MV/LV PDS transformers: Novel approach for the maximization of the preventive maintenance activities- A case study

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Abstract—**In today's energy market in Morocco, a stable and reliable electric power supply system is an inevitable prerequisite for the technological and economic growth of the kingdom. Due to this, many public distribution companies are increasing their competitiveness by adopting new maintenance philosophies to reduce their Operation and Maintenance (O&M) costs. Indeed, being one of the most important parts of the medium voltage network, MV/LV public distribution substations transformer (PDS) play a key role in distribution of electricity, one of the main challenges for electricity distribution companies in Morocco is to manage the existing MV/LV PDS assets in the comprehensive and complex distribution system infrastructure. Moreover, the reliability of the electricity supply has become a subject of discussions at many different levels of society. There is an increasing awareness on developing preventive maintenance strategies which take into account the different aspects of risk which the companies are facing. One principal characteristic of preventive maintenance strategies is that the condition of the substation components is inspected on a regular basis. This paper describes a framework for criticality based maintenance management. The presented methodology shows how MV/LV PDS maintenance can be optimized on the basis of a multicriteria prioritization matrix. The proposed model has been demonstrated and tested for the maintenance schedule and for the prioritizaton of maintenance activites. Obtained results have shown that the operational expenditure (OPEX) of MV/LV PDS asset maintenance and the KPI's of quality of electricity supply (SAIDI&SAIFI) can be both reduced and improved.**

Keyword-MV/LV PDS, Distribution networks, Optimization, Operation and Maintenance, OPEX, SAIDI, SAIFI, Preventive maintenance.

I. INTRODUCTION

Nowadays, Moroccan electric utilities are confronted with a myriad of challenges that include aging infrastructure, enhanced expectation of reliability, and coping effectively with uncertainties and changing regulation requirements. Utilities rely on asset management programs to manage inspections and maintenance activities in order to control equipment conditions [14].

However, development of strategies to make sound decisions in order to effectively improve equipment and system reliability while meeting constraints such as a maintenance budget is a challenge [1], [2]. Indeed, electricity is the backbone of our society and industry, efficient management of the distribution network is vital for society. The reliability and quality of this electricity supply are inherent needs of our lives. Hence the number of outages which have influence on all inhabitants has to be decreased. The process of restructuring and deregulation will create a competitive, national market place for energy [15], [5]. Early preparation to market competition and best use of technology will drive success in this new and challenging environment [16], [4], [3] ,[14]. The performance of a network depends on the reliability presented by the various constituents, by the way to design them, to build them and maintain them.

The patrimony of MVLV PDS network by these essential components constitute the most important part of fixed assets and that represent the expensive and complex works for which the degree of reliability of every component is generally raised regardless of technical level used [4]. On the other hand, the MV/LV PDS transformer systems are characterized by being widely geographically dispersed, having vast numbers of relatively simple components which together constitute a complex system. Most of the infrastructure consists of static components (e.g. transformers), while a minority of the components have moving parts (e.g. load breakers, sectioning switches), component lifetimes are typically 10 to 15 years [12], [13], [2].

The main goal of the project is to determine a precise line control method for each MV/LV PDS with a high quality provision of service to answer the ever increasing demand of component control. Effective inspection and proactive component management can prolong the use of the actual network infrastructure, decrease costly replacements, minimize the occurrence of MV/LV PDS failure, increase safety, and save utilities money in maintenance costs. Then the foundations of the maintenance philosophy are described, before we present the main steps in the procedure for establishing maintenance strategies. The application of the methodology is illustrated through an example.

The present study was conducted in Oujda Exploitation Maintenance Service (EXMS), in charge of operation and maintenance of distribution networks at a large metropolitan area in eastern Morocco (electric distribution is a monopoly activity in eastern region of Morocco, province of Oujda in the Oriental Region of Morocco). Two basic assumptions underpin the study and takings into account namely:

- The study does not address CAPEX options in detail.
- The study assumes that MV/LV PDS are reasonably maintained and operated normally.

The paper is organized as follows: we describe the maintenance management system for MV/LV PDS in section II. Approach proposed for the optimization of maintenance work in section III. A Pilot Case Study: Maintenance of the MV/LV PDS in section IV, followed by conclusions in section V.

II. Maintenance Management System for MV/LV PDS

A. Description of Distribution Network Structures

Distribution Network (DN) is a complex of substations, switching centres and power lines designed to transmit electrical energy from the transmission network (TN) to the end customer. The DN consists of Medium Voltage Distribution Network (MVDN) and Low Voltage Distribution Network (LVDN). The main components of the DN are: Control Centers, HV/MV Transformer Substations, Switching Stations, Distributed Energy Resources (DER), MV/LV PDS and Electricity Meters [17]. DN's are typically of two types, radial or interconnected. A radial network leaves the station and passes through the network area with no normal connection to any other supply. This is typical of long rural lines with isolated load areas. An interconnected network is generally found in more urban areas and will have multiple connections to other points of supply. In this part of the manuscript we are going to describe briefly the characteristics and architecture of MV/LV PDS.

B. Different types and classification of MV/LV Public Distribution substation

The MV/LV PDS designated for public use (domestic customers, buildings, subdivisions,) to convert permanently the MV (22 kV) and LV (380V or 220V), they are a node of a network, which includes a set of equipment designed to protect and facilitate the operation of the electrical energy [18]. The MV/LV substations provide the interface between the distribution MV and LV. The MV/LV PDS adapts to all modes of operation and why should fulfill the following functions: Distribute the power, protect the LV lines and isolate the MV/LV substation in case of default and manage the MV network in case of default and the position by remote control. They are classified into 3 types:

- Substation in masonry (Buildings & indoors): Installed in a dedicated enclosure prefabricated or not, with indoor equipment (switchgear and transformer).
- Pole mounted with dedicated outdoor equipment (switchgear and transformers). These substations are mainly used to supply isolated rural consumers from MV overhead line distribution systems, it is used in cases where the power transformer is less than or equal to 160 kVA.
- Prefabricated substations: The MV/LV prefabricated are made using: MV cells, transformer etc, grouped in an envelope whose role is the protection of internal equipment against external influences and to ensure a degree of protection against the public [15], [20].

C. Maintenance management

Nowadays electricity distribution business, and success in it, requires good MV/LV PDS network condition management during the whole life-cycle. The knowledge of features and condition of MV/LV substation are the base for the maintenance management which is one of the essential tools to enable the reliable and cost-effective life extension of existing MV/LV substation to be achieved [6]. Maintenance is a way to act aimed at avoiding failures of equipments by taking care of them.

The role of maintenance is important especially in a business, where results' formation depends a lot on the usability of the assets and it has a key role in operations. The electricity network business is a good example of this kind of business, where almost all operating is based on the ability of distribution network energy delivery. Therefore maintenance is planned with operations, which purposes are to ensure the safeties, operational reliability, failure's prevention and fast repairing of the occurred failures on optimum costs [15], [21].

When the issues which are mentioned above are in order, it is possible to achieve a longer lifetime of the assets, lower operating costs and increase the reliability. Maintenance operations may be give important information of the condition of the assets and in this way the timing of the replacement investment can be improved

D. Strategy and planning maintenance of the MV/LV PDS

The maintenance policy of the MV/LV PDS is a complex action, made up of a large number of activities, moving different equipment. It is carried out within a strict regulation framework and must satisfy with the requirements of quality and traceability. The key issue in maintenance of reliable power service for ONEE (Office National de l'Eléctricité et de l'Eau Potable) customers is the performance of the infrastructure that carries the electricity to the end user. Determination of the reliability at any time during the service life of all the components provides the basic information for the manager team decisions. To increase the challenge, the maintenance program includes all the many different components for distribution network infrastructure like MV/LV PDS where some parts have been in service for more than 15 years.

Traditionally, the maintenance consists in inspecting in a periodic way the network in order to control his state and his performance level [3], [6]. There are two main approaches to create maintenance strategies, namely, corrective and preventive maintenance (PM) [1], [22]. PM can further be divided to time-based maintenance (TBM) and condition-based maintenance (CBM) [2]. TBM is based on the service history of the component using regular and scheduled intervals on the basis of a periodic visit in order to ensure a good performance and to reach a technical life span beforehand established. CBM is based on the condition and state of the component, for example, a maintenance activity is determined when the condition of the component falls below acceptable standard [16], [5]. A synthetic survey of interactions among different maintenance interventions is given in the Fig.1 below.

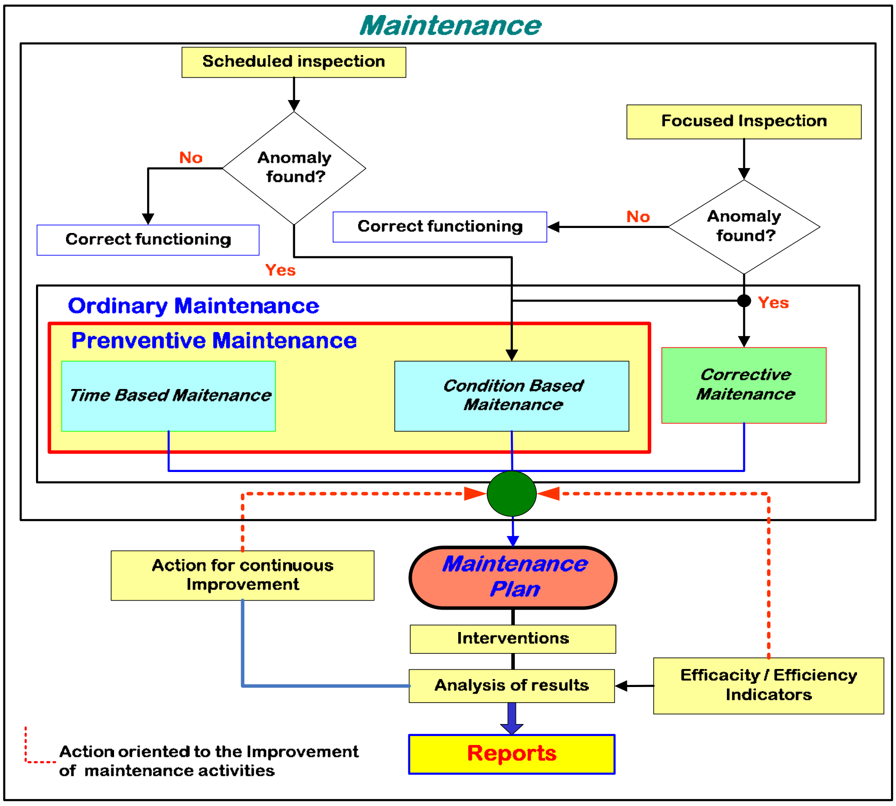

Fig.1. Schematic representation of maintenance typologies in EXMS

The optimal operation of MV/LV PDS network is functions of several factors and parameters that influence directly or indirectly the sustainability of service and the operational reliability. However, the planning of the activities and maintenance work constitutes an important step if one wishes to optimize and synchronize the maintenance interventions. Indeed, it aims at organizing as well as possible the operation activity with upstream the forecasts of work with to make on each asset (action of TBM and CBM) and downstream the logistics (supplies, stocks and exchanges of parts) and the management of technical and human capacities. The objective is to minimize the duration of fixed asset of the assets and the cost of operation [7], [8].

The planning of the PM is an important subject for any company exploiting a park of equipment when it has a great quantity of strategic and different natures of assets. The objective is to optimize spending commitments in terms of OPEX (the expenditure which generates maintenance work is recorded charged to the operating budget for EXMS), and to identify and schedule work in time, while estimating the needs, resources and required constraints. The objective of the maintenance planning process is to determine the most cost-effective method for managing the levels of network risk and allowing the network assets to achieve their expected level of service potential. With up to 802 MV/LV PDS installed on the EXSM distribution network at the end of 2011, it is necessary to establish a standard philosophy of maintenance to make it possible to keep an asset in good state.

Thus, this asset will be able to carry out effectively and in full safety the service for which it is used. It results a minimization from it from the unforeseen stops caused by breakdowns of equipment.

In order to optimize the operation of MV/LV PDS installations and reduce the impact of certain break-downs the EXMS identifies several types of maintenance to maintain MV/LV PDS in good state of walk and to preserve a good quality of service. This one must be well periodically maintained according to a maintenance plan that is translated into different types of visit as an example for the MV/LV PDS in (on the ground):

- Condition monitoring maintenance: MV/LV PDS inspection, substation thermograph inspection and earthing system measurements.
- PM: Overhaul of MV/LV substation with air insulated switchgear, overhaul of MV/LV substation with epoxy insulated switchgear, cleaning inside safety distance, cleaning outside safety distance, oil-filling on distribution MV/LV transformer, oil-filling on cable terminations, maintenance of MV switches, control and maintenance of transformers, maintenance of LV panels and adjacent components [19].

III. Approach Proposed for the Optimization of Maintenance Work

A. Objectives of the approach

In maintenance, the main objective is to preserve the reliability performance of the infrastructures that supply electricity to the consumer in order for the customers to benefit from a reliable service. Reliability performance measurement is used to target areas where maintenance needs to be directed to improve the delivery service or where the frequency of maintenance may be reduced without the risk of reducing service. Indeed, knowledge of the components at any time of their service life represents important information, which facilitates decision making. The general principle we follow to determine a maintenance priority is that the MV/LV PDS asset supplying the greater number of consumers receives the higher priority. Generally assets are not replaced on age alone, but are kept in service until such time as their continued maintenance is uneconomic or until they pose a safety, environmental or reliability risk [15].

The method that we will present in this article can be defined as a global approach searching, the best decisions concerning the operational management of the maintenance works of MV/LV PDS, as well as the identification of the causes of non-productivity or lost revenue, for to remedy it. The mission is the planning of the execution of the works stopped on the basis of the evaluation of the MV/LV PDS assets and this one planned during the past year and not yet realized by the operational teams raising the EXMS. The proposed method is to select MV/LV PDS networks a maintenance planner is able to focus their efforts based on the criticality and performance of the MV/LV substation due to the limitation of funding. Also, to inform strategic management decision making regarding both operational OPEX and CAPEX decisions [1], [12]. In general, the main objectives looked for with this new methodology is optimize and organize the maintenance activities and work process, improve the productivity and the reactivity of the teams and to develop a defensible logic for valuing and prioritizing preventive maintenance.

B. The overall maintenance management and approach process

In order to have clear primary goals and visions when working with establishing and implementing maintenance strategies, the following three principles have been identified as guidelines for the EXMS work:

- Developing an overall philosophy for the maintenance activities

The maintenance philosophy gives the overall principles for how to maintain the system as a whole. To make the philosophy operational, the principles need to be applied to the components constituting the MV/LV PDS:

- The maintenance activities shall be based on criticality evaluation, meaning that the activities shall be seen in light of the consequence of the incidents they are intended to control.
- Description of maintenance actions. To ensure the unambiguous interpretation of what is meant by the different terms describing maintenance actions, standardised descriptions are needed. The maintenance activities shall be economically evaluated minimizing costs of operation, electrical interruptions [22].
- MV/LV PDS specific maintenance strategies are established through using the overall maintenance principles on dedicated component. The maintenance strategies provide a generic description of what maintenance activities to do and with what intensity to perform them.
- Working procedures: They are the service provider’s description on how to perform a specific maintenance action. The maintenance shall be performed in compliance with existing rules and regulations.

- Developing decision support and maintenance work descriptions based on criticality analysis.

- Defining indicators and targets for maintenance monitoring.

The main maintenance philosophy objectives are as follows: maintenance undertaking at the optimum time and in the optimum amount; cutting down the maintenance costs; diminishing the decommissioning periods of time, providing the requirements on the investment work promotion, correlating the maintenance and rehabilitation programs.

The principles stated above represent the essence of the maintenance philosophy. To follow these principles in practice, the maintenance should be included in a pragmatic maintenance management process where results and experience continuously are being used to improve routines and working processes. The process is illustrated in Fig.2. All the different parts of the model are not described in detail. In the next items we will begin the studies and the implementation of a new methodology to optimize the MV/LV PDS maintenance activities.

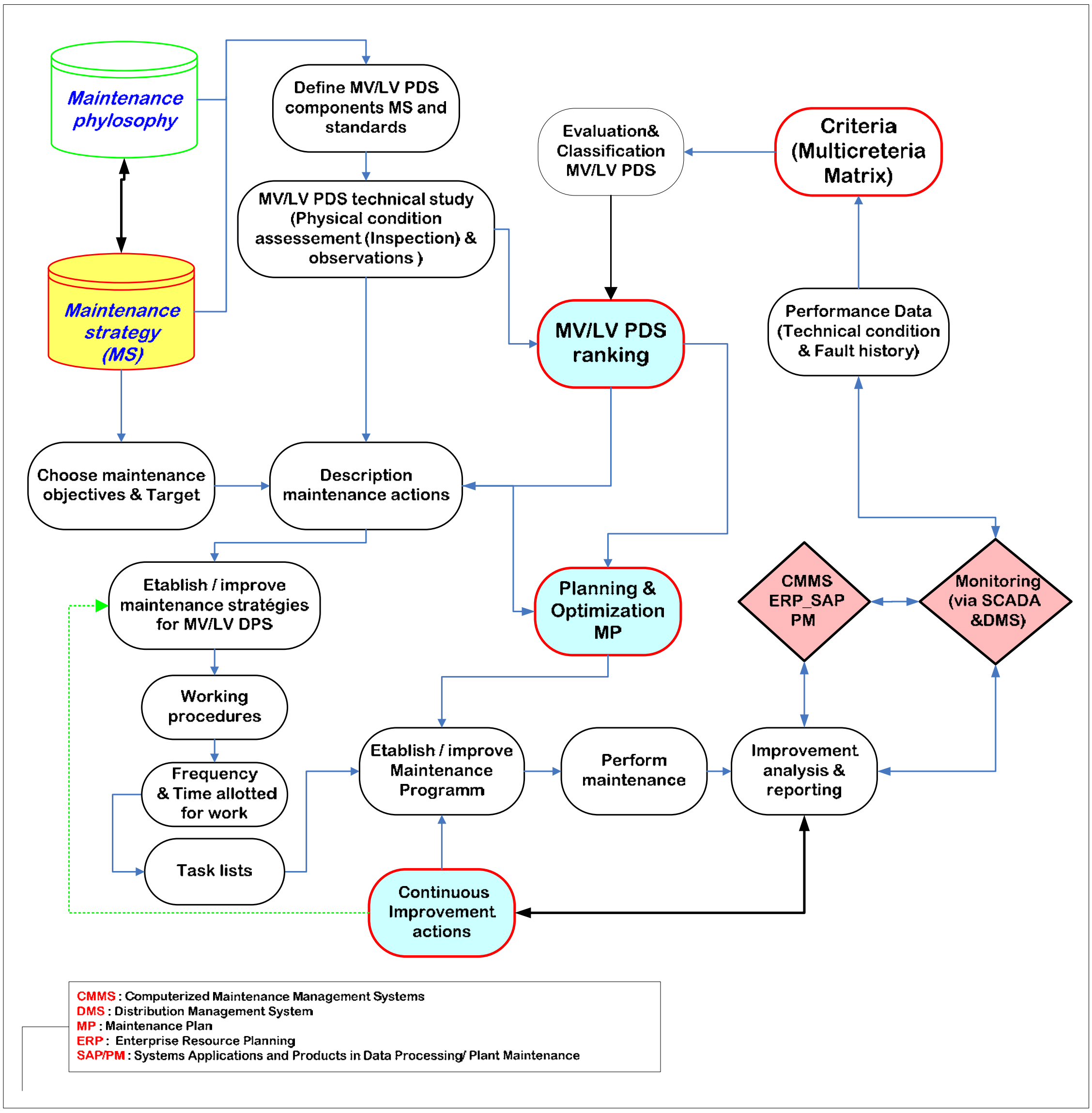

Fig 2. Proposed flowchart model of the maintenance management system in EXMS

IV. A Pilot Case Study: Maintenance of the MV/LV PDS

C. Stages of the maintenance prioritization method

1) Steps:

Maintenance prioritization can be used for identifying MV/LV PDS of the distribution system that require the most immediate attention as a result of their impact on the overall system reliability. To remain competitive, it is crucial to prioritize maintenance actions so as to achieve a higher reliability irrespective of the increasingly constrained maintenance budget. The proposed target process suggested is centred on the exhaustive identification of the requirements in maintenance by proceeding to a visit of the MV/LV PDS managed by

EXMS, before the launch the preparation of the annual PPMP (plan for preventive maintenance projects). The development and implementation of the approach was initiated through a pilot case study in EXMS that were studied between October and December of 2011. The implementation ended during the year of 2012, the design steps for the proposed method are given as follows:

- Steps A

Evaluating and mapping of the existing maintenance practice: One first step is therefore to examine what activities are being performed today, and to take on a discussion on why different solutions have been chosen earlier. Review the last four years history of maintenance work and separate into four categories of proactive, reactive, improvement and assistance work, compile costs and man-hours per category to determine proportions of cost and effort spent for each.

- Step B

Classification of the MV/LV PDS by importance: The classification of MV/LV substations is dependent on the existing sensitivity and importance of the clients connected on determined substation. It is necessary to identify the impact of losing each item of MV/LV PDS on quality of supple, safety, reputation and economic impact. This is done by conducting a criticality assessment. The classification of MV/LV PDS is categorised into four classes of MV/LV PDS as following [23]:

– Red MV/LV PDS (Urban high density): This grade considers the services and activities that are fundamentals to the society like hospitals, prisons, water and sewer treatment facilities, telecommunication, etc. Also considers clients particularities like self generation installations.
– Black MV/LV (Urban medium density): MV/LV substations feeding urban agglomerations, industrial zones. etc.
– Orange MV/LV PDS (Rural medium density): Substation in masonry feeding a rural area.
– Green MV/LV (Rural low density): Pole mounted substation feeding a rural area.

The Table I summarizes the distribution of MV/LV PDS by priority with regard to the total number of MV/LV substations.

TABLE I
Number of MV/LV PDS by classes and maintenance team

MV/LV PDS maintenance team	Number of MV/LV PDS by Classes			
	P_1	**P_2**	**P_3**	**P_4**
T_1	81	279	34	153
T_2	13	41	4	71
T_3	14	31	8	73
Total MV/LV PDS by class and priority	**108**	**351**	**46**	**297**
Percentage per classes of MV/LV PDS	14%	44%	6%	37%

- Step C

Identification of the MV/LV PDS technical condition: The data and information from operational behaviour monitoring on the history of defects, results of measurements and maintenance applied are used to quantify the technical condition of installations and their components managed by EXMS [23].

- Step D

Identification of the volume of the estimated preventive maintenance workload necessary per group based on the global physical inspection of the MV/LV PDS for a period of 2 months of the N-1 year. It is also necessary to identify what proportion of maintenance effort is being used on not doing maintenance related work [23].

- Step E

Identification of the necessary works, in order to know the state of the MV/LV PDS and to identify the requirements for estimating maintenance work, census initiatives and data collection relating to the networks were led within the framework of the preparation of the annual PPMP of 2012.

- Step E

Identification of the available capacity and the existing potential by MV/LV PDS maintenance team at EXMS level: To develop and determine the potential available in Man-Hours (MH) based on operational teams. This valorisation enabled us to release the available potential for each team during one year of exercise.

– 3 MV/LV PDS operational maintenance team is in charge of the exploitation and maintenance of a number of lines on a well determined territory according to administrative national territorial cutting.
– The available global potential is about 12592 HM [23], see Table III.

- Step F

Identification of the potential target for the realization of the totality of the projected works on the basis:

– A timing and standard normative durations for to make each operation of maintenance.
– The frequency of each PM operation and singular action, and the travel time.
– The man-hours required monthly are related to the maximum of man-hours required in one month if suburban and rural area were considered as a whole.
– The target potential necessary is about 18684 HM, see Table IV.

- Step G

Valorisation of the annual PPMP in HM and compare of the available resources with those necessary for the realization of the totality of the identified works.

- Step H

Development of the rules and the procedures for prioritizing maintenance work, and MV/LV PDS ranking by assessment criticality matrix: Priority of the PM work is set function of the technical condition and criticality of MV/LV PDS based on statistically processing.

- Step K

Development of the projected maintenance plan: Develop guidelines and roadmaps for developing and to optimize the program and the PPMP (deadlines and resources). Options for network performance improvement: Operations and maintenance practices / activities (impact through reduced failure rates and restoration times), preventive maintenance actions (e.g. substations inspections, transformer load monitoring. etc.) and optimised work order batching, network operating for fault finding philosophy and technical support centre placement/locations (impact on response time).

- Step L

Finalization of the optimized preventive maintenance plan and introduced the operating ranges for MV/LV PDS maintenance preventive program in a CMMS/SAP PM, to automate creation, the edition and the follow-up of the work orders.

- Step M

Formalization of the monitoring of the execution of the maintenance program: The results from maintenance activities can in general be difficult to measure in an objective manner. This is due to the fact that maintenance primarily has the purpose of preventing unwanted events, and the effects of this work can be hard to keep track of [19].

2) Assessment criticality matrix:

The main objective is the optimization of the allocation of available resources considering the constraints of the available potential aiming at the improvement of the teams maintenance productivity by the means of the organization of the maintenance process. Thus, a process of planning of work and rules and selection criteria basic for prioritizing work and visits were developed in this article [10]. To conceive a management system and of follow-up of maintenance and to effectively implement it, the classification of MV/LV PDS according to a set of priorities is very useful. Indeed, within the framework of this study, the substations must be arranged by decreasing set of priorities in order to direct the efforts of the team of maintenance charged to maintain them. We can couple this method with that of Pareto [11]. Indeed, we can determine the Pareto classes using as a classification criterion, the statistical data, the balanced total notes obtained by the multicriteria matrix.

3) Matrix Prioritization Criteria:

The EXMS needed to decide over a maintenance strategy by considering several issues: costs, safety of personnel, distribution network’s reliability and public opinion. Due to the great amount of existing MV/LV PDS [23] (The total number MV/LV substation is about 802: Urban 350, rural: 452), a ranking is necessary for studying. To each substation, a score based on the current state of the network is attributed. The objective is to define and to indicate clearly, where the substations are which show weak performances and high criticality and which deserves a special attention. The prioritization criterion to MV/LV PDS considers two aspects that fit the expectation of any electrical distribution business: the M/LV performance and the criticality of the region supplied by them. The performance indicator defines which MV/LV PDS must be prioritized to achieve quality on energy supply continuity improvements. The prioritization criteria were established to tow dimensions:

Criticality (Technical criteria of maintenance efficiency and economic criteria of maintenance efficiency), Performance (Criteria of service quality and statistical indicators).

3.1) Performance indicators (I_p): The parameters used to performance indicator are: In order to establish a base of measurement for reliability trends, the collected data of interruptions are averaged for the previous three years (2009, 2010 and 2011).

- I_{P1}: SAIFI (System Average Frequency Duration Index): Is the average number of sustained interruptions (>3min) experienced per customer served per year.
- I_{P2}: SAIDI (System Average Interruption Duration Index): This index indicates the total duration of interruption for the average customer during a predefined period. The SAIFI&SAIDI [21], [23] of each substation is calculated based on the proportion between the number of clients of the electrical cluster and the total number of clients supplied by the substation.
- I_{P3}: Number of incidents or faults by MV/LV PDS: From CMMS records for past three years identify the failure modes, frequency of failures and the annual maintenance costs per substation. The historical failure rates and the maintenance costs come from corrective and preventive maintenance data base (ERP/SAP PM).
- I_{P4}: Number of transformers and number of LV feeders installed per substation [23].
- I_{P5}: Number of the connected customers and sensitivity, importance of the area supplied with the MV/LV PDS [23].
- I_{P6}: Overload transformer in kVA: substations are classified according to the average load, compared with the rated load [23].
- I_{P7}: Safety and environmental risk or impact: The operational environment the substation is exposed to the humid environment has a negative impact on the installations inside the building, the risk of flooding.

3.2) Criticality indicators (I_c): The parameters used to criticality indicator are: The criticality of asset is a very important notion, how to be sure to maintain correctly and defines why to improve certain MV/LV PDS and not on others if you don't know what is important and reflects the sensitivity and importance of the clients connected on determined substation. To the criticality four parameters are employed:

- I_{C1}: Cost of energy not supplied (CENS): The reliability of supply from the substations has been measured through the expected CENS both residential and commercial customers are connected to the substation. An essential aspect affecting the cost is the considered time frame and timing of costs. For the cost criterion, estimations based on the current procedures and practice in the distribution company has been used [23].
- I_{C2}: Maintenance preventive OPEX: Is expenditure directly associated with running the electricity distribution network that cannot be capitalized (OPEX include maintenance expenditures required to operate or maintain the MV/LV PDS assets) [23].
- I_{C3}: Outdatedness or the rate of outdatedness per substation [24].
- I_{C4}: Outage costs per substation (Average costs of unplanned outage): Outage cost is composed of customer interruption cost (CIC) and the network repair cost. The outage costs in general have two parts: that seen by the utility and that seen by society or the customer [23], [24].

3.3) MV/LV PDS ranking: Due to the great amount of existing substations in the EXMS network, a ranking is necessary for studying. To each MV/LV PDS a score based on criticality matrix is attributed. Each substation is analyzed individually through a total weighted score A_j that takes into account these criteria.

- For each value of these criteria and after registering the criteria we attribute a weights coefficient W_i from 0 to 5 for each one, thus ranking the substations for studying.
- Attribution for each MV/LV PDS (j), from ranking (i), a note (S_{ij}) and this note goes from 1 to 5.
- For each substation, we calculate the total weighted score A_j which is equal to the given note multiplied by the corresponding weighting factor and to inform the multicriterion matrix for each criteria. The following expression for the calculation was proposed in equation (1) and Table II:

$$A_j = \left(\sum_{i=1}^{i=j} \left(W_i \times S_{ij} \right) \right)_{I_p} + \left(\sum_{i=1}^{i=j} \left(W_i \times S_{ij} \right) \right)_{I_c} \tag{1}$$

Where:

- S_{ij}: the attributed note for substation Sj of the classification criteria i.
- W_i: the weight of the classification criteria of i.

- I_p: Performance indicators.
- I_c: Criticality indicators.

TABLEAU II
Multicriteria prioritization matrix of MV/LV PDS

Criteria C_i	**Weighting W_i**	**MV/LV Substation S_1**	**MV/LV Substation S_2**	**….**	**MV/LV Substation S_j**
C_1	W_1 →	S_{11}	S_{12}	…	S_{1j}
C_2	W_2 →	S_{21}	S_{22}	…	S_{2j}
C_3	W_3	S_{31}	S_{32}	…	S_{3j}
⋮	⋮	↓	⋮	⋮	⋮
⋮	⋮	↓	⋮	⋮	⋮
⋮	⋮	↓	⋮	⋮	⋮
⋮	⋮	↓	⋮	⋮	⋮
⋮	⋮	↓	⋮	⋮	⋮
C_i	W_i	↓	…	…	…
Total		$A_1 = (A_1)_{Ip} + (A_1)_{Ic}$	A_2	…	A_j

The values of the classification criteria will be treated by the law of PARETO, and the quartile method to make it possible to classify MV/LV PDS in 4 classes. Each MV/LV PDS is classified as one of four MV/LV substations classes and priority (P_1, P_2, P_3 and P_4) as following:

- $\mathbf{P_1}$: Very high criticality;
- $\mathbf{P_2}$: High criticality;
- $\mathbf{P_3}$: Moderate criticality;
- $\mathbf{P_4}$: Low or stable criticality.

The classification results associated with the criticality are listed in Table I and Table IV.

D. Case study results and reviews

These prioritization criteria have been applied to the MV/LV PDS maintenance throughout 2012. The table III shows the obtained difference between the existing and the target potential to realize the totality preventive maintenance plan 2012 is of the order **-6092** HM (Table III). Indeed, the analysis of this table shows clearly that the manager may only make **67%** of the PPMP (Table III) before the prioritization of the MV/LV PDS. The results presented in table II summarize the number of MV/LV PDS by priority classes after utilization of the matrix optimization. They got results one adopting this prioritization of the MV/LV PDS and by frequency of maintenance scheduled given to each group according to the criteria of criticality, enabled us to obtain HM after prioritization. The results in table II shows that the necessary target potential in HM for the realization of the whole maintenance plan after the prioritization is of **16700** HM (Table IV). Indeed, as it is shown in Table IV, we could improve the team's productivity by gaining **793** HM at the end of 2012. This time was calculated on the basis of timing on the ground of various maintenance actions by using these new materials by the exploiting.

TABLE III
The target potential in HM

Teams	Number of MV/LV PDS	Number of agent per team	Available Potential per team in HM	Target Potential in HM	Variation in HM
T_1	547	4	6944	11384	-4440
T_2	129	3	2580	3800	-1220
T_3	126	3	3068	3500	-432
Total	802	10	12592	18684	-6092
Cover of PPMP 2012 in %	67%				

TABLE IV
The obtained classification results

MV/LV PDS maintenance team	Number of MV/LV PDS by priority			
	P_1	**P_2**	**P_3**	**P_4**
T_1	81	279	34	153
T_2	13	41	4	71
T_3	14	31	8	73
Total MV/LV PDS by class and priority	**108**	**351**	**46**	**297**
Percentage per classes of MV/LV PDS	14%	44%	6%	37%
Potential wanted (**P_{bp}**) in MH before prioritization	**P_{bp}**=18684 HM			
Available potential (**P_{av}**) of the teams in year 2012 in MH	**P_{av}** =12592 HM			
The difference in MH	-6092 HM			
The cover of PPMP 2012 in % before prioritization	**67%**			
Potential wanted (**P_{ap}**) in MH after prioritization	**P_{ap}** =16700 HM			
Gain in MH	**G**=1984 HM			
Potential lost (**P_l**) due to the teams interventions (Fortuitous incidents) in HM	**P_l**=1210 HM			
The gain recovered through the use of new appropriate materials in MH	**G_m**=793 HM			
New Potential (**P_n**)of the teams in year 2012 in MH	**$P_n=[(P_{av} - P_l) + G]$**=14159 HM			
The novel cover of PPMP 2012 in % after prioritization	**85%**			

These prioritization criteria have been applied to the MV/LV PDS maintenance since 2012 financial year. The achieved results are:

- The percentage of realization of the PPMP obtained after prioritization of the lines is about **85**%. Thus from performance point of view and with the existing potential, the adoption of this prioritization has improved the capability of execution of PPMP of 18% on the level of EXMS.
- The approach of work maintenance management implementation beyond an increase of the system reliability measured by the full number of the incident and interruptions provided a reduction by 24% of the number of incidents and, consequently, of the cumulative interruptions duration for LV customers at the end of the 2012 financial year comparing with the 2011 results [23].

- A reduction of 17% of the HM worked in the MV/LV PDS maintenance activities at the end of the financial year 2102, in this same period the OPEX showed an improvement of 21% comparing the 2011 and 2010 amounts.
- A reduction of 10 % in the investments comparing the 2011 and 2010 amounts, and an improvement of 22,4% in SAIFI indicator in the same period [23].
- An improvement of the indicators of performance SAIDI by 30%. On the other hand, the achieved result was a reduction of 17% in CENS comparing with the 2010 and 2009 results.
- To reduce breakdown maintenance costs below 10% of total maintenance cost for the plant by conducting planned maintenance activities that renew plant and equipment before failure occurs.
- To reduce the maintenance costs in the plant to industry standard percentage of replacement asset value.

V. Conclusion

Today, reducing operations and maintenance costs and preserving service reliability are the top priorities for managers of utility distribution systems. The approach outlined in this paper supports the assessment of a new optimization maintenance strategy as applied to MV/LV PDS. Outcomes are measured in terms of OPEX, energy not supplied, cost of un-served energy and reliability measurement indices such as SAIDI and SAIFI.

Indeed, understanding the relationship between performance and preventive maintenance is a critical part of any network performance improvement strategy. Fact based decision making must be applied such that the maximum level of performance improvement can be obtained with available resources.

In this paper, we have proposed a newly developed methodology for planning MV/LV PDS preventive maintenance actions to be implemented in EXMS that takes into consideration technical, economical and quality of the supply aspects, with an optimum balance between cost of maintenance and reliability improvement.

The approach is pragmatic using readily available network information, and a range of inputs relating to network. Indeed, the successful completion and implementation of the approach summarized in this paper are intended to make a quantum step change in the quality and effectiveness of EXMS MV/LV PDS network maintenance. In addition it was shown, that the optimization approach, which is part of the newly developed methodology, can determine optimal resource scheduling for maintenance measures and thus be used as a planning tool in order to minimize maintenance costs. On the basis of the results we can formulate general conclusion overall value obtained as follows:

- Reduction of the component failure rates for major components of MV/LV PDS, and improvement the rate of realization of the PPMP, reduction of the man x hour worked and reduction on operational expenditures.
- New optimal strategy has been found that decreases the OPEX, SAIFI and SAIDI.

For the future prospects, the approach was being validated by the Top management of the ONEE distribution and will be generalized and will be demonstrated on other assets of the ONEE distribution network (LV lines, HV/MV substations) for a number of investment scenarios with the intention to inform strategies to ensure appropriate investment that balances the costs and benefits of improving network performance (Provides input into the forecasting of OPEX and CAPEX budgets). To further illustrate the application of the model we construct two scenarios and investigate the impact of the approach on network Key performance indicators (KPI's: SAIDI and SAFI) as follows:

- First we investigate the reliability implications of operational improvements.
- Lastly, we investigate infrastructure (CAPEX) interventions applied with the sole objective of reducing SAIDI and SAIFI for the other MV distribution assets.

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