ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 6, Issue 4, July 2017

Seven Basic Pillars of Analytic Hierarchy Process to Assess Condition Criteria for High Voltage Transmission Line System

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Abstract*—Failures in a large electric power system comprising several transmission hardware and substation equipment are inevitable. It is clear that the number of annual failures depends on the system topology itself as well as on the environmental conditions. One of the primary reasons of major transmission line outages are severe weather conditions. The stress created by severe weather is much higher than in normal weather and increases with the severity level of the weather, leading to increases in line outage rates. This paper proposes a program development for condition and importance assessment of high voltage transmission line. The condition criteria consist of age, stress, symptom, failed-type, obsolescence, as well as environment and safety while importance criteria consider line loading, N-1 criteria, system stability, possible of force outage, pollution and social impact. The score and weight techniques are applied to the assessment. In addition, Analytical Hierarchy Process is used to determine weighting of criteria. The components of transmission system such as conductor, conductor accessories, insulator structure, foundation, lightning, accessories and right of way are evaluated while subcomponents of each component and classified. The 10 of 500 kV transmission lines network is used in example in the assessment program. The results show the criteria renovation index, equipment performance index, and equipment importance index in forms of percentage and finally risk of ten lines is shown in risk matrix. The results can provide an effective maintenance schedule for transmission system.

***Keywords*— Condition Assessment, Importance Assessment,** Asset **Management, Transmission Line, AHP, Risk Matrix.**

I. INTRODUCTION

Electric power transmission systems are one of the most complex networks among the infrastructures that exist in the world. They often traverse long distances to transport the electrical energy to the load centers. Although transmission system-originated load interruptions are rare events, they have a great impact when they do occur.

Outages of transmission system components are undesired but inevitable events which significantly affect the performance of industrial and commercial power systems as well as the processes they control. Moreover, interruptions in electric power consumption result in financial losses for the industrial companies. On the other hand, electric utilities also suffer from these faults due to the shortage of electrical energy sales.

Reliability assessment aims to minimize both the number and the duration of those power outages as well as their negative consequences for the costumers and for the utilities. Quantitative reliability evaluation of the system strongly depends on data availability and on data reliability. Historical transmission system outage data provides the ability to predict the performance of various transmission line configurations and assess the impact of forced outages on industrial and commercial power systems. Therefore, data collection is the initial phase of development of new models, methods, technologies and tools to understand the outage mechanism, to predict the outage propagation and to prevent and restore the outages.

At the beginning, the first transmission line outage data collection aimed to inform the manufacturers and the designers about the performance of the components and to force them for higher-quality products [1]. However, the studies were mainly concentrated on the line outage rate per unit length but not providing the correlation between the line performance and the design parameters. In addition, there was no distinction made between terminal and line related outages.

Due to the increasing cost of electrical energy, utilities started planning the transmission network so that they could balance the cost of system reinforcement with the reliability benefit. The potential benefits of a probabilistic approach have led to the development and implementation of transmission network outage data collection and analysis systems [2, 3, 4].

ISSN: 2319-5967
ISO 9001:2008 Certified
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Outage data collection systems differed in many ways. The differences were mainly due to some specific objectives and some priorities of data collecting entities. In general, the collection systems have been initiated with the aim of analyzing and quantifying the component performance as a function of design parameters (voltage, type of construction, length, number of terminals, etc.) and as a function of environmental factors. Environmental factors were principally taken as atmospheric conditions, but later extended by line routing, geographic topology and some other specific external factors.

HV transmission line is important for power transmitting system. HV transmission lines are deterioration over the period of use due to normal operating as well as abnormal condition such as effects of lightning, corrosion from pollution, and etc. The failure of HV transmission line and its components can affect stability of power system. Thus, the transmission system needs to be maintained in proper manners of both condition and importance criteria. Therefore in this paper, the methods for condition and importance assessment of HV transmission line are proposed. The HV transmission line is classified into eight components that are conductor, conductor accessories, insulator, structure, foundation, lighting system, accessories, and right of way as given in Table I. The sub-components of each component are also given. There are six criteria in condition assessment such as age, stress; symptom, failed-type, obsolescence; environment and safety are considered [1]. As well as six criteria in importance assessment such as line loading, N-1 criteria, system stability, possible of force outage, pollution, and social impact are taken into consideration [2]. **978-1-4673-97490/16/$31.00 ©2016 IEEE .**In the assessment, score and weight techniques, a form of multi-criterion analysis [3], is applied to determine condition and importance indices. In addition, the Analytical Hierarchy Process (AHP) [4] is applied to determine a percentage of weight of each criteria or sub-components. Finally for condition assessment, the Equipment Renovation Index (%ERI), Line Renovation Index

(%LRI) and Equipment Performance Index (%$LPI_{condition}$) are calculated. For importance assessment, the Equipment

Importance Index (%LII) and Equipment Performance Index
(%$LPI_{importance}$) are determined. Both %$LRI_{condition}$ and
%$LII_{importance}$ are plotted in the risk matrix. This assessment integrates Information Technology (IT) by developing a web application program connecting to equipment information database, calculation, evaluation and display via internet network. The results can be effectively applied to renovation planning and maintenance scheduling management in the future. Condition and Importance Assessment

II. CONDITION AND IMPORTANCE CRITERIA

To assess the performance of HV transmission line, the condition and importance of transmission system are considered. The condition assessment of transmission line includes of age, stress, symptom, failed-type, obsolescence, as well as environment and safety while the importance assessment consists of line loading, N-1 criteria, system stability, possible of force outage, pollution and social impact.

The score and weight techniques [4] are applied for the assessment. The score needs to classify sub-components' performance into 5 levels such as 0 (very good), 1 (good), 2 (satisfy), 3 (fair) and 4 (poor condition). The weight shows importance of the components and subcomponents. Table II shows examples on score and weight classification for symptoms of lightning, right of way and accessories components [7]. Only for symptom criterion, sub-components of each component are evaluated to calculate %ERI for condition assessment. The symptoms of other sub-components are such as 0 (low importance), 2 (moderate) and 4 (High importance) also evaluated but they are not given in this paper because of page limitation. Similarly, Table III shows score for importance criteria. [7]

TABLE I. COMPONENTS AND SUB-COMPONENTS OF TRANSMISSION ASSET

Components	**Sub-Components**
Conductor	conductor
Conductor accessories	conductor splices, dead end, spacer, damper, aircraft warning sphere, OPGW/ADLASH, anchor guy, phase insulator

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
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TABLE II. SYMPTOMS OF CONDUCTOR, INSULATOR, STRUCTURE, LIGHTNING, ACCESSORIES AND RIGHT OF WAY

Insulator	insulator, insulator accessories
Structure	structure
Foundation	concrete foundation, grillage foundation, anchor guys, earthling, counterpoise
Lightning	GSW/ OPGW, GSW's jumper, arching horn, grounding
Accessories	counter weight, vangnet, danger sign, tower sign, tower indicator lamp, conductors aviation lamp
Right of way	right of way

TABLE III. IMPORTANCE CRITERIA AND SCORE FOR TRANSMISSION LINE

Criteria	Score			Weight (%)
	0	*2*	*4*	
C onductor				
Conductor	Normal	Expanded	Broken strand	100
I nsulator				
Insulator	Normal	Polluted Corrosion Level 1/2	Corrosion Level 3 Broken Flashed over, Object Presence	70
Insulator accessories	Normal	Pin Loss, Corrosion Level 1/2	Corrosion Level 3, Object Presence	30
S tructure				
Structure	Normal	-	Tiled, Shifted	100
Li ghtning				
GSW's jumper	Normal	detached		24
Arching horn	Normal, unequipped	unsymmetrical, corrosion level 1/2	corrosion level 3	55
Arching horn	Normal	loosen, broken strand, corroded, missing		21
Rig ht of Way				
Right of Way	Normal	below standard		100
Accessories				
Counter Weight	Normal, unequipped	shifted, loosen, missing		31
Vangnet	Normal, unequipped	shifted, loosen, missing		26
Danger sign	Normal	loosen, faded, missing		12
Tower sign	Normal	loosen, faded, missing		8
Tower indicator lamp	Normal, unequipped		missing, broken	10
Conductors aviation lamp	Normal, unequipped		missing, broken	13

ISSN: 2319-5967
ISO 9001:2008 Certified
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TABLE IV. SIX CRITERIA FOR CONDITION ASSESSMENT

Criteria		**Score**		**Weight (%)**
	0	***2***	***4***	
Line loading	<0.6	0.6-0.8	>0.8	51
N-1 criterion	yes	n/a	no	20
System stability	low	moderate	high	11
Possible of force outage	low	moderate	high	11
Pollution	low	moderate	high	4
Social impact	low	moderate	high	4

Criteria	**Score**					**Weight (%)**
	0	***1***	***2***	***3***	***4***	
Age	0-10	11-15	16-20	21-25	<25	41
Stress	<0.6	n/a	0.6-0.8	n/a	>0.8	24
Symptom	0-0.29	0.30-0.49	0.50-0.59	0.60-0.79	0.8-1.0	22
Failed-type	low	n/a	moderate	n/a	high	6
Obsolescence	Available	n/a	lacking but still product	n/a	unavailable and cannot be modified	4
Environment and safety	low	n/a	moderate	n/a	high	3

III. THE ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process (AHP) is a flexible and powerful technique to find the important weighting factor in performance evaluation. It is a classical technique for MultiCriteria Decision Making (MCDM) [4]. The AHP is suitable for complex decisions involving in the comparison, which is difficult to quantify. As the AHP is based on pair-wise comparison of any decision criteria, all individual criterion must be firstly paired against other criteria when the qualitative criteria are identified and organized in a hierarchical structure. Finally, the important weighting factor of each criterion will be calculated. From the AHP theory, after setting up the hierarchy according to a brainstorming, the experts group filled in pairwise comparison matrix. Then the AHP pair-wise comparison matrixes are obtained by different perspective among each group. However in this paper, the AHP evaluation is judged by three different groups of experts who are specialized in engineering, system operation, maintenance and testing of HV equipment. The important weighting factor is subsequently calculated. In addition, to fulfil the decision making, the judgment matrix must be consistent by observing the consistency ratio (CR), which must be lower than 0.1 [4].

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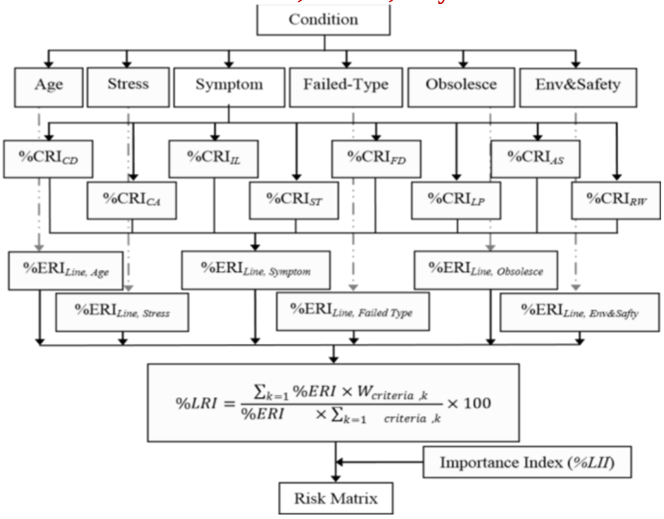

$$\%LRI = \frac{\sum_{k=1} \%ERI \times W_{criteria\_k}}{\%ERI \times \sum_{k=1} criteria\_k} \times 100$$

Fig. 1.Flow chart of condition index calculation

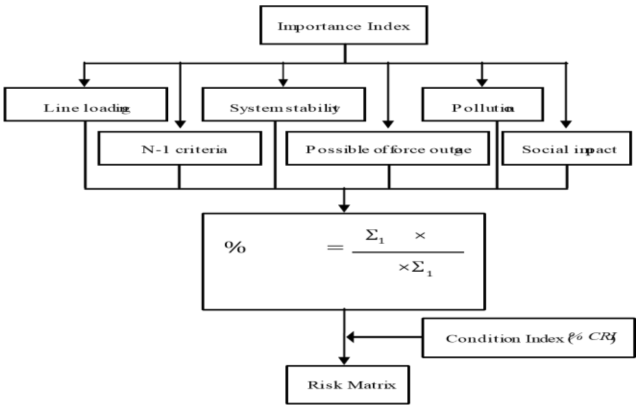

Fig. 2.Flow chart of importance index calculation

IV.THE SEVEN PILLARS OF THE ANALYTIC HIERARCHY PROCESS

The seven pillars of the AHP are

(1) Ratio scales, proportionality, and normalized ratio scales are central to the generation and synthesis of priorities, whether in the AHP or in any multicriteria method that needs to integrate existing ratio scale measurements with its own derived scales; in addition, ratio scales are the only way to generalize a decision theory to the case of dependence and feedback because ratio scales can be both multiplied, and added—when they belong to the Same scale such as a priority scale; when two judges arrive at two different ratio scales for the same problem one needs to test the compatibility of their answers and accept or reject their closeness. The AHP has a non-statistical index for doing this. Ratio scales can also be used to make decisions within an even more general framework involving several hierarchies for benefits, costs, opportunities and risks, and using a common criterion such as economic to ensure commensurability; ratio scales are essential in proportionate resource allocation as in linear programming, recently generalized to deal with relative measurement for both the objective function and the constraints obtaining a ratio scale solution vector form which it is possible to decide on the relative values of the allocated resources; one can associate with each alternative a vector of benefits, costs, time of completion, etc., to determine the best alternative subject to all these general concerns;

(2)Reciprocal paired comparisons are used to express judgments semantically automatically linking them to a numerical fundamental scale of absolute numbers (derived from stimulus response relations) from which the principal eigenvector of priorities is then derived; the Eigen vector shows the dominance of each element with respect to the other elements; an element that does not have a particular property is automatically assigned the value zero in the eigenvector without including it in the comparisons; dominance along all possible paths is

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obtained by raising the matrix to powers and normalizing the sum of the rows; inconsistency in judgment is allowed and a measure for it is provided which can direct the decision maker in both improving judgment and arriving at a better understanding of the problem ;scientific procedures forgiving less than the full set of n(n - 1)/2 judgments in a matrix have been developed; using interval judgments eventually leading to the use of optimization and statistical procedures is a complex process which is often replaced by comparing ranges of values of the criteria, performing sensitivity analysis, and relying on conditions for the insensitivity of the eigenvector to perturbations in the judgments; the judgments maybeconsideredasrandomvariableswithprobabilitydistribution ;theAHPhasat least three modes for arriving at a ranking of the alternatives: (a) Relative, which ranks a few alternatives by comparing them in pairs and is particularly useful in new and exploratory decisions, (b) Absolute, which rates an unlimited number of alternatives one at a time on intensity scales constructed separately for each covering criterion and is particularly useful in decisions where there is considerable knowledge to judge the relative importance of the intensities and develop priorities for them; if desired, a few of the alternatives can then be compared against each other using the relative mode to obtain further refinement of the priorities; (c) Benchmarking, which ranks alternatives by including a known alternative in the group and comparing the other against it;

(3) Sensitivity of the principal right Eigen vector to perturbation in judgments limits the number of elements in each set of comparisons to a few and requires that they be homogeneous; the left eigen vector is only meaningful as reciprocal; due to the choice of a unit a some of the two elements in each paired comparison to determine the relative dominance of the second element, it is not possible to derive the principal left eigen vector directly from paired comparisons as the dominant element cannot be decomposed a priori; as a result, to ask for how much less one element is than another we must take the reciprocal of what we get by asking how much more the larger element is;

(4)Homogeneity and clustering are used to extend the fundamental scale gradually from cluster to adjacent cluster.

(5) Synthesis that can be extended to dependence and feedback is applied to the derived ratio scales to create a unidimensional ratio scale for representing the overall outcome.
Synthesis of the scalesderivedinthedecisionstructurecanonlybemadetoyieldcorrectoutcomeson known scales by additive weighting. It should be carefully noted that additive weighting in a hierarchical structure leads to a multilinear form and hence is nonlinear. It is known that under very general conditions such multilinear forms are dense in general function spaces (discrete or continuous), and thus linear combinations of them can be used to approximate arbitrarily close to any non linear element in that space. Multiplicative weighting, by raising the priorities of the alternatives to the power of the priorities of the criteria (which it determines through additive weighting!) then multiplying the results, has four major flaws: (a) It does not give back weights of existing same ratio scale measurements on several criteria as it should; (b) It assumes that the matrix of judgments is always consistent, thus sacrificing the idea of inconsistency and how to deal with it, and not allowing redundancy of judgments to improve validity about the real world; (c) Most critically, it does not generalize to the case of interdependence and feedback, as the AHP generalizes to the Analytic Network Process (ANP), so essential for the many decision problems in which the criteria and alternatives depend on each other; (d) It always preserves rank which leads to unreasonable outcomes and contradicts the many counterexamples that show rank reversals should be allowed;

(6) Rank preservation and reversal can be shown to occur without adding or deleting criteria, such as by simply introducing enough copies of an alternative or for numerous other reasons; this leaves no doubt that rank reversal is as intrinsic to decision making as rank preservation also is; it follows that any decision theory must have at least two modes of synthesis; in the AHP they are called the distributive and ideal modes, with guidelines for which mode to use; rank can always be preserved by using the ideal mode in both absolute measurement and relative measurement.

(7) Group judgments must be integrated one at a time carefully and mathematically, taking into consideration when desired the experience, knowledge, and power of each person involved in the decision, without the need to force consensus, or to use majority or other ordinal ways of voting; the theorem regarding the impossibility of constructing a social utility function from individual utilities that satisfies four reasonable conditionswhichfoundtheirvaliditywithordinalpreferencesisno longertruewhen cardinal ratio scale preferences

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ISO 9001:2008 Certified
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are used as in the AHP. Instead, one has the possibility of constructing such a function. To deal with a large group requires the use of questionnaires and statistical procedures for large samples.

V. CONCLUSION

The proposed methods are used to determine transmission line renovation indices using six condition criteria such as age, stress, symptom, failed-type, obsolescence, environment and safety, and six importance criteria as line loading, N-1 criteria, system stability, possible of force outage, pollution and social impact. The score and weight method is applied in the calculation process. The transmission assessment results are shown in risk matrix. All data and procedure are developed in Microsoft Excel program, which can be effectively used to manage the maintenance task by ranking transmission lines that encounter low/high risk according to condition and performance. The proposed method is applied with simply usage and less time consuming to assess HV transmission line.

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