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Decision making on power customer satisfaction and enterprise profitability analysis using the Analytic Hierarchy Process

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The purpose of this paper is to investigate the customer satisfaction of power users using the Analytic Hierarchy Process (AHP) method. The objective is to safeguard the interests of electricity consumers and to increase the profitability of the energy distributer. Compared with previous work based on customer questionnaires describing the level of satisfaction, and where the solution is judged to be random due to the low significance of the studied sample, this paper develops a novel strategy. It is based on a global and transparent process regarding the reliability and economic criteria associated with alternatives, highlighting technical and organisational measures taken by the enterprise. The importance of reliability and economic criteria to the alternatives is processed using reliability indices analysis and cost benefit analysis methods. To analyse the customer's reactions to the decisions taken by the system's manager, and to validate the obtained results using the AHP method, we introduce economic criteria often used in the case of an uncertain future. The obtained results indicate the advantage of investment to improve customer satisfaction and enterprise profitability. It is also shown that reliability criteria are significant in the performance of a business and are an important asset for the justification of new projects.

Keywords: electrical energy system; AHP method; economic criteria; customer satisfaction

1. Introduction

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 individualised 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 effect of actions to enhance performance are immediate. However, in the case of electricity, there is a certain inertia, because the measures to be taken to improve performances are considerable. They concern the reorganisation of the enterprise and restructuring of the system. This paper deals with two main aspects directly related to concerns about delays and uncertainty. First, power customer satisfaction expressed by the requirements of a high quality of service at a lower cost of electricity and enterprise profitability are not possible in the immediate future. Second, the strategies used by managers for the success of the measures and the consumers' reactions to the objectives are unknown. To make a transparent and objective analysis, this paper proposes the use of the Analytic Hierarchy Process (AHP) method. This allows system managers to choose the best organisational and technical measures to obtain both customer satisfaction and enterprise profitability. To make a judgement concerning the decision making, we compare the results with those obtained by the application of economic criteria often used in the case of an uncertain future.

The rest of the paper is organised as follows. Section 2 sets the background for the AHP method and the economic criteria in an uncertain future applied to electrical engineering. Section 3 develops the AHP method applicable in the engineering area. The reliability indices and the cost benefit analysis applied to the case study are presented in Sections 4 and 5, respectively. Section 6 is devoted to the application of the AHP method to a real case study (the electrical system of Bejaia City, Algeria) and the results are discussed. Section 7 presents economic criteria

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for decision making under uncertainty. Finally, the conclusions of the research are presented in Section 8. A list of helpful acronyms is provided in Table 1.

2. Background

In the engineering area, the AHP method has attracted much interest with respect to applications. However, to our knowledge, it has not yet been applied to power customer satisfaction. A review of a total of 150 AHP application papers (1980–2003) is provided by Omkarprasad and Sushil (2006) 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*. (2003) as an expert system to identify the vulnerability of special protection schemes (SPS), and by Malik and Sumaoy (2003) for impact evaluation and logical prioritisation of demand side resources to planning criteria. ANP and AHP processes were jointly used by Chen *et al*. (2009) for the strategic selection of a feeder management system applied to the power industry in China. Customer satisfaction refers to the customer's mental state after comparing the products and services received with their expectations. For its evaluation, in a recent publication, Guo and Niu (2007) developed a method based on a decision tree, where the analysis is conducted by choosing 20 customer questionnaires. The solution is judged to be random due to the low significance of the considered study sample. The evaluation index system corresponds to quality, service, sensibility and liability. Regarding decision making under uncertainty in the electrical engineering field, some investigations (Voropai and Ivanova 2003, Ivanova and Varopai 2004) have been conducted 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 behaviour of the other concerned subjects and the problem can be associated with the game statement. The most commonly used criteria in the present paper are the Laplace–Bayes criterion, the Wald or maxi–min criterion, the Savage or mini–max Regret criterion and the Hurwitz criteria. Three scenarios are considered: when consumers are unsatisfied, they react only weakly to the initiative taken by the power supply company and it is difficult for the latter to recover unpaid bills; when they are satisfied, the response is firm, but not aggressive, the recovery of unpaid bills is possible, but consumers are not encouraged to invest and to increase consumption; however, when they are quite satisfied, they react quickly and forcefully. In addition to the recovery and investment agreement, they accept to contribute financially to quality of service improvement.

Table 1. List of abbreviations.

Abbreviation	Description
A	Availability
A_i	Alternative
Ag	Aging
AHP	Analytic hierarchy process
ANP	Analytic network process
C	Cost
C_i	Criterion i
CBA	Cost–benefit analysis
CIC	Customer interruption cost
CRF	Capital recovery factor
EDC (h)	Expected duration of a curtailment
EDLC (h/yr)	Expected duration of load curtailment
EFLC (faults/yr)	Expected frequency of load curtailment
EENS (kWh/yr)	Expected energy not supplied
L	Load
LC	Losses cost
M	Maintainability
MDF	Mean duration of a fault
PQ	Power quality
R	Reliability
TOC	Total cost
UC	Utility cost

3. Analytic hierarchy process method

The procedure for using the AHP is summarised as follows (Saaty and Peniwati 2008).

(1) Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it and the criteria for evaluating the alternatives.
(2) Establish priorities among the elements of the hierarchy by making a series of judgments based on pair-wise comparisons of the elements.
(3) Synthesise 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) Analyse the sensitivity to changes in judgment to study the margin of stability and the decision.

Let us consider AA the $n \times n$ matrix of elements a_{ij} representing a quantified judgment on a pair of elements C_i and C_j,

$$AA = [a_{ij}] = \begin{pmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ . & . & \cdots & . \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{pmatrix}. \tag{1}$$

In matrix AA, the problem becomes one of assigning to the n elements $C_1, C_2, \ldots, C_n$ a set of numerical weights $W_1, W_2, \ldots, W_n$ that reflects the recorded judgments. If AA is a consistency matrix, the relations between weights W_i and judgments a_{ij} are simply given by $a_{ij} = W_j/W_i$ (for i, $j = 1, 2, \ldots, n$). The largest eigenvalue $\lambda_{\max}$ is given by (Saaty 1990)

$$\lambda_{\max} = \sum_{j=1}^{n} a_{ij} \frac{W_j}{W_i}. \tag{2}$$

If AA is a consistency matrix, the eigenvector X can be calculated from

$$(AA - \lambda_{\max} I)X = 0. \tag{3}$$

The consistency index (CI) and the consistency ratio (CR) have been proposed to verify the consistency of the comparison matrix. It is found that (Saaty 2008)

$$CI = \frac{\lambda_{\max} - n}{n - 1}. \tag{4}$$

In the AHP, pair-wise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding CR is less than 10%. Many questions revolve around this value of 0.10, which is considered excessive by many users of this method. Saaty (2006) states that the requirement of 10% cannot be made smaller such as 1% or 0.1% without trivialising the impact of inconsistency. But inconsistency itself is important because, without it, new knowledge that changes preferences cannot be admitted. To the question: how to use the analytic hierarchy process in the context of customer satisfaction and profitability analysis? The answer is target reliability allocation, planning, cost benefit analysis and conflict resolution. An application of this method for a real case study is given in Section 6 and the results are discussed.

4. Reliability indices analysis

The reliability criteria for power customer satisfaction evaluation are selected from commonly used reliability indices (Endrenyi 1978, Billinton and Wangdee 2007) such as: expected frequency of load curtailment, expected duration of load curtailment, expected duration of a curtailment and expected energy not supplied. Regarding these developments, the investigation of Yang (2007) for a manufactured product is extended to electricity services. Power customer satisfaction is expressed as follows: n important customer's wants (what they need) power availability,

Table 2. System reliability input parameters.

System reliability parameter	
t_{g^s}, mean time to travel to sub-station	15.0 min
t_{r^s}, mean time to repair an MV/LV sub-station	1200.0 min
t_{r^c}, mean time to repair an 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)

power quality, a proper and aesthetic environment and safe supply, denoted $E_1, E_2, \ldots, E_n$, and these are linked to m critical performance characteristics (EFLC, EDLC, EDC and EENS) denoted $Y_1, Y_2, \ldots, Y_m$. The thresholds of $Y_1, Y_2, \ldots, Y_m$ are $D_1, D_2, \ldots, D_m$, respectively. The degree of customer satisfaction for E_i can be expressed as the probability that the critical performance characteristics values do not exceed the threshold values, and can be written as $S_i = \Pr(Y_j \leq D_j)$, $i = 1, 2, \ldots, m$. Nearly every electricity utility computes reliability indices on an annual basis. The most important criteria for decision-making are

$$EFLC = \sum_{k=1}^{n} \lambda_k, \tag{5}$$

$$EDLC = \sum_{k=1}^{n} \lambda_k T_k, \tag{6}$$

$$EENS = L \cdot (EDLC), \tag{7}$$

where λ_k and T_k are, respectively, the failure rate and the failure duration of item k, and L is the load curtailed at a considered load point. Table 2 shows the input parameters for the current state of the system under study. The studied system is part of a distribution system of Bejaia City, Algeria, actually in operation.

In addition to the above parameters, it is necessary to provide others such as network topology, section lengths, the power value at load points and its evolution and the fault search method. The overall system reliability indices results are shown in Table 3.

The average of the annual interruption rate per km is very significant ($\lambda_c = 0.38$ (1/km · yr)) compared with the results obtained in the case of well maintained lines. To improve reliability, technical and organisational measures are considered during system planning and operation.

The actions currently carried out are as follows.

(a) Intensifying maintenance operations to reduce the number of failures.
(b) Reorganisation of the networks for more flexibility in failure conditions by building more high-voltage/medium-voltage (HV/MV) stations, so that the lengths of the outgoing MV transmission lines will be reduced.
(c) Automation of networks by adding remote control switches on outgoing MV lines to limit the interruption duration and to reduce the geographical area affected by failures.
(d) Realisation of work under voltage and automation of failure research by installation of fault detectors.
(e) Load transfer between feeders, undergrounding circuits and replacement of aging equipment.

These actions are carried out on three principal alternatives A_i ($i = 2$, 3 and 4). The actual state of the system is added as the fourth and denoted A_1. These alternatives are described as follows.

- **Alternative 1 (A_1):** Do nothing new and keep the system functioning routinely.
- **Alternative 2 (A_2):** Install fault detectors at each sub-station, and consequently the time t_{gs} for fault search decreases from 15.0 to 05.0 min.
- **Alternative 3 (A_3):** Add to alternative A_2 remote control switches on outgoing MV lines to reduce the number of customers affected by a failure.

Table 3. System reliability indices of the current state.

Overall system reliability index	
Expected frequency of load curtailment (EFLC (faults/yr))	2.716
Expected duration of load curtailment (EDLC (h/yr))	826.6
Expected energy not supplied (EENS (kWh/yr))	80,320.0
Mean duration of a fault (MDF (h))	4.1

Table 4. System reliability indices according to alternatives.

Overall system reliability indices	Alternative (A_i)			
	A_1	A_2	A_3	A_4
EFLC (faults/yr)	2.716	2.716	2.716	0.464
EDLC (h/yr)	826.6	604.0	322.0	164.0
EENS (kWh/yr)	80,320.0	58,650.0	31,380.0	16,020.0
MDF (h)	4.1	2.8	1.8	0.8

- **Alternative 4 (A_4):** Underground the overhead circuits and change aging cables (sections exceeding the threshold number of joints). The failure rate falls from 0.38 to 0.04 ($1/\text{km}\cdot\text{yr}$). The obtained results are shown in Table 4 and constitute prerequisite knowledge aiding the expert judgment.

Comparison of the results is performed with respect to the influence of the latter on the allocation of weights by experts to the various proposed alternatives. Compared with the first reliability index, it is obvious that Alternative 4 must have the largest weight and is more important than the other alternatives, because the gap is very significant. For the other three reliability indices, the weights of the alternatives increase from the first to the fourth.

5. Cost–benefit analysis

Cost–benefit analysis (CBA) is a common technique used for decision-making. CBA evaluates the costs and benefits of the alternatives on a monetary basis. A balance is achieved by minimising the total cost (TOC) given by the following expression:

$$\text{Total cost (TOC)} = \text{Utility cost (UC)} + \text{Customer interruption cost (CIC)} + \text{Losses cost (LC)}.$$

In the present paper, based on load flow techniques for power loss evaluation, the cost of losses is computed using Equation (10). During the planning and operation of an electrical system, the company invests in the acquisition of multiple components where the lifetimes could be either greater or shorter than the planning period. The system planner has to take out the cost of the residual lifetime of the item at the end of the planning period as shown by Equation (8), or has to define and to consider the annual capital cost of the item as shown by Equation (9). The formula currently used for the cost function is (Medjoudj and Aissani 2002)

$$\min E\left[\sum_{t=1}^{T} \frac{UC_t + CIC_t + LC_t}{(1+i)^t} - \frac{V_{T+1}}{(1+i)^{T+1}}\right], \tag{8}$$

where E is the expectation operator, taking into account the random variables that affect the system, T is the planning horizon, t is the time step index, V_{T+1} is the practical value of the system at the end of the planning period, and i is the present value characterising the financial policy of the company. This rate allows us to express the

Capital Recovery Factor (Billinton and Wangdee 2007), given by $CRF=\gamma^n(\gamma-1)/(\gamma^n-1)$, with $\gamma=i+1$ and n the year of use.

Let I_k be the unit capital cost of item k. The annual capital updated cost of item k is given by

$$I_{ak}=I_k\frac{\gamma^n(\gamma-1)}{(\gamma^n-1)}.$$

The total utility cost of k' items over the period $T=[t_1,\ t_2]$ of the updated planning is

$$UC_t=\sum_{t=t_1}^{t_2}\sum_{k=1}^{k'}I_{ak}(t)\gamma^{-t}. \tag{9}$$

The maximum losses correspond to the value of the active power $P_{\max}$ in the overhead transmission lines, underground cables and sub-stations. The annual cost of losses in section k is $R_k=(K_p+K_w\theta T_a)P_{\max}\upsilon$, with K_w the tariff per kilowatt-hour (kWh), K_p the tariff per kilowatt (kW), θ the ratio defining the proportion of the network in use, υ the demand variation factor, and $T_a=8760$ h. The total updated losses for k' sections is

$$LC_t=\sum_{t=t_1}^{t_2}\sum_{k=1}^{k'}R_k\gamma^{-t}. \tag{10}$$

The customer interruption cost is mainly experienced by users of the network. This cost is a function of the reliability indices and is given by $CIC=L\cdot(K_p\cdot EFLC^2+K_w\cdot EDLC)$ or $CIC=L\cdot(K_p\cdot EFLC^2+K_w\cdot ENNS)$. CIC is a quadratic function of the number of failures. Consequently, its value directs investments to the most disturbed zones in priority order. The updated customer interruption cost is then given by

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

Finally, the optimum reliability level is determined by minimising the expected cost

$$ECOST_t=UC_t+LC_t+CIC_t. \tag{12}$$

The application is carried out for all of the alternatives, where the common parameters for computation are as follows: $\upsilon=1.07$, $T=5$ years, $K_w=\$$US 0.6, $K_p=\$$US 0.23, $\theta=30\%$ and $T_a=8760$ h. From a practical point of view, the alternatives are described with the enumeration of item costs as follows (Medjoudj *et al.* 2011):

- Alternative A_1 is carried out without investments.
- Alternative A_2 corresponds to the installation of 205 fault indicators in the system, where the unit cost is $I_f=\$$US 600.
- Alternative A_3 corresponds to alternative A_2 with the addition of five reclosers in the line, where the unit cost is $I_r=\$$US 3500.
- Alternative A_4, as described above, corresponds to undergrounding 2.75 km of cable (70 mm^2) and replacing 7.25 km of the oldest sections. The cost of the cable is $US 18,000 per km.

The obtained results for cost assessment using the Matlab 6.5 software package are shown in Table 5, and the computation is performed for three values of the worth rate i.

The cost–benefit analysis aids in evaluating the importance of the sub-criteria relative to the costs. For example, the CIC is more important than the LC. The notion of criteria importance is developed in the following section dedicated to the application of the AHP method.

6. Application of the AHP method to a case study

The case study considered in this section consists of the application of the AHP method for power customer satisfaction. The system studied is a part of the electrical distribution system of Bejaia City (Algeria). Five selection criteria C_j (for $j=1,2,3,4$ and 5) are considered to be relevant to this case study and are, respectively: cost, reliability, availability, maintainability and power quality. Three sub-criteria are associated with the cost criterion

Table 5. Matrix of costs (US dollars) versus alternatives.

Alternative	Worth rate $i=0.02$	$i=0.03$	$i=0.04$
A_1	52,108	50,629	49,215
A_2	49,671	53,683	57,655
A_3	33,923	38,863	43,625
A_4	858,320	833,970	810,680

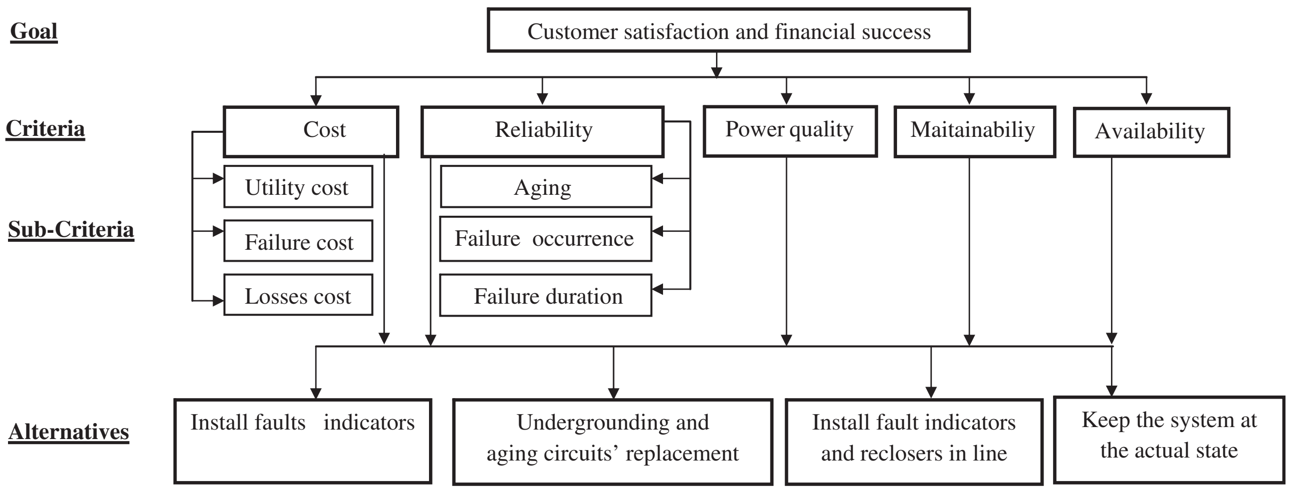

Figure 1. Decomposition of the problem into hierarchies.

C_1: UC, LC and CIC, given respectively by Equations (9), (10) and (11). Three sub-criteria are associated with the reliability criterion C_2: aging or degradation (Ag), EFLC and EDLC expressed by Equations (5) and (6). Four alternatives are selected, denoted by A_i (for $i=1,2,3$ and 4), already developed in Section 5. This first step is summarised in the flowchart shown in Figure 1.

The second step is a pair-wise comparison of the importance of the criteria. This is done by assigning a weight between 1 and 9 (Saaty 1990, Triantaphyllou *et al.* 1997) and the reciprocal of this value is then assigned to the other criterion in the pair. The results are given in Table 6 and correspond to the pair-wise comparison of the main criteria with respect to the goal.

The third step consists of the extraction of the relative importance implied by the previous comparisons. Given a judgment matrix with pair-wise comparisons, the corresponding maximum left eigenvector is approximated by using the geometric mean of each row. The numbers are then normalised by dividing them by their sum (Saaty 2008). The pair-wise matrices of the sub-criteria with respect to both cost and reliability are given in Tables 7 and 8, respectively.

In the fourth step, the consistency of the judgments is checked using Equations (2), (3) and (4). The results of this operation are shown in Table 9.

We note that the priority vector P_j (eigenvector), the maximum eigenvalue λ_{max}, the consistency index CI and the consistency ratio CR are processed using a program under the Matlab 6.5 software package. The algorithm describing the steps is given as follows.

Step 0: Read the inputs.

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

Table 6. Pair-wise comparison matrix of the main criteria with respect to customer satisfaction.

	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. Pair-wise comparison matrix of the sub-criteria with respect to 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 8. Pair-wise comparison matrix of the sub-criteria with respect to 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

Table 9. Comparison matrices and local priorities.

PQ	A_1	A_2	A_3	A_4	Priority
A_1	1	1	1/3	1/7	0.0797
A_2	1	1	1/2	1/6	0.0917
A_3	3	2	1	1/5	0.1787
A_4	7	6	5	1	0.6499
$\lambda_{max} = 4.0649$ $CI = 0.0216$ $CR = 0.0240$					

A	A_1	A_2	A_3	A_4	Priority
A_1	1	1/3	1/5	1/7	0.0537
A_2	3	1	1/3	1/5	0.1151
A_3	5	3	1	1/4	0.2394
A_4	7	5	4	1	0.5918
$\lambda_{max} = 4.1776$ $CI = 0.0592$ $CR = 0.0658$					

M	A_1	A_2	A_3	A_4	Priority
A_1	1	1/5	1/2	2	0.1432
A_2	5	1	1/2	3	0.3543
A_3	2	2	1	3	0.3985
A_4	1/2	1/3	1/3	1	0.1040
$\lambda_{max} = 4.2990$ $CI = 0.0997$ $CR = 0.0110$					

Ag	A_1	A_2	A_3	A_4	Priority
A_1	1	1	1/3	1/6	0.0937
A_2	1	1	1/2	1/4	0.1147
A_3	3	2	1	1/3	0.2295
A_4	6	4	3	1	0.5621
$\lambda_{max} = 4.0412$ $CI = 0.0137$ $CR = 0.0153$					

EDLC	A_1	A_2	A_3	A_4	Priority
A_1	1	1/3	1/5	1/7	0.0537
A_2	3	1	1/3	1/5	0.1151
A_3	5	3	1	1/4	0.2394
A_4	7	5	4	1	0.5918
$\lambda_{max} = 4.1776$ $CI = 0.0592$ $CR = 0.0658$					

EFLC	A_1	A_2	A_3	A_4	Priority
A_1	1	1	1/3	1/7	0.0756
A_2	1	1	1/3	1/5	0.0756
A_3	3	3	1	1/6	0.1790
A_4	7	7	6	1	0.6698
$\lambda_{max} = 4.1135$ $CI = 0.0378$ $CR = 0.0420$					

LC	A_1	A_2	A_3	A_4	Priority
A_1	1	1	2	1/6	0.1279
A_2	1	1	2	1/6	0.1279
A_3	1/2	1/2	1	1/7	0.0733
A_4	6	6	7	1	0.6709
$\lambda_{max} = 4.0365$ $CI = 0.0122$ $CR = 0.0135$					

CIC	A_1	A_2	A_3	A_4	Priority
A_1	1	1/3	1/5	1/7	0.0539
A_2	3	1	1/3	1/6	0.1103
A_3	5	3	1	1/3	0.2579
A_4	7	6	3	1	0.5779
$\lambda_{max} = 4.1256$ $CI = 0.0419$ $CR = 0.0465$					

UC	A_1	A_2	A_3	A_4	Priority
A_1	1	3	5	7	0.5627
A_2	1/3	1	2	6	0.2487
A_3	1/5	1/2	1	4	0.1398
A_4	1/7	1/6	1/4	1	0.0488
$\lambda_{max} = 4.1344$ $CI = 0.0448$ $CR = 0.0498$					

Step 1: Compute the geometric means,

$$m(i) \leftarrow \left(\prod_{j=1}^{N} A(i,j)\right)^{1/N}, \quad \text{for } i = 1 : N.$$

Step 2: Compute the priorities,

$$P(i) \leftarrow \frac{m(i)}{\sum_{l=1}^{N} m(l)}, \quad \text{for } i = 1 : N.$$

Step 3: Compute the spectra of matrix AA,

$$SPA \leftarrow eig(AA).$$

Step 4: Determinate the maximum of the eigenvalues of AA,

$$lambdamax \leftarrow max(SPA).$$

Step 5: Compute the consistency index CI,

$$CI \leftarrow \frac{lambdamax - N}{(N-1)}.$$

Step 6: Compute the consistency rate CR,

$$CR \leftarrow \frac{CI}{RCI}.$$

Step 7: End.

The synthesis corresponding to the rankings of the four alternatives against the nine criteria and sub-criteria is given in Table 10. With this synthesis, we come to the final step involving the final decision of this process.

For customer satisfaction, based on the four alternatives proposed initially, the highest priority is given to alternative A_4.

Sensitivity analysis is carried out by modifying the importance values for the criteria. Proposals are made by assigning a greater weight to the power quality and to reliability compared with the cost. Table 10 shows that changes are apparent in the first line corresponding to the priorities assigned to the criteria. The sensitivity analysis results are given in Table 11.

The high score recorded by Alternative 4 was reinforced looking to the scores deduced from the overall priority shown in the last column of Table 10. These scores highlight the effectiveness of the alternative on the reliability indices.

Note that, according to the AHP method, the priority increases along the lines of increasing investment. This explains why, in the case of customer satisfaction and profit research during medium- and long-term planning, it makes sense to enhance reliability in order to reduce the undistributed energy and consequently reduce the loss to the company. This is only possible by strengthening the network structure and automation equipment. This requires much investment.

7. Decision making under uncertainty

The strategies used by managers for the success of the measures and the consumer reactions to the objectives are unknown. The most adequate approach is based on scenarios interpreting customers' reactions and strategies highlighting manager behaviour. These aspects are termed decision making under uncertainty.

Usually, this approach is applied when we are faced with several players. Compared with electricity grids, there are several companies in a competitive environment (Neimane 2001). In the case discussed in this paper, the decisions must be taken in relation to a range of alternatives proposed by the same company. Let us consider the cost matrix in which the rows correspond to scenarios for consumer satisfaction (especially industrial) and their reactions to future investments and collaboration; the columns correspond to the strategies developed by the decision makers. The elements of the matrix designate the corresponding costs. The criteria used in the present paper are the Laplace–Bayes criterion, the Wald or maxi-min criterion, the Savage or mini-max Regret criterion, and the Hurwitz criterion. For the case study, the implementation of customer reactions is performed through the values of the capital recovery factor (RCF).

Under the Bayes–Laplace criterion (expected cost criterion), a probability or weight is associated with each scenario. The weighted average of the costs of a strategy (or an alternative) under the different scenarios yields the

Table 10. Final results using synthesis.

Criteria	C 0.5027			R 0.2715			A 0.1185	M 0.0721	PQ 0.0351	
Sub-criteria	UC 0.6910	CIC 0.2176	LC 0.0914	Ag 0.1047	EFLC 0.6370	EDLC 0.2583				Overall
A_1	0.5627	0.0539	0.1279	0.0937	0.0756	0.0537	0.0537	0.1432	0.0797	0.2670
A_2	0.2487	0.1103	0.1279	0.1147	0.0756	0.1151	0.1151	0.3543	0.0917	0.1710
A_3	0.1398	0.2579	0.0733	0.2295	0.1790	0.2394	0.2394	0.3985	0.1787	0.1810
A_4	0.0488	0.5779	0.6709	0.5621	0.6698	0.5918	0.5918	0.1040	0.6499	0.3810

Table 11. Synthesising results for sensitivity analysis.

Criteria	C 0.1660			R 0.3765			A 0.1258	M 0.0588	PQ 0.2729	
Sub-criteria	UC 0.6910	CIC 0.2176	LC 0.0914	Ag 0.1047	EFLC 0.6370	EDLC 0.2583				Overall priority
A_1	0.5627	0.0539	0.1279	0.0937	0.0756	0.0537	0.0537	0.1432	0.0797	**0.1335**
A_2	0.2487	0.1103	0.1279	0.1147	0.0756	0.1151	0.1151	0.3543	0.0917	**0.1355**
A_3	0.1398	0.2579	0.0733	0.2295	0.1790	0.2394	0.2394	0.3985	0.1787	**0.2035**
A_4	0.0488	0.5779	0.6709	0.5621	0.6698	0.5918	0.5918	0.1040	0.6499	**0.5275**

Note: Bold values show the growth of priority under the alternatives. These results clearly highlight the contribution of the sensitivity analysis.

expected cost for each strategy. If the cost associated with scenario j for strategy i is V_{ij} and the probability of each scenario is Q_j, then the selection is made as follows:

$$Z_{\mathrm{BL}} = \min_i \sum_j Q_j V_{ij}. \tag{13}$$

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, according to this criterion, the solution is obtained without estimation of the possible consequences after the occurrence of a particular scenario, therefore it may lead to a risky decision. Laplace's criterion is 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 an assumption can turn out to be groundless. The optimal solution is the one minimising the arithmetical mean of costs over n scenarios:

$$Z_{\mathrm{L}} = \min_i \frac{1}{n} \sum_j V_{ij}. \tag{14}$$

Table 12 contains the results obtained after the calculation of the cost for each combination of scenario and strategy for technical and organisational measures of the studied power system using the CBA method.

Assuming that the weights or probabilities of occurrence associated with each scenario are known, the results shown in Table 12 are obtained. The decision according to the expected cost criterion corresponds to Strategy 3. In the case of Laplace's criterion, the decision also corresponds to Strategy 3.

The mini-max decision rule seeks the decision-maker's action that minimises the maximum potential loss. A decision-maker who uses the mini-max criterion acts extremely conservatively. He seeks the actions that achieve the best outcome under the worst scenario. The optimal solution is given by

$$Z_{\mathrm{mM}} = \min_i \max_j V_{ij}. \tag{15}$$

Table 12. Example illustrating the expected cost and laplace's criterion.

Scenarios	Weights	Alternative strategy			
		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 $(1/n)\sum(V_{ij})$		50,650	53,636	**38,803**	834,323
Maximum $\max_i(V_{ij})$		52,108	57,555	**43,625**	858,320
Minimum $\min_i(V_{ij})$		49,215	49,671	**33,923**	810,680

Note: Bold values show the dominance of alternative 3 for the two decision criteria taken in the calculation example.

Table 13. Cost of alternatives versus criteria under uncertainty.

Alternative criterion	Laplace criterion	Wald criterion (max–min)	Hurwitz criterion	Min–Max criterion	Bayes–Laplace criterion
A_1	50,650	49,215	50,660	52,108	51,010
A_2	53,640	49,671	53,610	57,555	52,640
A_3	<u>38,800</u>	33,923	38,770	<u>43,625</u>	<u>37,580</u>
A_4	834,320	<u>810,680</u>	<u>834,500</u>	858,320	840,320

Note: Underlined values indicate the cost of selected alternatives versus the decision criteria applied.

Adopting the Wald (maxi-min) criterion corresponds to a prudent attitude of the decision maker. It will seek to identify, for every possible strategy, a scenario that would lead to worse outcomes. He will then 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:

$$Z_{\mathrm{Mm}} = \max_i \min_j V_{ij}. \tag{16}$$

Hurwitz proposes a criterion that consists of calculating, for each strategy, a weighted average of the worst and the best of its potential outcomes and to choose the one for which the solution is the largest. According to this criterion the best strategy is the one minimising the linear combination of minimal and maximal costs according to the following solution:

$$Z_{\mathrm{H}} = \min_i \left[\alpha \max_j (V_{ij}) + (1-\alpha) \min_j (V_{ij}) \right], \tag{17}$$

where $0 \preceq \alpha \preceq 1$ is a parameter indicating the planners attitude towards risk. The value $\alpha = 1$ reduces the Hurwitz' criterion to the mini-max criterion described above and corresponds to an extremely pessimistic decision-maker. The value $\alpha = 0$ corresponds to extreme optimism. Based on a cost assessment for different alternatives, the various criteria are applied and the results are shown in Table 13. The underlined results indicate the costs retained and consequently the corresponding alternative following the considered criterion.

The first point to be learned by exploiting the results of Table 13 is that both Alternatives 3 and 4 are dominant. They agree on the need to engage in investment. From a strategic perspective, managers must be optimistic or conservative. Under no circumstances should they be pessimistic.

By selecting Alternative 4, two criteria reinforce the views of the experts concerning the results of the application of the AHP method. This provides information on the alignment of the decisions between the adoption of the AHP method and optimistic criteria.

8. Discussion and conclusion

Reliability is one of the most important criteria for customer satisfaction in relation to products of widespread consumption. In this case what the customer wants is readily detectable and management plays a huge role in the approaches of both producers and distributors. It is convenient to make improvements because the process is largely controllable. Unfortunately, this is not the case for electricity distribution systems, where any technological development or policy change has a certain inertia and consequently favourable results are slow in coming. By the simulation of a real system in operation, we have successfully highlighted not only the improvement in the quality of service to consumers (reduction of failure frequency and duration), but also the increase in company profitability by reducing the shortfall or financial prejudice (non-distributed energy). This was achieved using the reliability indices widely discussed by specialists. The novelty of this work is the application of the AHP method for the analysis of the customer satisfaction of a public service. Indeed, the AHP method has been applied in the past to several areas of human activity, but only very recently (and not impressively) has it been applied in the field of electrical systems and perhaps non-existently compared with customer satisfaction. As already developed in the past, this method combines criteria and scenario (alternatives) weights, designating the importance of each in relation to the other. In the context of the current financial crisis, the greatest importance was given to cost and then reliability. For the alternatives, the greatest importance was given to the restructuring of the system and the renewal of aging equipment. This choice was guided by the results given by the reliability indices assessment where it should be noted that, for Alternative A4 describing the replacement of aging components and the undergrounding of overhead circuits, the reliability indices are significantly improved and the investment commitment is the heaviest.

A second method based on decision making under uncertainty was applied to highlight the reactions of customers to the manager's decisions. The latter was initiated by several researchers each with his own interest or objective.

First, usually in a liberal environment, if a consumer is not satisfied with the services of Company A, he accepts the services of Company B. But, in the case where there is a monopoly, the consumer has several ways to react and often there are conflicts of interest with negative effects for both parties. It was shown that, depending on customer dissatisfaction, there is some reluctance concerning investment, thus reducing consumption and consequently negatively influencing profitability.

Second, the manager's decisions are taken on an uncertain future. To highlight the interest of this investigation, we simulated the behaviour of the manager according to the situation. We considered four scenarios: the manager is prudent, the manager is a gambler, the manager is pessimistic and finally the manager is optimistic. In the cases where the manager is optimistic or prudent, the obtained results converge to those obtained using the AHP method. These findings highlight the importance of the extension of multi-criteria methods in the management of electricity systems. Above all, the application developed in this paper has shown that reliability criteria are significant for the performance of a business and are an important asset for the justification of new projects.

Why is the AHP method of particular interest for the development of manufacturing in Algeria? The transition of the economy from a sustained market to a liberal market, the prospect of accession to the World Trade Organisation and the opening of the Algerian market to foreign capital require existing enterprises to be successful. The Algerian electricity and gas company wants to play an important role in this new policy and customer satisfaction remains a major concern. It is an objective in the quest for international standards, which are a unit of measure of performance. The submission of our work with the obtained results have allowed the construction of a gateway between the university and the economic sector, however they are still limited to technical fields. It is time to move on to the decision area and to provide the company with tangible tools of management. As shown at the last ISAHP2011 conference, it was the first time that Algeria had submitted a paper dealing with the AHP method and its application. The recommendations in the paper were well received by the company and some actions have been implemented, namely the automation of fault research, which contributes to a reduction of the duration of an interruption, viewed as one of the customers' requirements. It should be noted that the most important criteria are system reliability and the cost of a kWh produced to the end user of the electrical system. This paper contributes to the popularisation of the AHP method in decision-making in Algeria.

References

Billinton, R. and Wangdee, W., 2007. Reliability-based transmission reinforcement planning associated with large-scale wind farms. *IEEE Transactions on Power Systems*, 22 (1), 34–41.

Chen, H.H., Lee, A.H.I., and Hang, H.-Y., 2009. A model for strategic selection of feeder management systems: a case study. *International Journal of Electrical Power and Energy Systems*, 32 (5), 421–427.

Endrenyi, J., 1978. *Reliability modeling in electric power systems*. Chichester: Wiley.

Guo, Y. and Niu, D., 2007. An analysis model of power customer satisfaction based on the decision tree. *International Journal of Business and Management*, 2 (3), 32–36.

Ivanova, E.Yu. and Varopai, N.I., 2004. Generation planning and electricity market: decision making procedures. *In: MedPower'04*. Lemesos, Cyprus.

Malik, A.S. and Sumaoy, C.U., 2003. Analytic hierarchy process approach in distribution utility local IRP. *Internatonal Journal of Electrical Power and Energy Systems*, 25, 623–631.

Medjoudj, R. and Aissani, D., 2002. Economic aspects of distribution power system reliability. *In: Proceedings of the third international conference on mathematical methods in reliability*, *MMR*2002, Trondheim, Norway.

Medjoudj, R., Laifa, A., and Aissani, D., 2011. Power customer satisfaction analysis using analytic hierarchy process. *In: Proceedings of the international symposium on the analytic hierarchy process, ISAHP2011*. 15–18 June, Sorrento, Naples.

Negim, K.A., *et al*., 2003. The application of analytic hierarchy process to analyze the impact of hidden failures in special protection schemes. *Electric Power Systems Research*, 63, 191–196.

Neimane, V., 2001. *On development planning of electricity distribution networks*. Dissertation (Doctoral). Royal Institute of Technology, Stockholm.

Omkarparsad, S.V. and Sushil, K., 2006. Analytical hierarchy process: an overview of applications. *European Journal of Operational Research*, 169, 1–29.

Saaty, T.L., 1990. How to make decision: the analytic hierarchy process. *European Journal of Operational Research*, 48, 9–26.

Saaty, L.T., 2006. *Fundamentals of decision making and priority theory with the analytic hierarchy process*. 2nd ed. (Vol. VI of the AHP series). Pittsburgh: RWS Publications.

Saaty, T.L., 2008. Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1 (1), 83–97.

Saaty, L.T. and Peniwati, K., 2008. *Group decision making: drowing out and reconciling diferences*. Pittsburgh: RWS Publications.

Triantaphyllou, E., *et al*., 1997. Determining the most important criteria in maintenance decision making. *Journal of Quality Maintenance Engineering*, 3 (1), 16–28.

Voropai, N.I. and Ivanova, E.Yu., 2003. Hierarchical game theoretical problem of electric power system expansion planning. *In: IEEE Bologna power technology conference proceedings*, Bologna, Italy, 163–168.

Yang, G., 2007. *Life cycle reliability engineering*. New York: Wiley.