Health Index Analysis of Transmission System Components

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Abstract

Optimizing maintenance strategies for power transmission components is crucial to prevent failure in the system while maintaining and enhancing the overall economic efficiency. Condition-based maintenance can fulfill this and in the present paper health index-based efficient condition assessment is applied as an essential input to this type of maintenance. A method for the calculation of the health index of primary transmission system components is presented and discussed. Condition-based assessment is utilized for developing a calculation method for evaluating the health index at different levels in the system. The health index of each component is calculated by using the Weighting and Scoring Method. Several factors affecting the condition of different equipment are considered in the algorithm including environmental effects, mechanical stress, and accessibility issues. The special focus is on assigning a numeric value to the health of individual sub-components of the equipment to plan the condition-based predictive maintenance of power system components. The data indicate that in contrast to considering the health index of the entire system, making decisions considering the individual component health indices can result in a more reliable operation.

1. Introduction

Reliable operation of transmission lines under optimized investment and operational costs requires a suitable maintenance strategy. Optimizing maintenance strategies for power components requires an effective evaluation of system conditions to generate an assessment-based data-driven solution. This could then be realized by calculating the overall condition of the system.

One common method to determine the service condition of the power system infrastructure is to calculate the health index (HI) [1]. HI represents a practical numerical assessment to quantify and integrate the different types of condition information like results of visual inspections, operating condition observations, and data from on-site and laboratory testing. The results are converted into an objective and quantitative index, providing the overall health of the assets.

Several studies have determined the HI, such as HI assessment of overhead line by image processing and HI assessment of underground cable by historical failure data [2]. While the existing methods of HI calculations have only be limited to studying one kind of system at a time, there is a need to extend such a study for getting an overall picture of complex systems like combined overhead line (OHL) and underground cable (UGC) configuration.

In this work, an attempt is made to extend the HI evaluation to assess the health of integrated transmission lines (OHL and UGC) and improve the reliability of the overall analysis. To achieve this, the proposed method includes the calculation of the health index at sub-component, component and system levels. Another aspect studied in this work is the inclusion of external factors that crucially impact maintenance strategies, such as environmental effects, mechanical stress, and accessibility issues to get a more practical HI value.

Section 2 of this paper describes in detail the methodology applied for calculating the health index of the transmission system at different levels. The method includes the HI calculation of the sub-components and the components of the OHL & UGC. This also includes the scores, and weights of the different component conditions, and the corresponding HI values. In section 3 the calculation results for 2 case studies are shown. A brief discussion of the HI result is given in section 4 which highlights the applicability of the HI for transmission system maintenance.

2. Methodology

2.1 Mathematical equations for calculating HI

Health index is calculated by condition-based assessment of the system, component, and sub-component of the transmission system. An example of a sub-component is a transformer bushing, where the transformer is the component. The overhead line or cable system with all components forms the system level.

The HI at each level is calculated based on the indicators from the subsequent level by using the weighting and scoring method (WSM) [3]. The results obtained from designated condition indicators are converted into scores based on a standard evaluating datasheet [1, 3-5]. The scores range from 0-5 and the outcome is categorized in three groups: good (5), moderate (3) & poor (0).

The scores $S_i i$ and assigned weights W_i of i indicators are applied as shown in equation 1 to calculate the health index HI of the sub-components of OHL and UGC. HI is the short representation of Health Index and $\%HI$ is system HI in a range of 100.

$$\%HI_{subcomponent} = \frac{\Sigma\,(S_i * W_i)}{\Sigma(S_{imax} * W_i)} 10 \qquad (1)$$

S_{imax} is the maximum score of the individual condition indicator.

In case of a component with j subcomponents the value of $\%HI_{subcomponent,j}$ is used to calculate the $\%HI_{component}$:

$$\%HI_{component} = \frac{\Sigma\,(\%HI_{subcomponent,j} * W_j)}{\Sigma W_j} \qquad (2)$$

Then additional component information is added in the calculation as a condition factor CF to get the actual component HI ($\%THI_{component}$).

$$\%THI_{component} = \%HI_{component} * C \qquad (3)$$

CF here stands for critical factor and represents a value that is calculated by the assessment of the component data and operational data (4):

$$CF = \frac{\Sigma\,(S_c*(W_c)}{\Sigma((S_{cmax}*(W_c)} * \qquad (4)$$

Here, S_c is the score of the individual component information and S_{cmax} is the maximum score of the individual component information.

Based on the individual HI of each component s ($THI_{component,s}$), the system HI (HI_{system}) is calculated (5):

$$\%HI_{system} = \frac{\Sigma\,(\%THI_{component,s} * Ws)}{\Sigma Ws} \qquad (5)$$

In this following, the HI of the transmission system is called system-HI or $\%HI_{system}$. The HI of an overhead line and an underground cable are $\%THI_{ohl}$ and $\%THI_{ugc}$, respectively.

Fig. 1 gives a schematic overview of the HI calculation process through different levels. Various component information is added at different levels as indicated. It is worth mentioning that the different levels are color-coded, for example, the condition indicators (extreme left) are all indicated using green color. The condition of these indicators are converted into scores and weights and the HI of the subcomponent is calculated (yellow box). The HI of different subcomponents are then used to calculate the HI at the component level, represented (blue box). Different component information like operating temperature, and environmental conditions are added at this stage to get more practical HI values. The component HI is used to calculate the final system HI (pink box).

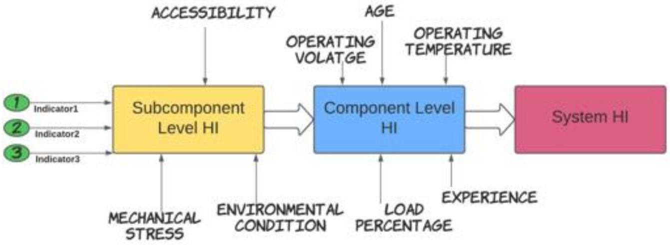

Fig. 1 - A brief overview of the HI calculation process

2.2 Health Index Ranges

The values of the system-HI proposed in this report are divided into four levels: healthy, minor defects, major defects and critical defects. The ranges of the HI and its referred condition with explanation are given in Table 1 with the four levels illustrated by different colors. When the HI result is zero, it indicates that the transmission system is not fixable.

2.3 Application of WSM Method

In this paper, the evaluation of HI is done for a transmission system consisting of both OHL and UGC.

Table 1 - Health Index Ranges

Health Index	Condition	Interpretation	Color ranges
81-100%	Healthy	The system is healthy and it is capable to perform required functions without any delay within a specific period of time. Maintenance can be delayed.	🟩
60-80%	Minor defect	The system is capable to perform the required functions within a specific period of time. However partial degradation has occurred. An advance maintenance plan is needed.	🟧
31-59%	Major defect	The system is still capable to perform the required functionality within a specific period of time. But some serious degradation of performance has occurred. Maintenance is required.	🟨
0-30%	Critical defect	The system is unable to perform the required performance. Maintenance is needed immediately.	🟥

Table 2 – Online indicators for assessing the condition of the overhead line.

Subcomponent	Indicators	Scores	Weights
Conductor	Conductor temperature	5	5
	Infrared thermography	3	5
	Corona discharge	3	5
	Sag	5	4
	Tension	5	4
	Vertical ground clearance	5	5
	Visual inspection	5	4
Insulator	ESSD test	5	5
	LCM	5	5
	Visual Inspection	3	4
Damper	Visual Inspection	5	5
Joints	LCM	5	5
	Partial discharge	5	3
	Infrared thermography	5	4
	Visual inspection	5	3
Connector	Visual inspection	5	5
	Infrared thermography	5	4
Lightning wire	Lightning withstand test	5	4
	Visual inspection	5	4

Table 3 - Indicators for assessing the condition of the underground cable.

Subcomponent	Indicators	Scores	Weights
Cable joints	AC withstand test	5	5
	Infrared thermography	5	3
	Partial discharge	5	4
	Dissipation factor	3	3
	Polarization index	5	4
	Visual inspection	5	4
Cable termination	AC withstand test	5	5
	Infrared thermography	3	3
	Partial discharge	5	4
	Dissipation factor	5	3
	Polarization index	5	4
	Visual Inspection	5	3
Link box	Visual Inspection	5	4
Manhole	Visual Inspection	5	3
Cable sheath	Partial discharge	5	5
	Dissipation factor	5	4
	Polarization index	5	5
Cable insulation	Partial discharge	5	4
	LCM	3	5
	Polarization index	5	5
	VLF withstand test	5	5
Conductor	AC withstand test	5	5
	Infrared thermography	5	3
	Partial discharge	5	4
	Dissipation factor	5	4
	Polarization index	3	3
	VLF withstand test	5	2

As mentioned in the previous section, the data of the condition indicators at each level are collected and converted into scores and weights. The scores and weights are given according to their corresponding standards [1,2,4-7]. The subcomponents and their condition indicators with scores and weights which are used to calculate the $\%HI_{subcomponent}$ of OHL and UGC are shown in Table 2 and Table 3 respectively.

Next we need to find out the *CF* value to determine $\%THI_{component}$. To calculate *CF* the component data and operational data including environmental data, accessibility and mechanical stress data are assessed carefully. Then these are converted into scores and weights for both OHL & UGC. The results can be seen in Tables 5 & 6.

Table 4 - Operational & component data and scores for condition factor of the OHL

Operational & component data	Condition	Scores	Weights
Operating temperature	30 °C	5	3
Operating voltage	No overvoltage	5	5
Load percentage	50%	3	4
Age in service	5 years	5	5
Failure frequency	0	5	5
Accessibility	Easily accessible	5	5
Mechanical stress	Material fatigue	3	4
Environmental condition	Partially polluted	3	5

Table 5 - Operational & component data and scores for condition factor of the UGC

Operational & component data	Condition	Scores	Weights
Operating temperature	27°C	5	3
Operating voltage	No overvoltage	5	5
Load percentage	48%	5	5
Age in service	5 years	5	4
Failure frequency	0	5	5
Cable lying condition	Direct buried	0	2
Accessibility	Difficult to access	0	5
Mechanical stress	Material fatigue	3	4
Environmental condition	Humid	3	5

3. Results

Based on the methodology presented in the previous section, the results for a case study on a transmission system consisting of both OHLs and UGCs are calculated as shown in Table 5. The HI values are calculated using (4) and (5) and the results are given in Fig. 2, showing both lines and system being in healthy condition.

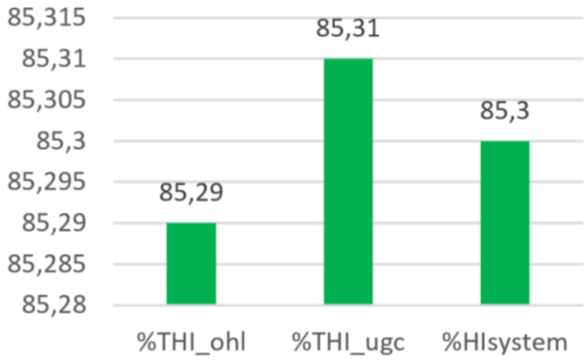

Fig. 2- HI value of the transmission system & its components

To understand the applicability of the HI for maintenance a case study has been done with the bad condition of the insulator. This case study is done on the same system, but with an assumed bad condition of insulators. A post insulator was exposed to pollution and therefore suffered insulator flashover as shown in Fig. 3. With this bad condition of a subcomponent the HI of the subcomponents of the OHL, the HI of OHL and the system-HI is recalculated.

Fig. 3 – Insulator condition post-flashover [2]

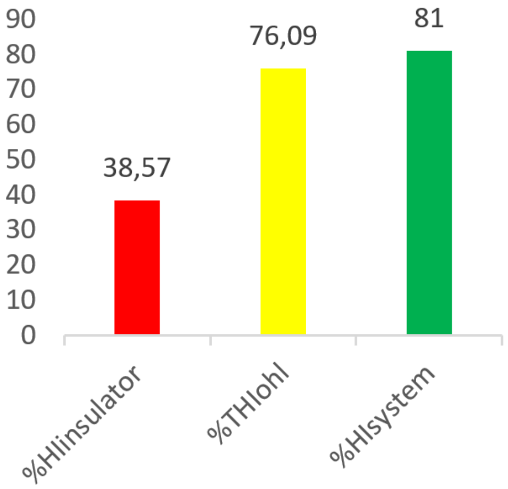

Fig. 4 -The HI value of the faulty insulator, overhead line and corresponding transmission system.

The results can be seen in the bar diagram in Fig. 4. Due to the damage, the HI of the insulator is 38.57%. This is indicator of an insulator having a major defect. On the other hand, the HI of the overhead line is only indicating a minor defect and the HI of the system shows a healthy system. The system HI of the normal condition is 85.3% (Fig. 2) indicating the healthy condition of the system. Whereas with the bad condition of the insulator the system HI is 81% which also indicates the healthy condition of the system. The difference between these two systems HI results is only 4.3%. The HI of the overhead line in the normal condition is 85.29%, indicating the healthy condition of the overhead line. With the bad condition of the insulator, HI of the overhead line is 76.09%, which indicates minor defects of the overhead line. The effect of the bad condition of the insulator is visible in the overhead line as the health index varies 9.2% and goes from a healthy to a defective overhead line. This is a serious concern in case of maintenance, decisions are mainly made by checking the HI at the system level. From the current case study, it is evident that the HI of the subcomponents is a considerably more reliable parameter for fault identification than the HI of the component or the system.

4. Discussion

The present study shows an effective way of conducting health index analysis of transmission systems containing both overhead lines & underground cables. The proposed methodology takes into account HI calculations based on the condition indicators at individual sub-components level, followed by the analysis of the information at the component level. It also suggests a method to separately add OHL and UGC system components in the calculation as condition factors to calculate the overall condition of the system. Such a study can be extended to include more transmission line components such as transmission towers, reactors and transformers as a single system in the HI assessment.

The second case study of the overhead line HI and system HI with a bad condition of an insulator indicates that the changes in the insulator condition are more visible in the overhead line HI as compared to the system HI. If the maintenance decisions are taken based on the system HI the bad condition of the insulator could be overlooked and might cause serious interruptions of the power supply. Therefore, it is suggested to make the maintenance decision based on the component HI instead of system HI. When the maintenance decision is made based on the component HI, it is also important to identify the fault location of the component. In this case, the HI of the sub-components can be used as an indicator of the fault location. The case study also shows that HI calculation at sub-component level is a more reliable factor for identification of faulty sections in the system. When the insulator has a bad condition, the HI of the insulator has significantly reduced from 88.57% to 38.57%. This 50% decrease of the HI is an indicator of serious fault in the insulator.

5. Conclusion

In this paper, a method for assessing the health index (HI) of the transmission system including both OHL and UGC by weight and score method (WSM) is presented. The HI is calculated based on the condition indicators of individual sub-components, supplemented with various component information to get a more suitable HI value. Analysis of sub-component HI as compared to higher-level HIs shows its significance in identifying critical conditions in a system. In general, the HI at component level approach appears to be suitable for conclusive condition assessment as basis for optimized condition-based maintenance.

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7. References

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