, there is certain inertia, because the measures to be taken to improve performances are considerable. They concern the reorganization of the enterprise and restructuring of the system. This paper deals with two main aspects directly connected to concerns about delays and uncertainty. First, the power customer satisfaction expressed by the requirements of high quality of service at lower cost of electricity and the enterprise profitability are not

possible in the immediate future. Second, the strategies used by the managers for the success of the measures and the consumers' reactions to the objectives are unknown. To make a transparent and an objective analysis, this paper proposes the use of the analytic hierarchy process (AHP) method. This allows system managers to choose the best organizational and technical measures to obtain both customer satisfaction and enterprise profitability. To make a judgment concerning the decision making, we compare the results with those obtained by the application of the economic criteria often used in the case of an uncertain future. The recommendations which resulted from the present paper were well received by the company and some actions have been implemented, namely: the automation of the fault research which contributes to the interruption durations reduction, viewed as one of the customer's requirements.

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