I hereby confirm that paper n° 1157 “An Approach for Critical Component Identification in Reliability-Centered Maintenance of Power Distribution Systems Based on Analytical Hierarchical Process “

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was selected for and presented during the 21st International Conference and Exhibition on Electricity Distribution (CIRED 2011) in Frankfurt (Germany) from 6 to 9 June 2011.

Liege, 15 June 2011

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AN APPROACH ON CRITICAL COMPONENT IDENTIFICATION IN RELIABILITY CENTERED MAINTENANCE OF POWER DISTRIBUTION SYSTEMS BASED ON ANALYTICAL HIERARCHICAL PROCESS

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ABSTRACT

In a distribution power system, vividly in a deregulated market and restructured environment, blind time based maintenance of all the distribution equipments is neither affordable nor economically justifiable. Moreover, an acceptable level of system reliability is an indispensable criterion for the successful operation of a power distribution system. To enhance the cost effectiveness of distribution maintenance policy and particularly from the asset management point of view, this paper proposes a new applicable qualitative-quantitative approach based on analytical hierarchical process (AHP) to determine the most critical equipments to be prioritized in maintenance scheduling. Entire attempt is to contribute all the major technical and practical parameters related to this problem to find the most optimized solution. The proposed method is applied to a practical distribution feeder of Iran's power grid to illustrate the applicability and effectiveness of the method.

INTRODUCTION

Major changes in the power industry, primarily raised by the restructuring and re-regulation, have motivated modern approaches in maintaining the health and reliability of the power system as cost-effective as possible. Along with the focus changes from consumers to customers, the focus on the transmission system is moving toward the distribution. Moreover, failure statistics reveal that electrical distribution systems themselves constitute the maximum risk to the power supply [1]. As experienced recently, distribution utilities have reached to a point that the need for a much efficient maintenance strategies is obviously inevitable. This requirement is mainly due to utilization of expensive equipments, the huge cost of power interruptions, and the remarkable cost of scheduled/unscheduled maintenances. The savings associated with preventing failures in some components would be in the order of millions of Dollars. As power systems become more complex and interconnected, it becomes more difficult to maintain them. Components wear and fail, or operating conditions change, causing performance degradation. Increased complexity and the demands for handling the preventive maintenance and the pressure to reduce operational and maintenance costs require new comprehensive approaches. Reliability-centered maintenance (RCM) is a systematic method wherein the maintenance of system components is related to improvement in system reliability. RCM provides a formal framework for handling the complexity of the maintenance issues by complementing all the traditional strategies [1]. So, it would seem rather logical to have the operators focus their priorities on some critical components to avoid missing the possible opportunities for cost-effective decisions. Only then can we focus and allocate our resources properly to make our actions as useful as possible. To meet this challenge, in the first and essential step of RCM, it would be of great value to prioritize the equipments to find the most critical to apply the maintenance strategies in a more efficient manner.

This paper attempts to accomplish the goal of development of an advanced methodology that can be used to prioritize the distribution equipments and in other words, find the most critical components to have the maintenance costs concentrated on them. Thus, maintenance can be performed on needed components rather than blind scheduled basis. The key component for the reliability of a distribution system will be found by means of a robust method referred to as AHP.

To achieve the above-mentioned goal and to illustrate the proposed procedure, the manuscript is organized as follows. First, asset management and its importance are described. Then the AHP which is exploited in this paper is presented and the decision making problem is discussed. Afterward, the priority determination and the details of implementation are scrutinized. Finally, the empirical study and the subsequent results precede the last section which establishes the conclusion.

POWER SYSTEM ASSET MANAGEMENT

Asset management, in general, means exploiting a group of assets over the whole technical life-cycle ensuring an apposite amount of return and guarantying a predefined service and security standards. In other words, Asset Management is the art and science of correct decision making in the area of process optimization [2]. Distribution power system operators have to find a balance between the requirements of the customers concerning service quality at an affordable price as well as the shareholder demands for appropriate returns on the invested capital. To optimize these demands, deregulation of power system market has provided the possibility of putting the reliability centered asset management into execution. Distribution power system asset management plays a key role in the detection and evaluation of decisions leading to long-term economical success and best possible earnings. A distribution company investment advisor should conduct an assessment of each equipment type's importance on power system reliability to be ranked in maintenance prioritization. The advisor then recommends appropriate investments on those equipments which are proposed to be covered.

ANALYTICAL HIERARCHICAL PROCESS

The Analytical Hierarchy Process Model designed by TL Saaty, is a multi-criteria decision-making (MCDM) technique which has been under widespread focuses and been used throughout many industries [3]. It can be helpful in the decision making process to easily encompass all the aspects of the decision when faced with choosing between several alternatives. It involves building hierarchy of decision fundamentals and then making comparisons between each possible pair in each cluster (as a matrix). This gives a weighting for each element within a level of the hierarchy and also combining them to reach the final decision. Therefore, AHP is a qualified method that carries out weight analysis with the combination of qualitative and quantitative aspects. Power system planners and operators are continually faced with decisions which both directly and indirectly impact its reliability and security. In this regard, AHP is, in this paper, exploited as a robust method in distribution power system asset management problem.

METHODOLOGY

Criteria Definition

Decision making in complex environments consisting of multiple options and criteria (quantitative and qualitative), is one of the most important issues in modern management. In these cases, decision makers faced with several options that should be investigated by different criteria, which stem from internal and external environment. The first step of AHP for evaluating the goal is to develop some effective criteria and then find a hierarchy of the problem. After attending in several meetings with power distribution engineers, several priorities and criteria (CRI.) presented in Table 1 are proposed. As it can be traced, five proposed criteria are to be compared at a time with respect to the goal. These criteria are investigated in both medium voltage (MV) and low voltage (LV) levels of a distribution power system and consequently, their weights can be found in both environments separately.

Table 1. Criteria defined to prioritize the candidate component types

CRI. 1	Total Number of Components
CRI. 2	Total Number of Component Failures
CRI. 3	Component Repair Duration
CRI. 4	Component Investment Cost
CRI. 5	Component Repair and Maintenance Cost

According to the first criterion, component multiplicity is one of the main factors in finding a critical type of component. A component type with a great number of components can transparently play an important role in a power system. Outage statistics is also assumed to be another criterion. Obviously, a component type which is referred to the most failures occurred in a specific time interval is much more critical to be operated and maintained. The third criterion is repair duration of components. The repair process can sometimes take a long time itself, or in some cases there are equipments that are placed somewhere which are difficult to access. For example, when a substation in a market is such that its door is closed till a specific time or where it substantially takes the operators a long time to repair a component such as transformers. In such circumstances, when a fault occurs, the time to repair will considerably increase and consequently will lead to more energy not supplied.
It's of great importance to take the factors of the component investment cost and the component repair cost into consideration as two crucial cost-based criteria in this survey.

Hierarchy Modeling and Criteria Weighting

Building of the Hierarchy model helps everyone involved in the decision process to understand and to interpret the problem in the same way. Simultaneously, it allows the visualization of the interrelationships between the factors of different levels. In modeling, the goal, the alternatives and the proposed criteria are determined to form the hierarchy. As can be traced in Figure 1, the goal is placed at the top. In intermediate levels, there are criteria and sub-criteria that have major impacts on the goal.

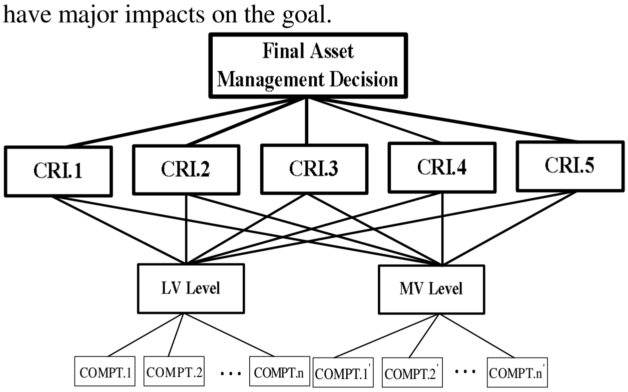

Figure 1. Analytic hierarchy process (AHP) scheme

Next, a judgment matrix has to be formed. The value of elements in the judgment matrix reflects the user's knowledge about the relative importance between every pair of factors. Once the pair-wise comparisons have been made for the five criteria, each alternative is compared against other alternative with respect to the corresponding criterion at a time. We do complete the judgment table for the described criteria for both MV and LV levels of a distribution system as in Table 2.

Table 2. Pair-wise comparison of criteria in power distribution system

	CRI. 1	CRI. 2	CRI. 3	CRI. 4	CRI. 5
CRI. 1	1	C_{12}	C_{13}	C_{14}	C_{15}
CRI. 2	C_{21}	1	C_{23}	C_{24}	C_{25}
CRI. 3	C_{31}	C_{32}	1	C_{34}	C_{35}
CRI. 4	C_{41}	C_{42}	C_{43}	1	C_{45}
CRI. 5	C_{51}	C_{52}	C_{53}	C_{54}	1
Final Weight	C_1	C_2	C_3	C_4	C_5

The evaluators would be the industry experts who have marvelous experiences dealt with the maintenance and operation of power distribution systems and those involved in the decision making problem and asset management. In completing the above judgment matrices, AHP adopts the 1-9 marking method which are nine fuzzy linguistic variables. The 1-9 scales are illustrated with the following comparison table [3].

Table 3. Fundamental scales for the pair-wise rating

1-9 Scale	The Relative Importance of the Criteria
1	Equally Important
3	Moderately Important with One Over another
5	Strongly Important
7	Very Strongly Important
9	Extremely Important
2,4,6,8	Intermediate Values

For example, according to the research and assumption, the criterion "Total Number of Components" is C_{12} times as important as the "Total Number of Component Failures" criterion. The "Repair Duration of Component" criterion is C_{34} times as important as the "Component Investment Cost" criterion and so on in which C_{ij} weights reflect the scaling method introduced in Table3. After completion of all pair-wise comparisons of the main criteria both in LV and MV levels, the relative priority of each criterion is mathematically synthesized using the geometric mean method. The final weight of each criterion is reached afterward.

Besides, the final weight of each component type according to the proposed criteria can be found quantitatively. This is introduced in Table 4. Each criteria-related data of the components in both LV and MV parts is normalized independently and the final weight of each component type will be reached then. Having found the final weight of each component type in both levels of power distribution system, the component type priorities can be reached to be considered in maintenance-focused resource allocations in each part separately.

Table 4. Distribution component types weighting

	CRI. 1	CRI. 2	CRI. 3	CRI. 4	CRI. 5	Final Weight
Comp. Type 1	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_1
Comp. Type 2	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_2
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
Comp. Type n	C_{n1}	C_{n2}	C_{n3}	C_{n4}	C_{n5}	C_n

If the distribution utilities and their asset managers have their annual budgets independently bifurcated in each LV and MV part, there will be no need to go further and combine the component types of both parts to prioritize them for maintenance consistently. However, if the total annual needed resources in each part have not been planned, it is more commonsensical to take all the equipment types of both levels dependently into consideration and make an annual resource allocation decision afterward. In this regard, AHP is used again to merge the component types of LV and MV levels. Having found the final weight of each criterion individually in both sections according to Table 2, the component types of the two parts can be joined and then, asset managers can easily decide on resource allocation using the weighting factors achieved through Figure 4 in the next section. This figure helps us to have a different viewpoint on LV and MV importance indices and lead to easily and efficiently deciding on maintenance scheduling of component types in the whole distribution system.

CASE STUDY

Description of Test Distribution Feeder

In order to obtain useful results and to investigate the possibility of expanding, the studied network is a part of the power distribution network in Tehran, Iran which is provided by having the distribution company engineers in collaboration with the authors. The proposed method is applied to the system and the results prove its effectiveness.

AHP Implementation

A critical component is required to be scrutinized in the power distribution system based on the proposed qualitative-quantitative method. Quantitative Pair-wise comparison results for the proposed criteria and accordingly their final weights are investigated in a normalized manner for both LV and MV levels of the test system as shown in Figure 2. Then, the components comparison matrix is formed through the defined criteria and is filled quantitatively. Finally, for the above results and according to what has been proposed before, final weight for each component type associated with both levels is obtained as shown in Figure 3.

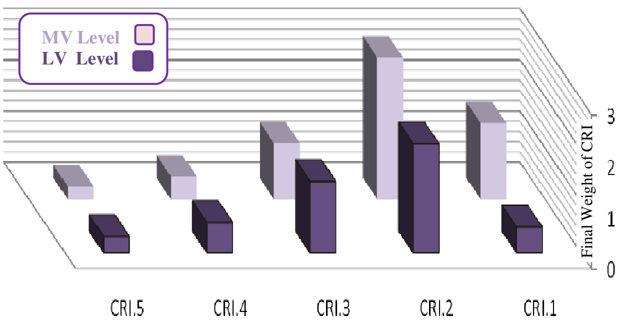

Figure 2. Final weight of each criterion in LV and MV

The resources which have to be allocated in each LV and MV level of the distribution test system are not decided separately. It is more advisable to rank all the distribution components together on the basis of their weights. As noted earlier, the MV and LV weights of the proposed criteria are contrasted in Figure 2 and accordingly, the final ranking of the distribution components are presented in Figure 4. It can be clearly traced that the MV lines and MV transformers are the most critical component types of the test feeder. It should be noted that LV lines are among the most critical component types of the test feeder and should be faced vigilantly. Also, it is worth of mentioning that the component criticality is fully dependent to the gird properties such as its aging conditions, environment conditions and so on. The annual resources can be allocated to both MV and LV parts through Figure 4 consequently to meet the maximum effects of the maintenance in the system reliability.

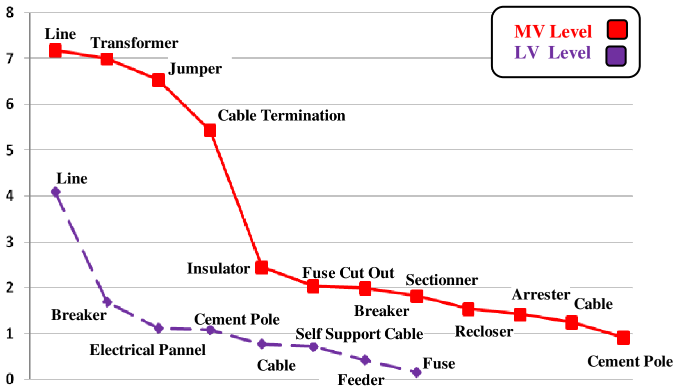

Figure 3. Final weight of all the distribution LV and MV components

CONCLUSION

Prioritizing components for maintenance activities due to the scarce resources in distribution power system utilities is indispensable and the first step toward a systematic maintenance trend named RCM. In this paper, some crucial criteria which are based on component type criticality and are often very important for maintenance decision making were

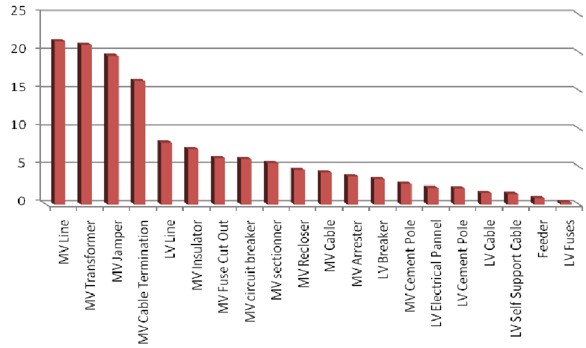

Figure 4. Final weight of all the distribution LV and MV components

proposed. Analytical Hierarchical Process as a very convenient method for analyzing components importance in both distribution LV and MV levels and understanding procedures of decision making was used. The approach suggested in this paper gives a possible and practical solution to maintenance planning problems in the area of prioritizing equipments for RCM procedure. This approach systematically formulates expert's knowledge about equipments prioritizing to efficiently allocate available resources. It is finally concluded that the most critical components of the test feeder were MV and LV lines respectively in the MV and LV levels. Having the LV and MV levels combined, the MV line was found as the most critical and LV line found its position among the most critical MV components.

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