An asset management technique applicable in electrical systems

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AN ASSET MANAGEMENT TECHNIQUE APPLICABLE IN ELECTRICAL SYSTEMS

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This paper focuses on presenting an asset management technique that may be used to assist prioritization of assets within electrical networks for major refurbishment/re-engineering exercises. A multi-criteria approach is adopted to this aim, making use of quantifiable measures of features that can be attached to complex groups of installation within electrical networks. Technical condition in conjunction with conveyed electric energy, to which operational and strategic importance measures are added, will be at the core of a grading mechanism that finally produces an objective hierarchy within a given set of entities from the electrical network.

The technique is described in the paper and critical aspects related to its implementation are also discussed. As with all multi-criteria approaches the selection of weighting coefficients set is one of the key elements for the success of the technique when it comes to achieve a good discrimination feature against a variety of conditions. Results from the implementation of technical condition assessment component to an individual real-life problem are presented also.

Keywords: asset management, electric energy systems

1. INTRODUCTION

In the Romanian increasingly competitive electricity market the pressures to maximize the return on investment and to optimize operational expenditures have become increasingly high. Both regulatory framework and competitiveness call on a revision of the traditional approaches used for the formulation of maintenance strategies and distribution network operations and reinforcement optimization such as operational security and the economic efficiency of specific activities to be increased.

Asset management approaches play an important role in the effective handling of these problems. Part of the mechanisms employed at decision level is conditioned by the availability of tools to deliver an objective prioritization of potential candidates for refurbishment/modernization from a given range of installations that are exploited by distribution operators.

There are some relevant works reported in the literature [1], [4], [5] regarding techniques to be employed for effective asset management, primarily aimed at transmission level installations. Asset management systems have gained a solid ground into the techniques aimed at maximizing the effectiveness of resource spending for system strengthening and improved operation capabilities. Usual functions performed with assistance from asset management systems cover:

- elaboration of maintenance strategies;
- decision on replacement or re-engineering of distribution networks assets;
- implementation of risk management features into the strategic operation of the networks.

The evolution of maintenance management systems correlated with ever more frequent utilization of methodologies based on cost management as function of duration/lifecycle, etc. facilitate the extension of asset life duration and may bring useful information to support their management across their life-time span.

Presently three main streams of maintenance strategies are widely applied at transmission and distribution network level: condition based maintenance (CBM), reliability centered maintenance (RCM) and risk-based maintenance (RBM). It is beyond the scope of present work to elaborate on pros and cons for these strategies. Any of these strategies make use of elaborate data gathering systems which may provide in turn valuable information for asset management systems.

The competitiveness pressures have created additional incentives to make room for more intelligent ways to capitalize on this information. Some of the directions indicated in literature [1], [3], [4] propose to make use of a blend of this information such as to assess installation technical condition and/or detect the criticality of this condition within a given set of installation.

The work reported here attempts to describe a consistent methodology to be used with the prioritization of actions to be taken in order to restore or maintain the operational capabilities of various installations part of a distribution operator network. The methodology aims at establishing a coherent recipe to detect critical points in the network

and it is intended to look at higher level entities such as nodes or connections.

In order to produce the critical points ordered list a multi-criteria analysis is described based on two main categories of criteria [6]:

- technical condition (physical usage condition, number of faults, unavailability duration and associated costs/effects);
- conveyed electric energy (observed electric energy flow, forecasted electric energy flow).

Each of these criteria will provide a mark that contributes to the overall score attached to each surveyed entity. In addition new criteria thought to bear on entity criticality are introduced, such as operational importance and strategic importance features of the entities. Since the entities we focus on with this methodology are in fact quite complex and several equipment types may be embedded in one such entity, the method we discuss here will use for the sub-criteria listed under the technical condition a set of weighting coefficients selected to represent the assumed importance of these equipment types within the given entity.

A discussion upon possible sensitivity-based weighting combinations of the listed criteria is also presented. These combinations have to ensure consistent behavior of the method when handling recently refurbished entities in conjunction with strategically less important entities. Results from applying the technical condition assessment on a real-life substation are also included in the paper.

2. STATEMENT OF ASSET MANAGEMENT CORE METHOD

The complexity of installation involved in electrical systems, either at transmission or distribution level, makes aggregation of assets into entities of various complexity degrees a preliminary working hypothesis. Electrical networks natural choice is convergent on nodes and connections concepts:

- nodes (bus bar systems and substation equipment apart from transformers/auto-transformers);
- connections (electrical lines, auto-transformers and transformers).

We shall focus primarily on NODE entity for the description of the method. Concepts can be easily extended to the other entities. For a NODE entity the following sub-systems or classes of equipment will be considered: primary equipment (switchgear, switch-disconnecters, current and voltage transformers), secondary equipment (relays, protection systems, controls, signals), surge arresters, construction elements (foundations, concrete frames, etc.) and earthing components.

The determination of critical points is based on a multi-criteria analysis. The criteria considered are:

- node technical condition - TC
- operational importance within network - OI
- conveyed electric energy - CE
- strategic importance within network - SI.

For each of these criteria a mark from 1 to 100 will be awarded to the nodes. Mark 1 corresponds to the best qualification, while mark 100 describes the worst case. The marks associated to each criterion will be multiplied by the following weighting coefficients, with their sum equating 1:

- node technical condition p_{TC} [p.u.]
- operational importance within network p_{OI} [p.u.]
- conveyed electric energy p_{CE} [p.u.];
- strategic importance within network p_{SI} [pu].

Selection upon the advisable set of weighting coefficients is subject to achieving a consistent behaviour when handling various entities within the network.

2.1. Technical condition assessment

Several potential features may intervene in the technical condition assessment. It all depends upon availability of dedicated data collection systems for implementation of management strategies such as condition-based maintenance or reliability-centred maintenance. In the absence of elaborated mechanism to collect such information an alternative may be applied in the form of using four sub-criteria with associated weighting coefficients (please refer to Table 1).

Table 1. Technical condition sub-criteria

Sub-criteria	Abbr.	Weight [p.u.]	Value
equipment physical usage	**PU**	p_{PU}	0.45
number of faults	**NF**	p_{NF}	0.20
unavailability duration	**UD**	p_{UD}	0.15
associated costs	**AC**	p_{AC}	0.20

The mark for technical condition will be composed as follows as a weighted sum of marks awarded under each of the nominated sub-criterion.

2.1.1 Equipment physical usage

As we mentioned before within the NODE entity a certain set of different pieces of equipment are usually found. They may be grouped into classes of equipment and operational importance centred weighting coefficients can be allocated (see Table 2).

Each of the physical units part of such a class will receive a mark related to its physical usage on a scale from 100 to 1, with 100 for the worst condition. Ideally this would be based on a condition-based maintenance data collection system. Because of relative scarcity of these systems the alternative way is to base the mark on a different approach, briefly described in the following:

1) a number of points corresponding to physical usage (correlated to equipment age and life-expectancy) is

computed for each physical unit from one of the equipment classes within the NODE entity under survey:

$$Pts_{PU} = \frac{CurrentYear - CommissioningYear}{LifeTimeExpectancy} \quad (1)$$

Table 2. Equipment classes for the NODE entity

Equipment class	Equipment type	Operational importance weighting coefficient WC_{OI}
1	Protections, automation schemes, controllers, signaling	6
2	Switchgears, switch-disconnectors, measuring current and voltage transformers	5
3	Busbar systems	4
4	Surge arresters	3
5	Constructions (foundations, concrete frames, etc.)	2
6	Earthing, lightning rods	1

2) based on the points for physical usage a ranking in descending order amongst physical units will be made. Correlated to this order a physical usage mark will awarded on the scale from 100 down to 1.
3) with these physical usage marks a grade per each class of equipment within NODE entity is computed as:

$$G_{avg\_eq,j} = \frac{\sum_{i=1}^{n_j} M_{j,i}}{n_j} \quad (2)$$

where $G_{avg\_eq,j}$ is the average grade for class j of equipment, n_j is the number of items in class j, while $M_{j,i}$ stands for the mark received by item i in class j.
4) based on average grades computed per types of equipment a physical usage mark for the mixture of equipment inside the node entity can be computed according to:

$$M_{PU} = \frac{\sum_{k=1}^{6} G_{avg\_eq,k} \cdot WC_{OI,k}}{\sum_{k=1}^{6} WC_{OI,k}} \quad (3)$$

where M_{PU} is the corresponding mark for the usage degree of equipment embedded in the node under survey; $WC_{OI,k}$ stands for the operational importance weighting coefficient for equipment class k; $G_{avg\_eq,k}$ is the average grade for usage in the equipment class k.

In the above, the *CurentYear* refers to present year when assessment is undertaken, *CommissioningYear* accounts for the moment the physical unit was commissioned, while *LifeTimeExpectancy* usually corresponds to the technical life expectancy of that equipment class (typically 30 years).

2.1.2 Number of faults

It is customary to associate a certain importance of the faults to the equipment class that is affected. In order to reflect this practice in the technical condition sub-criteria assessment a similar set of weighting coefficients as in the previous case (Table 1) is employed when the mark for number of faults is calculated from fault statistics.

Depending on the level of detailed information available, an *equivalent number of faults* per each type of equipment may be computed. This equivalent number is calculated as ratio of total number of faults experienced by the units of a precise equipment type divided to the number of units. Afterwards a descending ranking based on this equivalent number of faults is created and marks on the scale from 100 to 1 are awarded. The next stages will imply computation of average grade per equipment classes (in a similar manner as with equation (2)), followed by final mark for number of faults M_{NF} computed as per equation (3).

On the minimal side one can use just NODE specific statistics with respect to number of faults, skipping the equivalent number of fault concept.

2.1.3. Unavailability duration

Following a similar reasoning as with previous sub-criterion the correlation of the unavailability duration to the equipment type has to be taken into account when unavailability duration mark is to be computed for the NODE entity.

Hence an *equivalent unavailability duration* is calculated per each equipment type within given classes for the whole set of units of an electrical system. This equivalent results as ratio between cumulative unavailability durations for the units of an equipment type to the number of units. Based on *equivalent unavailability duration* a ranking in descending order is created. To this ranking marks from 100 down to 1 are awarded for each equipment type. A grade for each equipment class is produced using an equation similar to equation (2). Then the mark for unavailability duration at NODE entity level is computed using an equation (3)-type approach.

On the minimal side one can employ just NODE specific unavailability duration statistics, without calculation of system-wide *equivalent unavailability duration*.

2.1.4. Associated costs

The associated costs incurred by a given fault occurrence should make inclusive part of the technical condition assessment. On the minimal side, when such statistics are not widely available, some way of quantifying the economic effects of faults should be introduced.

Table 3. Associated costs for equipment item

Equipment	Recorded faults	Preventive maintenance	Corrective maintenance	Unserved energy penalties	Dispatching expenditure
E_j	F_{j1}		CM_{j1}	UE_{j1}	
	F_{j2}		CM_{j2}	UE_{j2}	
	…		…	…	
	F_{jn}		CM_{jn}	UE_{jn}	
		PM_{Tj}	CM_{Tj}	UE_{Tj}	DE_{Tj}

The associated costs fall into a number of categories, briefly indicated in Table 3, which can be summed up into an associated cost per equipment E_j of type *i*:

$$AC_{j,Tj} = PM_{Tj} + CM_{Tj} + UE_{Tj} + DE_{Tj} \quad (5)$$

The average associated cost for all physical units of a given equipment type will be used for ranking these equipment types. A mark from 100 down to 1 will be awarded to the descending ranked list. A grade for equipment class is produced using equation (2)-type approach, while the final associated costs mark results from using equation (3)-type with similar weighting coefficients as throughout this paragraph for equipment classes.

2.2. Operational importance within network

This concept can be approached from a variety of angles but the most consistent is by associating it with the relevance for secure operation of the network. The secure operation of the network is independently assessed by a dedicated software which integrates a number of variables and effects related to the operation of the particular entity under scrutiny.

Briefly this software integrates the following features:

- the affiliation of NODE/CONNECTION entity to characteristic section from system stable operation point of view;
- the technical importance of the NODE or CONNECTION, judged via the effects upon loadability margins across the system (CONNECTION), or via the effects upon transient stability resulted from short-circuit experienced (NODE);
- the magnitude of energy non-deliverable in the neighbouring power stations due to outage on NODE or CONNECTION entity.

2.3. Conveyed electric energy

The third relevant criterion to be considered in the assessment process is represented by the amount of conveyed electric energy. One option would be to determine the mark associated to this criterion based on the values of energy flow through the given entity for the previous year and with the forecasted energy flow for the coming period of one year.

It is envisaged to award the following weighting coefficients:

- for *Observed Electric Energy Flow*, measured, through each node or connection, across the previous year it will be p_{OE} -> 0.40.
- for *Forecasted Electric Energy Flow*, which is estimated via computation of operation regimes for characteristic season and day it will be p_{FE} -> 0.60.

2.4. Strategic importance within network

This criterion is relatively new and enjoys a certain degree of volatility in terms of definition options. It is primarily intended to characterize the involvement of the entity into the regional electricity market. Therefore it will represent the degree of contribution of the entity to international exchanges and evacuation of energy from nuclear power stations.

2.5. Summing-up remarks

The method previously described has a certain degree of versatility to suit several subsystems of the electrical network. Given the extent of weighting coefficients potential impact on judging the resource allocation, a sensitivity analysis to help decision as to the most appropriate set of weighting coefficients is a must to for the development of the method.

These weighting coefficients are not a set rule, as they may vary from a system to another. A consistent implementation should seek achieving results such as to avoid repetitive selection of the same candidates from a given set of entities.

Some fine tuning is also needed in order to make sure the available data from other systems fed directly into the system. To this end flexibility is expected when handling the lack of independently assessed marks for the applicable criteria.

3. WEIGHTING COEFFICIENT SENSITIVITY ANALYSIS

A range of weighting coefficient sets (table 4) has been proposed with an aim to explore their capability to correctly identify the ranking of entity candidates for refurbishment activities in a variety of conditions.

Table 4. Proposed weighting coefficient sets

			Inner partition	P2		P3		P4		P5		P6	
TC	Physical Usage	PU	0.45	0.2500	*0.1125*	0.2500	*0.1125*	0.3000	*0.1350*	0.3100	*0.1395*	0.3500	*0.1575*
	Number of Faults	NF	0.20		*0.0500*		*0.0500*		*0.0600*		*0.0620*		*0.0700*
	Unavailability Duration	UD	0.15		*0.0375*		*0.0375*		*0.0450*		*0.0465*		*0.0525*
	Associated Costs	AC	0.20		*0.0500*		*0.0500*		*0.0600*		*0.0620*		*0.0700*
OI	Operational Importance	OI	1.00	0.2500	*0.2500*	0.2300	*0.2300*	0.2000	*0.2000*	0.2000	*0.2000*	0.2000	*0.2000*
CE	Observed Energy Flow	OE	0.40	0.3000	*0.1200*	0.2700	*0.1080*	0.2500	*0.1000*	0.2600	*0.1040*	0.2500	*0.1000*
	Forecasted Energy Flow	FE	0.60		*0.1800*		*0.1620*		*0.1500*		*0.1560*		*0.1500*
SI	Strategic Importance	IS	1.00	0.2000	*0.2000*	0.2500	*0.2500*	0.2500	*0.2500*	0.2300	*0.2300*	0.2000	*0.2000*

Two potentially occurring conditions have to be correctly discriminated by the selected weighting set.

Firstly, it should clearly single out an entity where recent refurbishment takes place, such as to avoid this entity to come top of ranks when subsequent analysis is ran. Secondly it is necessary to create fair chances for an entity of lesser operational and strategic importance to access high positions in the hierarchy leading to refurbishment entry list.

Two scenarios were considered. The first one looks into the effects of weighting sets when the entity is subject to refurbishment action that improves dramatically the technical condition. Results are indicated in Table 5 and show maximum depreciation of final mark when set P6 is employed.

Table 5. Weighting set performance for the same entity before and after refurbishment is undertaken.

	Notes		P2		P3		P4		P5		P6	
	before	after	before	after	before	after	before	after	before	after	before	after
PU	100	1	11.250	0.113	11.250	0.113	13.500	0.135	13.950	0.140	15.750	0.158
NF	100	1	5.000	0.050	5.000	0.050	6.000	0.060	6.200	0.062	7.000	0.070
UD	100	1	3.750	0.038	3.750	0.038	4.500	0.045	4.650	0.047	5.250	0.053
AC	100	1	5.000	0.050	5.000	0.050	6.000	0.060	6.200	0.062	7.000	0.070
DI	50	50	12.500	12.500	11.500	11.500	10.000	10.000	10.000	10.000	10.000	10.000
OE	55	55	6.600	6.600	5.940	5.940	5.500	5.500	5.720	5.720	5.500	5.500
FE	47	47	8.460	8.460	7.614	7.614	7.050	7.050	7.332	7.332	7.050	7.050
IS	53	53	10.600	10.600	13.250	13.250	13.250	13.250	13.780	13.780	10.600	10.600
			63.160	38.410	63.304	38.554	65.800	36.100	66.242	35.552	68.150	33.500

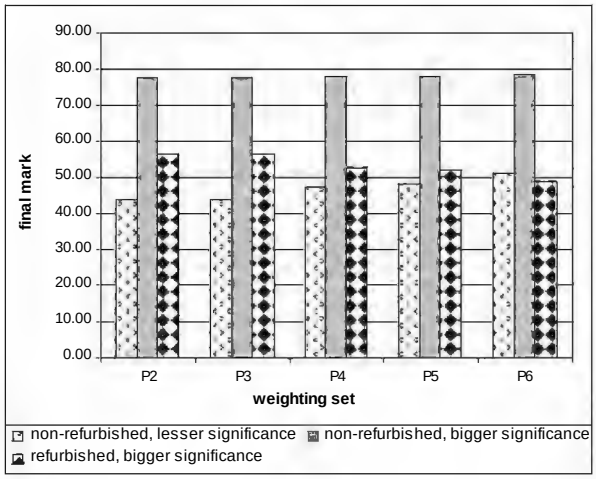

Figure 1. Weighting set effect on comparing entities under different status.

The second scenario explores the discriminating powers of the weighting sets when applied to entities of different status. Two different entities are considered, on one hand an entity with no refurbishment/re-engineering undertaken, of lesser importance both in terms of operational and strategic criteria and with little conveyed energy. On the other hand there is an entity of completely different status, bigger importance, larger conveyed energy, which will experience a major refurbishment process. Prior to refurbishment the method should place high in hierarchy the most important entity, whereas after refurbishment a better position should result for the lesser important entity. This outcome is achieved to a sensible degree by the P6 weighting set which is deemed to provide the better discriminating features of the explored sets.

4. STUDY CASE ON TECHNICAL CONDITION ASSESSMENT

A real-life application of the method previously described is presented for a transmission substation with the following particulars:

- 19 switchgear units, aged from 30 down to 2 years;
- 65 switch-disconnectors, aged from 31 down to 2 years;
- 21 earthing rods, aged from 30 down to 2 years;
- 18 current and voltage transformers, aged from 30 down to 1 year;
- 4 busbar systems, aged from 24 down to 2 years;
- 4 surge-arresters, aged from 27 down to 3 years.

The lack of relevant data for the computation of associated costs per faults experienced during the period since the equipment is in service has prompted for an alternative route to handle this part of the technical condition assessment. A corresponding marking system to the degree of severity of fault side effects on surrounding installations is put in place (Table 6).

Table 6. Fault effects quantification

Fault has affected :	Mark
just the piece of equipment involved	20
all the operational assembly from which the piece of equipment is part of	40
the node to which the faulted piece of equipment is part of	60
the substation to which the faulted piece of equipment is part of	80
other nodes or substation of the transmission system	100

The analysis for awarding the physical usage marks is not included due to large amount of data involved. Results of this analysis will be however embedded in the final technical condition mark per entity.

Table 7. Number of faults mark assessment.

Equipment class	Equipment in the class	No of faults per class (nf)	Class weighting coefficient	nf * CF_k	N_{MF}	N_{MF}
I	switch-disconnecters, switchgear, current transformer	28	5	140	100	42.69
II	earthing rods	9	1	9	6.429	
III	surge-arresters	4	3	12	8.571	
IV	bus bars	2	4	8	5.714	

Table 8. Unavailability duration mark assessment.

Equipment class	Equipment in the class	Unavailability duration per class (ud) [h]	Class weighting coefficient	ud * CP_k	N_{LUD}	N_{UD}
I	switch-diconnecters, switchgear, current transformer	283,4	5	1417	100	39.92
II	earthing rods	26	1	26	1.835	
III	surge-arresters	12.4	3	37.2	2.625	
IV	bus bars	8.2	4	32.8	2.315	

Available fault statistic allow for the determination of related grades as it is presented in Tables 7 and 8. The technical condition mark per classes of equipment is indicated in table 9, with the convention that the higher the mark the worse the technical condition is.

The results single out the condition of the switchgear, switch-disconnectors and their likes from the substation under scrutiny.

Table 9. Technical condition marks for the study case

Criteria:	Physical Usage	Number of Faults	Unavailability Duration	Fault effects	Mark
Weighting coeffcient	**45%**	**20%**	**15%**	**20%**	
Equipment class I	50.94	100	100	40	***65.92***
Equipment class II	48.57	6.429	1.835	20	***27.42***
Equipment class III	46.66	8.571	2.625	40	***31.11***
Equipment class IV	30	5.714	2.315	80	***30.99***

5. CONCLUSIONS

This paper represents an attempt to produce a formal methodology able to deliver an objective prioritization of the candidates for refurbishment/re-engineering from a given set of entities (NODES/CONNECTIONS). The prioritization is based on a multi-criteria analysis that spans across elements such as technical condition of the components of the entity, their operational and strategic importance and nonetheless important the conveyed electric energy during normal operation.

The design of such a methodology depends on a number of factors from which critical are the availability of data and level of detail to which this data exists. An ideal recipe is instructed here but elements of flexible approach were presented as alternatives. The marking process may be to some extent a non-objective one, but extracting information from as many as possible physical units helps smooth this effect.

The selection of the adequate weighting coefficients set is of paramount importance for the discrimination capabilities of the method when applied to a variety of on-the-ground cases. There are no such portable features from one system to another to solve this problem and a continuously refining exercise has to be undertaken from time to time.

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