Reconditioning Process Optimisation
Power Transformers – EDP D

Ana Catarina Vieira Martins
ana.v.martins@tecnico.ulisboa.pt

Department of Engineering and Management, Instituto Superior Técnico

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Abstract

This study aims to develop a methodology to support decision-making within the reconditioning process of low medium voltage Power Transformers of EDP Distribuição, which has about 67 thousand units in service, of which 1.25 thousand are, on average, removed annually from the network for damage or for the purpose of preventive maintenance.

The current situation is of an excessive accumulation of such equipment in the warehouses distributed on mainland, where they await the decision to be scrapped or dispatched to one of the two contracted repairers; the answer to this problem is to quickly decide what action to take on the transformers and determine the constitution of optimal batches to send to a repairer.

The definition of optimal lots is the main difficulty to be resolved because of the numerous factors to consider, and the vagueness of the priority criteria. In this study a preliminary analysis of the available historical data was made, enabling us to relate the characteristics of the equipment with repair costs, and the component of logistics costs was also analysed; a proposal of a new four-phased procedure is presented, with the objective of enabling the selection of equipment for intervention based on the minimisation of total costs.

The first two phases developed in this paper categorise the transformers by the action to be taken, using acceptance/rejection criteria and a method of multi-criteria decision analysis, ELECTRE TRI-C. Later phases focus on the creation of repair lots as well as sets of equipments to be destroyed.
Keywords: Optimisation, Reconditioning Process of Power Transformers, Multicriteria Decision Analysis, Stocks Categorization, ELECTRE TRI-C

1. Introduction

This study focuses on the Reconditioning Process of medium low voltage Power Transformers in EDP Distribuição (distribution). This process implies some logistics that, together with the characteristics of the equipment itself, are extremely important factors on the determination of the method used. This optimization will enable some improvements, particularly in terms of distribution logistics, warehouse management and maintenance, resulting on the entire process cost reduction.

The process has some restrictions, where the main concern is the stocks management. This paper focuses on modeling a generic case for the determination of optimal transformers clusters, taking into account various factors such as their technical characteristics, history, location and more. The Multicriteria Models are presented as the most appropriate for this study since we are facing a problem as the achievement of an objective taking into account multiple decisional criteria resulting from the variability of characteristics relevant to modeling. This paper is structured as follows:

Section 2 presents the main problem characteristics,

Section 3 reviews the relevant literature on the MCDA methodology and the ELECTRE method,

Section 4 proposes a new procedure,

Section 5 presents the formal model, implements it and its results are analysed,

Section 6 discusses the future work and

Section 7 presents the final remarks.

2. The Problem

Considering the universe of approximately 67,000 PTs MV/LV in service in Portugal, about 1250 units are annually taken from the network.The aim is to analyze the process of reconditioning these transformers so they can be reintegrated into the network once guaranteed their good technical condition.

The current state of the reconditioning process has some constraints. On the one hand, the ability to repair is about 450 units per year, and given that it is estimated that about 570 transformers are sent to be parked for future reconditioning, is immediately deduced that every year the stocks are increased by about 120 units, thus results the first issue: the number of parked equipments tend to accumulate. On the other hand, having been a historical tendency for decrease in the average annual consumption of processors, this problem is further exacerbated necessarily, resulting in an increase of the annual surplus growth trend.

3. Literature Review

The proposed methodology is a multicriteria decision analysis methodology (MCDA). The main steps of ADMC methodologies are characterized by problem's context, problem formulation, evaluation of alternatives and final recommendation [1]. The contextualization of the problem is carried out from the identification of the actors involved in the process and their roles, the goals or interests of the different actors and the resources allocated to each actor and to each object. In the problem formulation stage, it is important to establish with the decision maker what strategy to adopt, since each strategy can drive the decision aid process to different recommendations. So at this stage the set of potential actions that can be taken depending on the problem situation are identified, as well as the number of areas of concern from which potential shares are observed, analysed, evaluated and compared, and the kind of expected outcomes. The third phase, the evaluation model, is the stage where the set of alternatives to which the model is applied is defined. The implementation of the evaluation model involves five steps: relations and functions that will be used for the customer's problem description; the set of elementary points of view on which alternatives are assessed; the set of criteria upon which each alternative is evaluated, taking into account customer preferences; all the uncertainties to be applied to alternative sanctions basic views; and finally the aggregation operators. The last phase, the final recommendation, checks whether the result of the evaluation is in accordance with the model defined previously. Also, it is important to analyse whether the result is consistent with the client's concerns, and the process of decision is in accordance with the problem. For such verification three parameters are recommended: performing a sensitivity analysis, robustness analysis and legitimacy analysis.

3.1. ELECTRE Method

The ELECTRE methods consider the decision makers' preferences and the actions performance, as well as the nature of the problem. The ELECTRE is based on the binary relation within a set of potential actions [2]. The development of this method generated several evolutions of the base method, creating the ELECTRE family, being ELECTRE I, ELECTRE II, ELECTRE III, ELECTRE IV and ELECTRE TRI some examples of the family. The method to be applied differs according to the degree of the problem's complexity, to the necessary information, or to the nature of the problem. These methods focus on pairwise comparisons [3]. These comparisons are required to obtain relationships of "a outranks b". Thus it is possible to affirm that these comparisons depend on the set of actions considered, and there may be changes in the hierarchy obtained, if this set suffers modifications. On the other hand, when new actions are introduced, the number of questions asked to the decision maker does not change, since both the thresholds and the weights are defined based on the criteria and not on the actions. The ELECTRE method can be considered complex and difficult to understand intuitively, if the decision maker has not knowledge of the same, because of the different data necessary for the application of the method. However, these data, allows analysts to generate various situations that enable obtaining more information about arguments made for and against the different decision alternatives, being a key factor in recommendations for more solid actions to decision makers [3].

Noting the interest and advantages of ADMC methodologies, this paper aims at building a MCDA methodology for the technical condition assessment of the transformers – in order to send the better ones to the repairer – followed by its evaluation by the ELECTRE Tri-C method, which belongs to the family ELECTRE.

4. Proposed Procedure

A correct characterization of power transformers will enable the optimization of their process of reconditioning. Since the construction of lots to be forwarded - to repairers or to be destroyed - must take into account their individual technical characteristics - promoting those that add more value to the company; and the group of characteristics - that will facilitate all the logistics in terms of storage and transportation. The proposed procedure comprises four phases, which together aim to solve the problem presented.

The procedure is performed from a database that contains all transformers that were removed from the national grid and are parked in outsourced warehouses, waiting for the decision for them to be sent to repair, to be destroyed or to be kept in reserve for future decision. This equipment universe is processed at the first stage of the procedure, initial screening, from which results the same now grouped universe. This screening allows a se-

		g_1 Custo de Intervenção €	g_2 Custo de Transporte (km)	g_3 Consumo Médio Anual (%)	g_4 Valor do Ativo €
	b_4	0	0	15	8000
$\mathcal{C}_3$	b_3	1000	100	8	4000
$\mathcal{C}_2$	b_2	2500	250	5	2000
$\mathcal{C}_1$	b_1	4000	450	2	1000
	b_0	5000	600	0	0
	q_j	300	15	1	500
	p_j	500	30	3	1000
	v_j	3000	150	5	3000
$z=3$	w_j^1	28,7%	11,7%	35,1%	24,5%
$z=5$	w_j^2	29,9%	7,4%	38,2%	24,3%
$z=7$	w_j^3	30,4%	5,7%	39,7%	24,2%

Table 1: Parâmetros Fase II – Alternativas de Referência, Limiares e Pesos dos Critérios

lection of transformers eligible for reconditioning, through rejection criteria that make the direct labeling of equipment that either have no minimum conditions for reconditioning or lack SGAI[1].

The second stage of the procedure, categorization, operates only on the set of Transformers considered as eligible (in the previous phase), this comprises an ordinal classification of equipment into three categories which are distinguished by merit of transformers that compose it, being an equipment categorized as "Prioritário" (priority) if it meets good conditions for reconditioning.

The third phase, batch repair, aims to build an optimal set of transformers. This phase is carried out only on the category containing transformers "Prioritários" (in the immediately preceding phase) and results in elected transformers for integration in batch to send to repair.

The fourth and final stage of the procedure, destruction batch, is responsible for the selection of processors to send to be destroyed and operated only on the set of transformers "Em Espera" (stand by – resulting from the categorization made in the second phase of the procedure). The equipment selected in this phase, together with those previously labeled without minimum conditions for reconditioning (resulting from the screening performed in the first stage) will be sent to be destroyed.

Completed the four phases, the transformers universe is featured in: elected equipment to the repair batch, selected transformers to be destroyed and units belonging to the equipment reserve (those who were not selected in any of the last two phases); the latter will enter the first stage of the procedure, together with the equipment initially categorized as "No SGAI record" in a future decision-making.

[1] Identifier document without which it is not possible to give any follow-up to equipment

5. Formal Model

The use of the ELECTRE TRI-C method for implementing the Phase II involves determining certain parameters, which are shown below in Table 1 . Whether the reference alternative, b_h for each criterion g_j related to defined categories, C_h, which determine the reference performance of each criterion in each category; the thresholds of indifference and preferably q_j and p_j, indicating the relevance of performance differences in the various criteria, taking into account the existence of imperfect information; and veto v_j, limiting the compensatory effect of criteria; and the set of weights of the criteria which illustrate the relative importance of each w_j.

The determination of the reference alternative results from the indication of the characteristic performance of the criteria for each category. Extreme reference alternative b_4 and b_0, represent the best and worst performances, respectively, in all criteria;

b_3 represents the expected performance for an alternative that will integrate the C_3 category that represents the best category, *"Prioritários"* , b_3 has very good performance in all criteria - ideally, a transformer categorized as priority should not have intervention costs much more than € 1,000 or exceed 100km distance from the repairer location, the average annual consumption should be around 8 % and the value of the asset should not be much less than € 4,000. The expected performance of transformers categorized as *"Secundários"* e *"Em Espera"* are shown using the b_2 and b_1.

The preference and indifference thresholds p_j and q_j, that allow the uncertainties inherent in the criteria valuations to be incorporated into the decision process. Regarding transport costs, the performance of transformers in this criterion is well known, being the only source of imperfect knowledge the possibility of alternative routes; for this reason it is determined that a difference of 15km is irrelevant and only from a performance difference

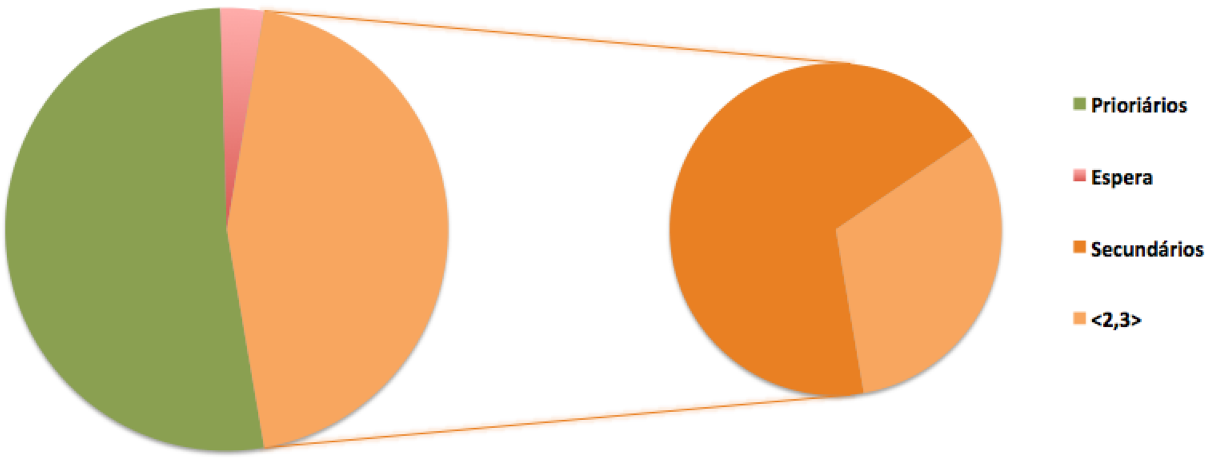

Figure 1: Categorization Results

in this criterion 30km define the existence of a clear preference. The thresholds should not address the relevance of the difference in performance itself, but the relevance of the difference in performance given that the information is not accurate and certain differences in the data may not correspond to a real difference. Thus, the allocation of different thresholds in the criteria recorded in euros is natural although we work in the same unit and scale; if in one hand we do not have access to all the information, on the other we have only an estimate; We are, in both cases facing a situation of imperfect knowledge of information data. For asset value, although ideally we consider the interventions already made in equipment amortization, these interventions can not be registered by computer, so the value of the transformer will not include this investment; this way we define that a difference of €500 between equipment is not relevant and only from a difference of € 1,000 we believe that there is a choice between two alternatives. For the cost of intervention criteria, since the performance of transformers is estimated from other variables, a difference in this estimate may not represent a real difference in the real cost of the equipment intervention, hence the need to determine preference and indifference thresholds - noting that although it is an estimate, this indicator is considered more accurate than the previous one, resulting in lower thresholds. Finally, for the criterion of consumption, the need for allocation of these thresholds relates solely by the fact that this indicator is the result of an average calculated from the last 4 years; on the one hand, the newer the data of the consumption best these indicators reveal, on the other hand, the sample size can not be sufficiently representative for this reason is defined as indifferent a difference of 1 % of consumption, and as preferred just a difference greater than 3 %.

Veto thresholds, v_j, are determined to prevent the prevalence of an alternative over another if it presents a very low performance in at least one of the criteria. A difference of € 3,000 for the cost of intervention or for the asset value can not be offset by better performance on other criteria, as well as a difference of greater distances to 150km and a consumption difference of 5 % between alternatives.

To specify the relative importance of the criteria, w_j, we opted for Simos Procedure revised [4], which aims, through a simple procedure, to determine the importance of coefficients.

5.1. Results

The use of MCDA-Ulaval *software* results in the categorization of the 536 alternatives evaluated in this case. It was determined that there are three categories to which they should be assigned: *"Pioritários"*, *Secundários*, textitEm Espera. The equipment are thus distributed in these categories, and in ambiguous cases the attribution is made to two categories simultaneously.

Figure 1 presents the distribution results of the categorization.

In the *"Em Espera"* category were assigned 17 PTs to be included in Phase IV of the proposed procedure.

In the category *"Secundários"* were assigned 163 TPs, which are not direct candidates equipment for reconditioning or to be destroyed.

There have been cases of ambiguity between the *"Prioritários"* category and the *"Em Espera"* category in 76 equipment, this set of PTs shall be considered solely for subsequent decisions, such as equipment categorized as *Secundários*.

Finally, for the *"Prioritários"* category were assigned 280 equipment, these are the ones to be integrated the Phase III of the proposed procedure,

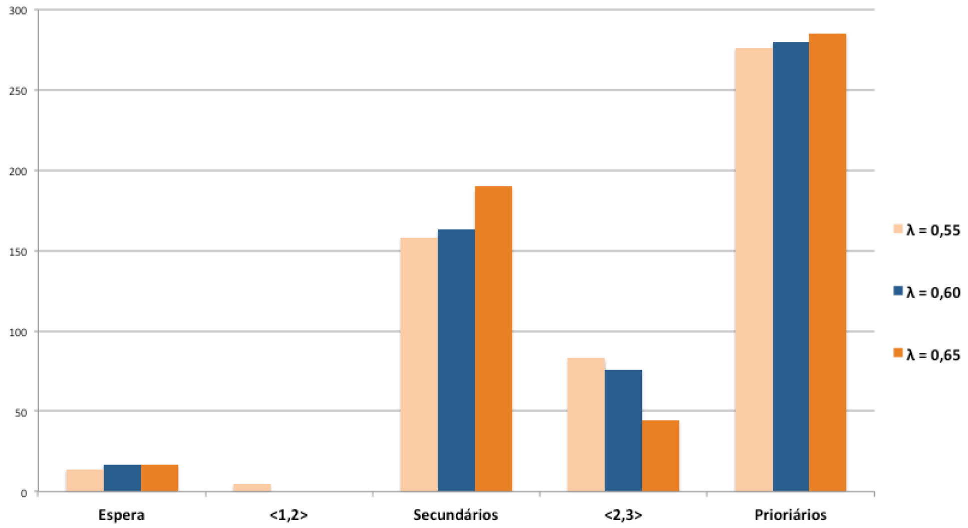

Figure 2: Sensibility analysis, parameter λ

resulting in the determination of a set of transformers to be effectively sent to the repairer - in this case located in Lisbon.

5.2. Sensibility Analysis

In order to verify the robustness of the results presented and, consequently, the credibility of the model, it is important to note the impact that small variations in the values of the parameters have in the results. We selected two parameters for the model sensitivity analysis: the level of credibility, λ, and the importance ratio between the most relevant criteria for the decision and the one with less importance, z.

In Figure 2 is presented the sensibility analysis for the parameter λ.

As expected can be seen a clear relationship between the level of credibility and affectation precision of equipment. The increase of the parameter is reflected in the decrease of cases in which the allocation of equipment to a class is ambiguous, resulting in increased number of devices assigned to a single class.

There is a reduced sensitivity of the model in relation to the parameter under study - it is observed that 96.5 % of equipment categorized as *"Prioritários"* are assigned to this category in any of the scenarios; as well as for the *"Em Espera"* category where 82.4 % of the processors categorized as such have been assigned to this same category in any of the scenarios - can thus confirm the robustness of this affectation.

In Figure 3 is presented the sensibility analysis for the parameter z.

It is observed a relationship between the amount ratio and the resulting affectation. The increase of the parameter is reflected in the decrease of units allocated to the extreme categories, which results in increase of equipment assigned to the *Secundários* category and cases of ambiguity. However, and as in the previous parameter, it should be noted the reduced sensitivity of the model, confirming the robustness of this affectation.

6. Future Work

The method developed in this thesis allows the determination of the TPs that are the best candidates for reconditioning, selects the set of equipment to be destroyed and those who will wait new decision-making. The procedure proposed in this study consists of four phases. The two initial phases are fully modeled, and analyzed implemented throughout this document. At a later stage it would be made a determination of the optimal batch to send to repair. It is suggested, therefore, that the construction of the optimal batch to send to repair is based on a methodology Ad-Hoc, which is differentiated by the motivation of the construction of the batch in question (as this may be for a need for specific equipment with certain voltage and power, or the urgency of removing TPs of certain PSEs). In the case of a decision-making driven by the need of special equipment, the type of voltage and power will result in the main selection criterion. Thus, from the universe of equipment resulting from Phase II of the procedure proposed as "Prioritário" equipment, are selected those which have characteristics based on the voltage and power sought. To determine the set to send, it should be considered the number of devices that the repairer is available to receive - which will be the set size to build. Thus, until the whole construction reaches this size, the devices that are already selected (with the characteristics sought base), should be

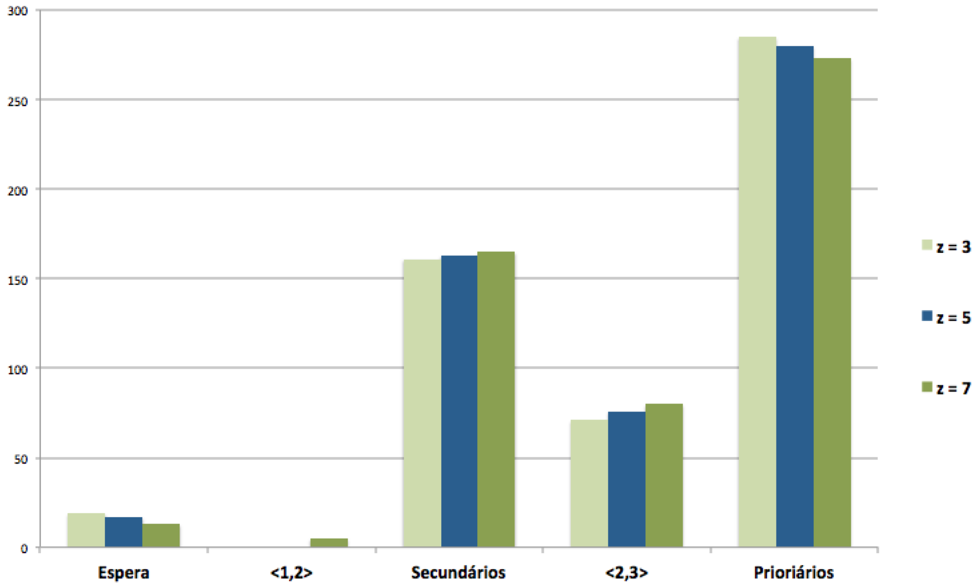

Figure 3: Sensibility analysis, parameter z

added, considering the proximity to which they are to each other. In the case of taking a decision motivated by the urgency of removing TPs of certain PSEs, the warehouse where they are will be the main selection criterion. Thus, from the resulting equipment universe of Phase II of the procedure proposed as "Prioritário" equipment, are selected those that are parked urgently in the withdrawal of transformers PSEs. Until it reaches the number of devices that the repairer can receive, must be added to the batch repair equipment belonging to the selection and that are as close as possible to each other. For the construction of the set of equipment to be destroyed, a similar methodology can be used – without a limit of transformers to be sent and without being relevant location or proximity of these. As future work, it is suggested the development and implementation of operational research models to be used in Phase III and Phase IV of the proposed procedure. This work will require a characterization of the inherent operating costs to process the survey of the PSE actual capabilities and respective occupations, determining the benefit of a particular equipment repair - data unavailable to date. In addition it is suggested to build a tool that integrates and automates the four stages of the procedure in order to optimize the process of reconditioning and the decision making process, resulting in reduced operating costs and reconditioning of equipment that actually are in better technical conditions.

7. Final Remarks

The scope of this study relates to the Process of Reconditioning of Medium/Low Voltage Power Transformers", aiming its optimisation through the development of a decision support methodology. This work outlines the procedure to implement, consisting of four distinct and consecutive phases, and develops the first two phases.

Much of the work done in this thesis focused on analysis of the current process, in order to: design the proposed new procedure, select the methodologies, and identify the relevant criteria for decision-making and for the identification of the parameters required by the selected models.

Thus, it is possible to identify some aspects for improvement in the process having in mind its optimization, and also to boost the implementation and usage of the procedure that is being proposed in this study:

- Review the capacity and quotas contracted with repairers;
- Determine stocks in warehouse, as well as a safety reserve, taking into account the specifics of the process - including repair times and consumption depending on the type of equipment;
- Building a database of TPs MV/LV integrated – a key investment that will allow the centralization of information and access to the history of each equipment;
- Monitoring of stocks in EDP warehouses in real time;
- Availability Control of outsourcing warehouses;
- More accurate computerisation of data.

Additionally, it could be relevant to make a small study to specify the costs and benefits of an investment in "digital" identification of thousands of medium/low voltage power transformers. This investment is especially interesting considering the lifetime of this equipment and the need for monitoring their location and characteristics. Thus, a simple technology can be suggested, like the use of barcode or RFID sensors in the equipment, depending on the initial investment considered reasonable in view of the benefits of each technology.

The optimisation of the process aims not only to reduce the associated costs (repair, logistics, or even acquisition costs), but seeks also to mitigate the risk of environmental impact, waste disposal, and potentiates greater turnover of assets.

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