ASSET MANAGEMENT DECISION INTELLIGENCE BASED ON THE CONDITION (RISK) IMPORTANCE METHOD WITH DYNAMIC WEIGHING FACTORS

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ABSTRACT

This paper discusses prioritizing the maintenance and replacement of protective relays while employing the Asset Management Decision Intelligence (MDI) strategy based on risk management. Moreover, this presented method should not disagree with some legal or manufacturer required maintenance activities but should insure that exceptional action in the right time for the required assets. In addition, this paper also discusses various asset management strategies that can be determined based on plot points on the decision index. For this analysis, the urgency to maintain or replace power system assets is determined by how the decision indices are plotted within condition parameters. World new logic of dynamic weighing factors is helping to better determine extreme problems and notify urgent activities. Further paper will describe capability of analyses trend estimation which allows future optimization of asset management strategy and prediction of the activities.

The detailed observations of this paper will explain how this strategy corrects the behaviour of maintenance decision intelligence while determining when to maintain and replace assets. This analysis utilizes plots against the condition and importance (risk) diagram, and compares the results without dynamic weighing factors to the results with the dynamic weighing factor calculations. Through this approach, it is recommended that the dynamic weight calculations be a simulation of real life situations when exposing power system assets to ever changing environments. The dynamics values of the weights can be associated with some critical criteria.

Power systems maintenance prioritization will be advantageous for utilities that have a plethora of power system assets to monitor while optimizing operation effectiveness and improving smart grid reliability. The MDI strategy can improve how time and budget is allocated when supporting critical power system assets and reduce service costs.

This strategy can improve allocated time when supporting critical power system assets and can reduce service costs. Further MDI Strategy supports optimal replacement strategy of protective relays. MDI Method is applicable on all asset groups. The difference is only in different evaluation criteria and different decision rules. Paper will present example for protective relays. This solution offers advantages in system reliability while providing economic benefits for today's power systems.

KEYWORDS

Condition Based Maintenance, Prediction Maintenance, Reliability Centered Maintenance, Maintenance Decision Intelligence, Risk Management

INTRODUCTION

New approach in the area of asset maintenance management is moving from standard time based and break-through maintenance to more sophisticated methods like condition based and predictive maintenance. In theory, condition based maintenance is defined with some selected input variables that together with customer specific or analytic formulas and weighting factors represents overall condition of the asset.

In this paper we will focus on condition assessment and prediction approach in the area of power system assets. Method presented in the paper is applicable on any asset group related to electrical power systems like: protective relays, power transformers, Overhead Lines, Cables, Generators, but as well complex asset groups like entire Substations. Further method is applicable to areas of Transmission, Distribution and Generation.

In paper, we will discuss using the condition and importance (risk) analysis matrix and the benefits of doing so. We will also discuss the prioritization of using the matrix as a maintenance decision strategy. The matrix will operate as a decision index that will be used to determine critical maintenance.

In order to run monitoring analysis, universal interfaces and data intelligent systems have the following capabilities:

1. to leverage data from almost any source without use of expensive and inefficient interfaces;
2. to execute conditional actions based on data conditions;
3. to define analyses of the data or to use a standard analytic method for asset condition estimation of existing data;
4. to alert and notify based on the condition data;
5. to publish data from different sources using the central publisher application;
6. to have a central dashboard with published special data, for example management supervision.

Core of the paper will concentrate on the analyses (point 3) for efficient and critical estimation of protective relay condition with the use of dynamical weighting factors.

TESTING AND ANALYSIS

When condition and importance values are applied, calculations are taken from a list of indices that sum up the representing condition index and importance index.
Condition of protective relay is in this paper calculated/defined from following indices types:

- Age Condition
- Protection Type related information
- Protection Device Instance related information
- Protection Maintenance Results related information

CONDITION INDICES WITH DYNAMIC WEIGHTING FACTORS

This section discusses the examples of condition analysis. It is very possible that some other experience factors and index values may be utilized or appended. Therefore, the method is not to understand as "the unique way." The purpose of this discussion is to offer a new way of thinking and to give decision makers more information to support more plausible decisions. Moreover, this section discusses the calculation of attributes that is used to determine the condition index.
Preconditions and explanations:

- Sum of Weighting Factors inside one condition analysis must be 100%;
- Deviation number represents highest numeric value of each individual condition index;
- Each condition index is calculated as $\frac{Numeric\ Value}{Deviation} \cdot \frac{Weighting\ Factor}{100}$;
- Alert Index represents **dynamic weighting factor** as a relative part of deviation number;
- Condition index can have any value between 0 - good and 1 very bad condition.

Table 1: Age condition

	Quality Value	Numeric Value (NV)	Weighting Factor (WF) [%]	Alert Index (AI)
Technlgy	Digital – Microprocessor	3		
	Analog - Static	4		
	Electromechanical	2		
Age [years]	0 – 2	10*TechNV		
	2 – 10	0*TechNV		
	10 – 15	5*TechNV		
	15 – 20	15*TechNV	15	0,45
	20 – 25	20*TechNV		
	25 – 40	25*TechNV		
	>40	30*TechNV		

Age condition index of the protective relay can be calculated based on the technology information. The most unreliable technology in the area of power system protection is analog – static. Due to the short lifecycle the condition of the analog – static devices has the highest numeric value. On the other hand electromechanical devices are used in their limited functional scope for many decades so they are treated as the technology with the longest lifecycle. Age weighting factor is related to the technology information.
With numeric values shown above in the table estimated alarm index is set to 0,45 which means that using dynamic weighting factor in asset management system there will be automatically generated replacement process for:

- analog – static devices between 15 – 20 years;
- digital – microprocessor devices 20 – 25 years;
- electromechanical devices after 40 years.

Table 2: Protection Type related information

Condition Index	Quality Value	NV	WF [%]	AI
Spare Parts Availability	Good	0	5	
	Fair	2		
	Poor	5		
Skilled Staff Availability	Good	0	5	
	Fair	2		
	Poor	5		
Operational Experience	Good	0	5	
	Fair	2		
	Poor	5		
Cost Level	Low	0	5	
	Normal	1		
	High	3		
	Very High	5		
Annual Failure Rate	0,1%	0	5	0,95
	0,5%	1		
	1,5%	3		
	2,0%	5		

Protection Type related condition indexes are based on operational knowledge, market development and annual statistics. First four indices (Spare Parts Availability, Skilled Staff Availability, Operational Experience and Cost Level) represent general condition factors with no need to use dynamic weighting factor functionality. If any of these factors reaches the worst condition stage this only summarize in overall index with no alarm.
In case of Annual Failure Rate index we have introduced an alarm index which will set alarm to all assets of the particular asset type in case that the annual rate of failures exceed 2% of installed protective relays of the same type. That condition will raise a requirement for replacement process of all protective relays of the particular type to limit costs of repair and the total cost of the ownership.
Atmospheric Stress Exposure and Pollution Exposure usually don't change during the asset lifecycle. It can probably change in case of location change. Corresponding condition indices are calculated as already stated in previous case.

Table 3: Protective Relay Instance related information

Condition Index	Quality Value	NV	WF [%]	AI
Atmospheric Stress Exposure	Low	0	5	
	Normal	1		
	High	3		
	Very High	5		
Pollution Exposure	Low	0	5	
	Normal	1		
	High	3		
	Very High	5		

The last information of protective relay condition calculation is coming from maintenance process. According to the maintenance protocol and level of acquired data there can be several different indices describing the real operational condition of the protective relay

Table 4: Protection Maintenance Results related information

Condition Index	Quality Value	NV	WF [%]	AI
Error Category	0 – 5%	0	5%	0,9
	5% – 10%	2		
	>10%	5		
Operational Time Tolerance Acceptance	Operation Assessment OK	0	5%	0,9
	Oper. Asses. False & Tol<max(10%,100ms)	2		
	Oper. Asses. False & Tol>max(10%,100ms)	5		
Reset Ratio Acceptance	Oper. Assessment OK	0	8%	0,9
	Oper. Asses. False & RR > 80%	2		
	Oper. Asses. False & RR < 80%	5		
Reset Time Tolerance Acceptance	Oper. Assessment OK	0	12%	0,9
	Oper. Asses. False & Tolerance < 200 ms	2		
	Oper. Asses. False & Tolerance > 200 ms	5		
First Electric Check Acceptance	First Electric Check OK	0	20%	0,9
	First El. Check Fail 1x	2		
	First El. Check Fail ≥ 2x	5		

Error Category condition index: According to the protective relay sensitivity and reliability, error categories can be selected based on test results. This is calculated value from testing point information defined during protection testing process. If tolerance exceeds 10%, alarm index will set alarm and raise a requirement for replacement process.

Operational Time Tolerance Acceptance: If test process is supported by test automation, test results already have information about assessment based on predefined technological data (min. operating time, relative and absolute tolerances…). In case that automated operation assessment gives positive result (**OK**) everything should be fine. But if automated operation assessment gives negative result of testing (**False**) there can be additional condition that in case that operational time tolerance is higher than 10% alarm index will set alarm to protective relay and raise a requirement for replacement process.

Reset Ratio Acceptance: Test results have information about assessment based on predefined technological data (reset ratio, relative and absolute tolerances…). If automated operation assessment gives negative result of testing (**False**) there can be additional condition that in case that reset ratio is lower than 80% alarm index will set alarm to protective relay and raise a requirement for replacement process.

Reset Time Tolerance Acceptance: Test results have information about assessment based on predefined technological data (min. operating reset time, relative and absolute tolerances…). If automated operation assessment gives negative result of testing (**False**) there can be additional condition that in case that reset time tolerance is higher than 10% alarm index will set critical condition (1) to the protective relay and raise a requirement for replacement process.

First Electric Check Acceptance: important, attractive and "must have" test in many power system protection departments. This should be the first test of the protective relay. This test should cover as much of the protection system as it can (if possible including trip circuit test). It might happen that protective relay will not operate as it should on the first check and that is a problem. In our case we set condition that protective relay should get alarm condition if first electric check is not successful for two times (in the current maintenance process or also from the past).

IMPORTANCE INDICES

Importance indices are used for the maintenance prioritization of the assets. More important assets should have higher priority in MNT decision process then assets with low importance. Preconditions and explanations:

- Sum of Weighting Factors inside one importance analysis must be 100%;
- Importance index can have any value between 0 (not important) and 1 (very important);
- Each importance index is calculated as $\frac{Numeric\ Value}{Deviation} \cdot \frac{Weighting\ Factor}{100}$;
- Deviation number represents highest numeric value of each individual condition index;

These indices can change during the asset lifecycle. They can probably change in case of location change or network topology change which causes the change on customer structure and system stability

Table 5: Protective Relay Importance Definition

Importance Index	Quality Value	NV	WF
Primary Voltage Level	< 1 kV	0	20%
	1 kV – 30 kV	2	
	30 kV – 100 kV	4	
	100 kV – 200 kV	10	
	200 kV – 300 kV	15	
	> 300 kV	20	
Influence On System Stability	Low	0	20%
	Normal	1	
	High	3	
	Very High	5	
Disconnected Power	< 0,1 MVA	0	20%
	0,1 MVA – 1 MVA	2	
	1 MVA – 10 MVA	4	
	10 MVA – 50 MVA	10	
	50 MVA – 100 MVA	15	
	> 100 MVA	20	
Component Criticality	Low	0	20%
	Normal	10	
	High	15	
	Very High	20	
Number of Protection Operations in last year	0 - 5	0	20%
	5 - 10	1	
	10 - 20	2	
	> 20	3	

MNT DECISSION INTELLIGENCE (MDI) AND PRIORITIZATION ALGORITHM

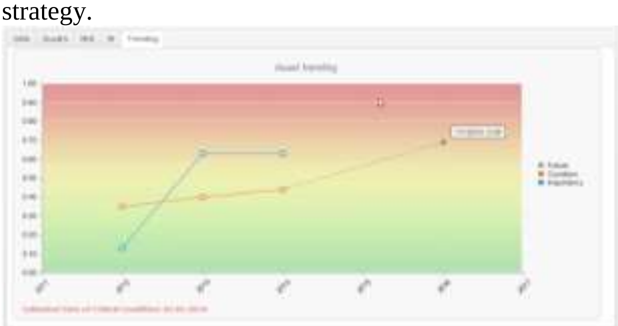
Once the condition and importance analyses are complete, the decision index which represents each individual protective relay is assigned to the six color-coded regions using critical analysis.
MDI is continuously updated with condition and importance factors and saves its results. Change of the condition factors is recorded in period of time as a trend analysis.

MDI shows each protective relay and has the advantage of offering improved system reliability study with customer defined decision plans – prioritization algorithm:

- Green – Standard MNT with condition supervision;
- Blue – Congested MNT according to condition;
- Yellow – Break through MNT. (If fail replace);
- Brown – Replace in less than 3 years;
- Red – Replace in less than one year (a.s.a.p).

PREDICTION MAINTENANCE

Using least square method it is possible to calculate predicted time when condition will go critical. This helps asset managers to additionally define a replacement strategy.



Used information technology system is capable of sending notifications and alerts to responsible people.

BENEFITS OF DYNAMIC WEIGHTING FACTORS USE

Next table is showing practical example of standard CBRM Condition Based Risk Management method compared with Dynamic Weighting Factor method.

Table 6: Difference between classic RCM method and Dynamic Weighting Factors method

Condition Index	Quality Value	NV	WF	Index
Technology	Digital	3		
Age [years]	5	15	15	0,01
Spare Parts Avail.	Good	0	5	0
Skilled Staff Avail.	Fair	2	5	0,02
Oper. Experience	Fair	2	5	0,02
Cost Level	Normal	1	5	0,01
Annual Failure Rate	0,5%	1	5	0,01
Atmospheric Stress	Low	0	5	0
Pollution Exposure	Normal	1	5	0,01
Error Category	5% - 10%	2	5	0,02
Op. Time Tol. Acc.	Op. Ass. OK	0	5	0
RR Acceptance	Op. Ass. OK	0	8	0
Reset Time Tol. Acc.	Op. Ass. OK	0	12	0
First El. Check Acc.	Fail ≥ 2x	5	20	0,2-> (1)
Protective Relay Condition Index	Normal Calc. With Dynamic Weighting F.			0,30-> (1)

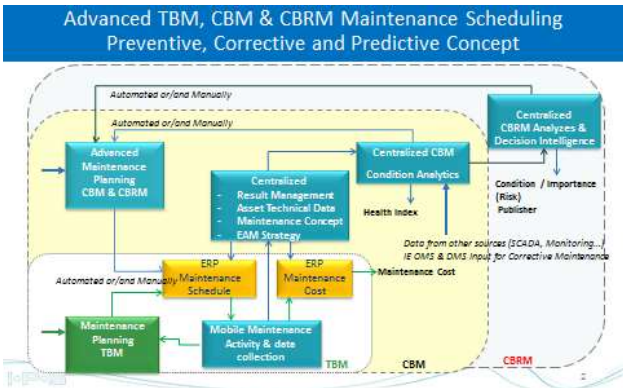
For protective relay with no special deviations the result of classical CBRM would just give a condition index 0,3. There is no notification or algorithm that would notify management about one very critical thing – that First Electric Check of the protective relay has not been successful even after second try. Using Dynamic Weighting Factors that we don't need to have any fear about skipping some very important information. In case that calculated index value exceeds alarm index, the overall protective relay index is set to the worst condition. Same time user can get a high priority notification and at the same time the maintenance cycle of the particular protective relay is set to the appropriate value (value depends on MDI prioritization algorithm).

Overall protective relay condition index is calculated as the sum of partial condition indices.

Dynamic weighing and condition alerts can be adjusted on any required parameter but usually this is defined on most vital parameter.

CONCLUSION

Last picture presents usage of MDI Method within comprehensive asset management and maintenance concept with mix of various maintenance methods like TBM – Time Based Methods, CBM – Condition Based Methods and CBRM – Condition Based Risk Methods.



As can be seen successful Enterprise Asset Management Concept is working simultaneous with various estimation and activity calculation methods. Be aware that method is relying on capability of mobile system to collect required data and relaying on data intelligence collect and process all other data needed for such analyses.

Condition and importance (risk) analysis and trending are advantageous in helping to determine the life cycle of power system assets. The ability to send notifications to the operator/administrator of the power system is useful. Benefits of using a condition versus an importance (risk) approach are reduced cost, improved system response time, and assurance in reaching full potential of the asset lifetime cycle. Each analysis displays asset groups according to condition and importance coordinates and set the maximum condition criteria to 1.0.

Condition and importance indices are highly valuable in supporting related decision processes, especially those that affect long-term system performance. Main aspect of any asset management process to increase efficiency in terms of resource use, is the prioritization of measures and network components. Shown cases demonstrate how a range step can help determine the coordinates of protective relays, how they are placed in various ranges of condition and importance and the prioritization algorithm of needing to maintain or replace power system assets.

This paper demonstrates a method that can be used for any asset group. Our example presented example for protective relays. Moreover, this method requires practical experience when understanding a parallel method compared to existing strategies. This paper further supports information for decision makers which will obtain more information in order to defense asset management strategies. The MDI method must sometimes be adopted for various countries in order to satisfy regulatory rules. These methods require appropriate information technology database support when the MDI approach is applied. MDI is an advantageous solution compared to manual usage like Microsoft® Excel® when supporting complex maintenance, risk management and cost effective decisions. MDI is treated as Analytics Monitor which is calculating and working all the time.

And last but not least, condition estimation is usually based on many partial indices which in summary can give a general estimation of asset condition. Huge disadvantage of classic CBRM method is a very high possibility of losing precious information about exceeding normal maintenance values in one or more partial indices. In practice that would basically mean that condition estimation of the asset is not correctly defined and it can bring a system to collapse without any notification. Introducing Dynamic Weighting Factors asset owner can always have latest and greatest information without losing alarm information in averaging process.

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