U.P.B. Sci. Bull., Series …, Vol. …, No. …, 2009 ISSN 1454-23xx

ASSET MANAGEMENT TECHNIQUE FOR ELECTRICAL SYSTEMS

Virgil DUMBRAVA[1], Paul ULMEANU[2], Mircea SCUTARIU[3], Philippe DUQUENNE[4]

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 adapted 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.

Keywords: asset management, electric power systems

1. Introduction

In the increasingly competitive electricity market the pressures to maximize the return on investment and to optimize operational expenditures have become increasingly high. 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.

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 present paper 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 in electricity networks.

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[1] Assoc. Prof., Power Engineering Faculty, University “Politehnica” of Bucharest, Romania

[2] Prof., Power Engineering Faculty, University “Politehnica” of Bucharest, Romania

[3] Ph.D., Transm. & Distrib. Div. of Mott MacDonald Ltd., Glasgow, United Kingdom

[4] Prof., ENSIACET, Institut National Polytechnique de Toulouse, France

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:

a. nodes (bus bar systems and substation equipment apart from transformers/auto-transformers);
b. 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 weighting coefficients, with their sum equating 1. Selection upon the advisable set of weighting coefficients is subject to achieving a consistent behaviour when handling various entities within the network.

3. 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).

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

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

3.1. 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 1 to 100, 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:

i. 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:

$$Pts_{PU} = \frac{CurrentYear - CommissioningYear}{LifeTimeExpectancy} \tag{1}$$

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

ii. 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.

iii. with these physical usage marks a grade per each class of equipment within NODE entity is computed as:

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

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.

iv. 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:

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

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).

3.2. 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.

When we have failure data from identical items that have been operating under the same operational and environmental conditions, we have a so-called *homogeneous sample*. The only information we need to estimate is the *failure rate* λ. The estimator of λ is given by:

$$\hat{\lambda} = n / \tau \tag{4}$$

where n is the number of failures observed during the aggregation time in service τ. Usually, the *uncertainty of the estimation* of λ may be presented as a 90% confidence interval:

$$\Pr\{\lambda_i \le \lambda \le \lambda_s\} = 0.9 \tag{5}$$

With n failures during an aggregated time in service τ, this 90% confidence interval is given by:

$$\left(\frac{1}{2\tau} Z_{0.95,2n}, \frac{1}{2\tau} Z_{0.05,2(n+1)}\right) \tag{6}$$

where $Z_{0.95,\nu}$ and $Z_{0.05,\nu}$ are the upper 95%, and 5% percentiles, respectively, of the Chi^2, with ν degree of freedom.

In many cases, *we do not have* a homogeneous sample of data. The aggregated data for an item may come from different installations with different operational and environmental conditions, or we may wish to present "average" failure rate estimation for slightly different items. In these cases, we may decide to merge several more or less homogeneous samples, into that we call now a *"multi-sample"*.

The various samples may have different failure rates, and different amount of data – and therefore different confidence intervals. To merge all the samples, and estimate the "average" failure rate as the total number of failures divided by the aggregation time in service will *not always* give an *adequate result.*

The following assumptions are rationale:

a) we have k samples. A sample may e.g correspond to a platform / site / etc., and we may have data from similar items used on k different sites;
b) in sample no. i we have observed n_i failures during a total time in service τ_i $(i=1,2,..,k)$;
c) sample no. i has a constant failure rate λ_i $(i=1,2,..,k)$.
d) due to different operational / environmental conditions, the failure rates λ_i may vary between the samples.

The variation of the failure rate between the samples may be modelled by assuming that the failure rate is a random variable with certain distribution given by a probability density function $\pi(\lambda)$.

The expected value of the failure rate is then:

$$\theta = \int_0^\infty \lambda \cdot \pi(\lambda) d\lambda \tag{7}$$

The variance is given by the following formula:

$$\sigma^2 = \int_0^\infty (\lambda - \theta)^2 \cdot \pi(\lambda) d\lambda \tag{8}$$

Apriori, π(λ) is assumed to be the probability density function of a Gamma distribution Γ with parameters α and β.

These parameters α and β are estimated by:

$$\hat{\alpha} = \hat{\beta} \cdot \theta^* ;\ \hat{\beta} = \frac{\theta^*}{\hat{\sigma}^2} \tag{9}$$

where θ^* is the final estimate of the failure rate θ :

$$\theta^* = \frac{1}{\sum_{i=1}^{k} \frac{1}{\theta_i / \tau_i + \hat{\sigma}_i^2}} \cdot \sum_{i=1}^{k} \left(\frac{1}{\theta_i / \tau_i + \hat{\sigma}_i^2} \cdot \frac{n_i}{\tau_i} \right) \tag{10}$$

The following confidence interval is now applied:

$$\left(\frac{1}{2\hat{\beta}} Z_{0.95,\, 2\hat{\alpha}}, \frac{1}{2\hat{\beta}} Z_{0.05,\, 2\hat{\alpha}} \right) \tag{11}$$

If no failures are observed for an item, the following approach is used to obtain lower, mean and upper values for “All failures modes”:

- let $\hat{\lambda}_P$ denote the failure rate estimation –one level up in the taxonomy hierarchy;
- let t the total time in service for the item of interest;
- let $\alpha = 1/2$ and $\beta = 1/(2 \cdot \hat{\lambda}_P) + \tau$
- an estimate for the failure rate is now: $\lambda = \alpha / \beta$
- the standard deviation is given by $SD = \sqrt{\frac{\alpha}{\beta^2}}$
- a 90% confidence interval is given by

$$\left(\frac{1}{2\beta} Z_{0.95,\, 2\alpha}, \frac{1}{2\beta} Z_{0.05,\, 2\alpha} \right) = \left(\frac{0.002}{\beta}, \frac{1.9}{\beta} \right) \tag{12}$$

An example of information available in reliability databases is presented in Tables 2A and 2B.

Table 2A

Reliability database (critical events)

Item	**Electric motors**					
Population	26	Aggregated time in service (10^6 hours)				
Sites	7	Calendar Time 0.6031		Operational time 0.5352		
Failures modes	**No. of failures**	**Failures rates (per 10^6 hours)**				
		Lower	**Mean**	**Upper**	**SD**	**n/τ**
Critical	22	9.15	87.03	98.25	28.54	38.45
Fail to start on demand	6	0.91	11.25	31.63	10.23	9.95
Fail to stop on demand	2	0.0	3.85	16.37	6.31	3.74
Overheating	1	0.0	1.67	8.07	3.33	1.87
Low output	11	0.01	15.81	66.70	25.61	20.55
Parameter deviation	2	0.04	4.06	13.50	4.95	3.74

Table 2B

Reliability database (degraded events)

Item	**Electric motors**					
Population	26	Aggregated time in service (10^6 hours)				
Sites	7	Calendar Time 0.6031		Operational time 0.5352		
Failures modes	**No. of failures**	**Failures rates (per 10^6 hours)**				
		Lower	**Mean**	**Upper**	**SD**	**n/ τ**
Degraded	12	0.81	39.68	122.5	43.21	27.54
Abnormal instrument reading	1	0.10	1.70	5.00	1.66	1.66
Noise	2	0.0	4.78	23.54	9.92	3.32
Vibration	5	0.69	9.06	25.74	8.45	9.34
Structural deficiency	2	0.00	6.64	31.96	13.18	3.32
Other	2	0.00	4.91	24.10	10.15	3.74

Depending on the level of detailed information available in databases, 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.

3.3. 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. An example of information available in maintainability databases is indicated in Table 3.

Table 3

Maintainability database

Item: Eletric motors	**Population: 26**	**Repair (manhours)**		
Failure Mode	Active rep. hrs	Min	Mean	Max
Critical	15.6	1	23.8	566
Breakdown	71.7	29	103	251
Vibration	216.0	100.	253	390
Degraded	52.5	1	83.7	1611
Fail to stop on demand	7	1.0	7.0	14.0
Faulty output voltage	10.5	1.	15.1	70.0

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*.

3.4. 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. The associated costs fall into a number of categories, briefly indicated in Table 4, which can be summed up into an associated cost per equipment E_j of type i:

$$AC_{j,Tj} = PM_{Tj} + CM_{Tj} + UE_{Tj} + DE_{Tj} \tag{13}$$

Table 4

Associated costs for equipment item

Equipment	Recorded faults	Preventive maintenance	Corrective maintenance	Un-served 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 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.

4. 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.

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. 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.

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