Lean Maintenance model to reduce scraps and WIP in manufacturing system:case study in power cables factory

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Abstract: - The aim of this paper is to develop an innovative Lean Maintenance model in order to optimize the process flow and reduce or eliminate scraps and work-in-progress (WIP) in a manufacturing context. To achieve these objectives has been formulated a new method, called Lean Root Cause & Defect Analysis (LRCDA), which merges the process steps of the existing Root Cause & Failure Analysis (RCFA) technique and basic principles of Lean Maintenance and Total Productive Maintenance (TPM).The LRCDA is a logical sequence of phases the leads the investigator through the process of isolating the facts surrounding the event or the fault. After the problem defining, the analysis determines the best actions, corrective and preventive, to will resolve the problem and its recurrence. The model has been implemented for the first time in a power cables factory with intent to reduce the partial discharges phenomena in medium voltage (MV) cables.

Key-Words: - lean maintenance, total productive maintenance, maintenance-production relationship, autonomous maintenance, root cause & failure analysis.

1 Introduction

Maintenance is considered as a key point for the manufacturing systemcompetitiveness because first its cost represents the major part of the operationalcost, and second, a system failure can have an important impact on product quality,equipment availability, environment, and operator [7].Effective maintenance extends equipment life, improvesequipment availability and retains equipmentin proper condition.Conversely,poorlymaintainedequipmentwill havea shorterusefullifeandexperience more frequent equipmentfailures,leading to low levels of equipment utilization and delayed production schedules.Misalignedormalfunctioningequipment will also result in scrap, work-in-progress (WIP) or products of questionable quality [1]. Maintenance has become a multidisciplinary activity and one may come acrosssituations in which maintenance is the responsibility of people whose training isnot engineering [2].

A good maintenance management requires an understandingof the links between the production and maintenance. However, in practice, these links are often ignored, or at least forgotten [11].The maintenance objectives are the organizational conditions that must be met in order to fulfill the mission; they should be synchronized, together with goals and targets, with the departmental mission statement and be consistent with the facility strategic and operations/production plans that are formulated to realize the company's vision.Maintenance Operation objectives must support both the plant's strategic and production plans and the plan's objectives. In addition they must support the maintenance operation's stated mission.

The number one objective for all maintenance organizations everywhere is maintenance of equipment reliability.It is essential to establish specific goals for achievement in relation to the plant's strategic and operational plans, both short- and long-term. Furthermore, targets must be set for maintenance performance in terms of equipment up time, maintenance costs, overtime, work-force productivity and supervisor's time at job sites. Such specific targets as these enable management to monitor progress and the effectiveness of the maintenance management program and to control activities by focusing corrective attention on performances or levels that consistently fall short of the targets [1].

Some companies too often rely on production volume as their ultimate test for success. Lean isn't about productivity, and that's hard for many manufacturers to accept. Lean Maintenance is a relatively new term, coined in the last decade of the twentieth century, but the principles are well established in Total Productive Maintenance (TPM). Lean Maintenance, taking its lead from Lean Manufacturing, applies some new techniques to TPM concepts to render a more structured implementation path. Tracing its roots back to Henry Ford with modern refinements born in Japanese manufacturing, specifically the Toyota Production System (TPS), Lean seeks to eliminate all forms of waste in the manufacturing process, including waste in the maintenance operation.All Lean thinking, the premise of Lean Manufacturing and Lean Maintenance, is originally based on manufacturing processes. Some believed that everything else would just naturally evolve, or fall into line, from those roots. Time, however, has unmasked the difficulties of instituting "Lean" in production support operations, those areas adjacent to the manufacturing production process, such as maintenance, without the presence of some prerequisite conditions. To reduce costs and improve production, most large manufacturing and process companies that have embraced the Lean Enterprise concept have taken an approach of building all of the systems and infrastructure throughout the organization. The result of this traditional approach has been erratic implementation efforts that often stall-out, or are terminated, before the benefits come. Plants can accelerate their improvements with much lower risk through the elimination of the defects that create work and impede production efficiency. Optimizing the maintenance function first will both increase maintenance time available to do further improvements and will reduce the defects that cause production downtime. Thus cost reduction and improved production are immediate results from establishing Lean maintenance operations as the first step in the overall Lean Enterprise transformation [1].

2 Lean Maintenance Analysis

The very foundation of Lean Maintenance is Total Productive Maintenance (TPM). TPM is an initiative for optimizing the reliability and effectiveness of manufacturing equipment. TPM is team-based, proactive maintenance and involves every level and function in the organization, from top executives to the shop floor [5]. TPM addresses the entire production system life cycle and builds a solid, shop-floor-based system to prevent all losses. TPM objectives include the elimination of all accidents, defects and breakdowns.The concept of TPM originated in Japan's manufacturing industries, initially with the aim of eliminating production losses due to limitations in the JIT process for production operations. Nakajima is credited with defining the fundamental concepts of TPM and seeing the procedure implemented in hundreds of plants in Japan; the key concept being autonomous maintenance [4].

TPM is a major departure from the ''you operate, I maintain'' philosophy. It is the implementation of productive maintenance by all associated personnel (whether machine operators or members of the management team), based on the involvement of all in the continual improvement of performance [6]. TPM endeavours to eliminate the root causes of problems, through team-based decisions and their implementation. Achieving low-cost improvements and zero-deficit product quality are striven for, while designing for minimum LCC maintenance and using the JIT procedure. All employees, through small-group activities, which include aiming for zero breakdowns and zero defects, should implement it. The three components of the concept are:

- optimized equipment-effectiveness;
- autonomous-operator maintenance;
- company-led small-group activities, throughout the entire organization.

This is a ''high-employee involvement'' approach. It leads to improved creative group-efforts, greater individual effort, personal responsibility, and lively innovative problem-solving meetings. TPM concepts involve commitments to long range planning, especially on the part of senior management. Typically, TPM is initiated as a ''top-down'' exercise, but only implemented successfully via ''bottom-up'' participation. However, consensus building may take about three years, from the planning phase, for sustainability to be achieved in a large organization [4,5].

TPM is a manufacturing-led initiative that emphasizes the importance of: (i) people with a 'can do' and continual improvement attitude and (ii) production and maintenance personnel working together in unison. In essence, TPM seeks to integrate the organization to recognize, liberate and utilize its own potential and skills. TPM combines the best features of productive and PM procedures with innovative management strategies and encourages total employee involvement. TPM focuses attention upon the reasons for energy losses from, and failures of equipment due to design weaknesses that the associated personnel previously thought they had to tolerate [6].

Autonomous maintenance looks into the means for achieving a high degree of cleanliness, excellent lubrication and proper fastening (e.g. tightening of nuts on bolts in the system) in order to inhibit deterioration and prevent machine breakdown.The Japanese Institute of Plant Maintenance in 1996 introduced autonomous maintenance for operations as a role for all employees' in order to achieve greater financial profits. The aim of TPM is to bring together management, supervisors and trade union members to take rapid remedial actions as and when required. Its main objectives are to achieve zero breakdowns, zero defects and improved throughputs by:

- increasing operator involvement and ownership of the process;
- improving problem-solving by the team;
- refining preventive and predictive maintenance activities;
- focusing on reliability and maintainability engineering;
- upgrading each operator's skills.

The TPM strategy includes:

- maximizing equipment effectiveness;
- improving quality, increasing safety and reducing costs;
- raising the morale of the team that is implementing TPM.

The uppermost echelon of management should be highly committed to the setting of wise TPM goals, achieving sustainability, standardization, pertinent education and training in TPM, measuring TPM effectiveness, developing an autonomous maintenance program and implementing Kaizen-teian programs. Workshop management is responsible for implementing TPM goals via group PM, small-group activities, maximizing equipment effectiveness, zero-accident and zero-pollution aims, improving operating reliability, reducing the LCC, and problem solving [1].

Manufacturing companies have to pay attention to the reliability of their production processes as well as to their quality management. In order to improve their production processes, various quality programs are implemented. Two major improvement programs in the field of production and operations management are TPM and Total Quality Management (TQM). The main objective of TPM is to achieve a reliable manufacturing system. This is accomplished by maximizing the overall equipment effectiveness so that plant and equipment productivity is increased. In addition to this, the main objective of TQM is to generate improved product quality in order to improve firm performance. With respect to their fundamental goals, a comparison of the two improvement programs indicates substantial similarities. Both TPM and TQM strive for continuous improvement, organization-wide involvement, and reduction of waste. By combining TPM and TQM techniques, a comprehensive and consistent set of manufacturing practices can be derived to improve firm performance. Therefore, many manufacturing firms consider a simultaneous implementation of these improvement programs in order to achieve synergetic effects. One of the main tools used to support both TPM and TQM programs is the Root Cause & Failure Analysis. This method can prevent problems from recurring or examine current operations and help to identify areas and activities that can be improved. RCFA is one of the basic reliability enhancement method. It is relatively easy to perform and many companies already do it, some using rigorous problem solving technique and some informally[10,13].

The concept of Root Cause Analysis (RCA), as illustrated by authors of publications [25] and [27], was originally developed by Sakichi Toyoda (the founder of Totota Motor Corporation) in 1958, who developed a process called the "Five Whys" to understand potential cause for problem beyond what was immediately obvious. Fatima A. in [25] consider the "Five Whys" one of the earliest models used in the history of RCA and it simply seeks to ask "why" five times until the main cause of the problem is revealed. The history of RCA continues, according to publications [25] and [26], with Six Sigma, indeed in 1986, Motorola developed a new strategy for risk management called Six Sigma, which uses specific methods, including statistical information, to outline a RCA, and with The Federal Aviation Administration (FAA) that has been actively involved in quality control, error reduction, and risk management to minimize accidents and In 1975, established the Aviation Safety Reporting System (ASRS) to conduct its safety management. Following its establishment, the FAA has reduced death rates from airline accidents by 80 percent. It has been said the success of the FAA's risk management system comes from its separation of power; ASRS being funded by FAA, but administered by the National Aeronautics and Space Administration (NASA).

J. Rose in [26] and Ghinassi in [28] consider that RCA evolution evolved during the years to accommodate many fields throughout time and most of these can be classed into five, very-broadly defined "schools" that are named by their basic field origin:

1. Safety-based RCA, which originated in the fields of occupational safety and health, as well as accidental analysis.
2. Production-based RCA, which originated in the field of manufacturing to ensure quality control.
3. Process-based RCA, which originated in the fields of business and manufacturing.
4. Failure-based RCA, called also Root Cause & Failure Analysis (RCFA), which originated in the fields of engineering and maintenance.
5. Systems-based RCA, which originated as a combination of all of the above root cause analysis techniques, as well as borrowing concepts from risk management, systems analysis, and change management.

Indeed in literature it is possible to find the RCA in every field, for example Wilson, Dell and Anderson in publication [29] in 1993 treated the RCA as a tool for Total Quality Management (TQM), but only as one of the many tools that should be used to support any TQM effort. For the authors of [29], the RCA can help identify the more obvious and needed improvements to current operations, since it focused on present obstacle.

Another viewpoint of RCA is in publication [30] where is illustrated that a retrospective approach to error analysis, called root cause analysis (RCA), is widely applied to investigate major industrial accidents. RCA has its foundations in industrial psychology and human factors engineering. Many experts have championed it for the investigation of sentinel events in medicine. In 1997, the Joint Commission on the Accreditation of Healthcare Organizations (JCAHO) mandated the use of RCA in the investigation of sentinel events in accredited hospitals [30].
Robert Latino in [32] defines the difference between RCA and RCFA. The first one implies the conducting of a full-blown analysis that identifies the Physical, Human and Latent Root Causes of HOW any undesirable event occurred. The word "Failure" has been removed to broaden the definition to include such non-mechanical events like safety incidents, quality defects, customer complaints, administrative problems (i.e. - delayed shutdowns) and the similar events, while the RCFA indicates conducting a comprehensive analysis down to all of the root causes (physical, human and latent), but connotes analysis on mechanical items only. I have found that the word "Failure" has a mechanical connotation to most people. Root Cause Analysis is applicable to many more than just mechanical situations. It is an attempt on our part to change the prevailing paradigm about Root Cause and its applicability [32].
R. Keith Mobley is one of the first author who speaks about the Root Cause & Failure Analysis (RCFA) in [18], publication of 1999. He treats the RCFA as an analysis technique usedto investigate and resolve a reliability-related problems. RCFA is a logical approach to problem solution that has to major objectives: preventing catastrophic failures of critical plant production system and avoiding deviations from acceptable performance levels that result in personal injury, environmental impact, capacity loss or poor product quality.
An important contribute to RCFA literature is given by Joy LePree in publication [31] in which the author underlines the viewpoints about RCFA of the main experts in Reliability and Maintenance fields. LePree defines the RCFA as a simple, yet disciplined process used to investigate, rectify and eliminate equipment failure, and it's most effective when direct at chronic breakdowns, according to Robert Latino who says that the "RCFA is applicable everywhere and you will save a lot of money if you use it on chronic failures". Latino has found that approximately 80% of a typical maintenance budget is stored away for chronic failures, meaning these events cost far more, in aggregate, than major breakdowns. So it makes sense that the greatest savings come from applying RCFA to routine breakdowns. The same opinion is given by Rick Kalinauskas, reliability engineering supervisor for Union Camp Paper Co., who says that his company initiated RCFA for just that reason: "We found that a large portion of downtime came from small events that occurred on a very frequent basis, rather than big, sporadic one-time failures. The power of RCFA process is that it shows you how to find the latent roots responsible for the breakdowns" [31].
Whit the evolving of Lean concepts, the RCFA becomes one of the most effective tool in sustaining the Lean Maintenance Transformation, as illustrated by R.Smith and B.Hawkins in [1]. The RCFA evolves in a most important functions of the Maintenance Engineering group used to find the root causes of failures and the mystery of why equipment failed.

3 Production and maintenance relationship

TPM is a synergistic relationship among all organizational functions, particularly between production and maintenance. This aims for continuous improvement of product quality, as well as operational efficiency and capacity assurance. An efficient TPM depends on both production and maintenance activities. The key supporting elements of TPM are shown in Figure 1 [5].

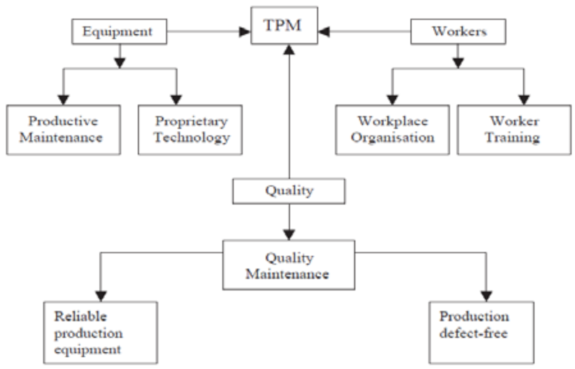

Figure 1: Key supporting elements of TPM

Also, Yamashina (1995) stated that no matter how well plants are equipped with advanced manufacturing techniques, it is always the operators, not managers or systems, who affect the plant's performance [5,1].
In this connection, operators should participate in the maintenance function by becoming responsible for the prevention of deterioration. The central role of operators in equipment operation, condition, and maintenance must be acknowledged. The co-operative effort allows maintenance personnel to focus their energies on tasks requiring their technical expertise and to learn about and use more sophisticated techniques for advanced manufacturing. Operators and maintenance personnel must reach mutual understanding and share responsibility for equipment (Jostes and Helms, 1994; Lawrence, 1999; Ben-Daya and Duffuaa, 1995). In fact, everyone concerned with equipment must co-operate with and understand the

role of everyone else. Operators should do the following:

- maintain basic equipment conditions (cleaning, lubrication, bolting);
- maintain operating conditions (proper operation and visual inspection);
- discover deterioration, mainly through visual inspection and early identification of signs of abnormalities during operation;
- enhance skills such as equipment operation, set-up, and adjustment, as well as visual inspection.

These activities constitute the operator's AM responsibilities. On the other hand, maintenance personnel should do the following:

- provide technical support for the AM activities;
- restore deterioration thoroughly and accurately, using inspections, condition monitoring and overhaul;
- clarify operating standards by tracing design weaknesses and making appropriate improvements;
- enhance maintenance skills for check-ups, condition monitoring, inspections, and overhaul.

Figure 2 illustrates the role of operations and maintenance in TPM [5].

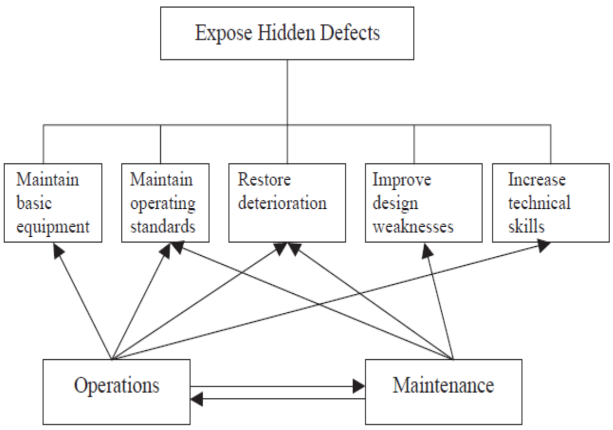

Figure 2: Relationship between operations and maintenance

4 Lean Root cause & defect analysis Model Construction

Reliability engineering and predictive maintenance have two major objectives: preventing catastrophic failures of critical plant production system and avoiding deviations from acceptable performance levels that result in personal injury, environmental impact, capacity loss, or poor product quality.Unfortunately, these events will occur include a process for fully understanding and correcting the root causes that lead to events having an impact on plant performance.

The aim of project has been to develop an innovative method focused on defects, called Lean Root Cause & Defect Analysis (LRCDA), which includes and merges the traditional RCFA steps integrated withfundamental principles of Lean Maintenance and TPM, as shown in Figure 3, with intent to improve the process flow and the quality standards optimizing the maintenance.

The LRCDA is a process designed for use in investigating and categorizing the root causes and, by corrective and preventive actions, decrease the quantity of defects and consequently to reduce or delete the scraps and the WIP in a manufacturing system and the related time and cost losses. The model is founded on the following concepts that need to perform step-by-step during the process analysis:

- *Team-working culture*: it is important to inculcate a team-working culture, a team help to break down the barriers that are inherent in the traditional approach and to identify problems. Moreover it could suggest new ideas and viewpoints for elimination of the defects, introduce new skills that are needed and define the LRCDA program.
- *Management team commitment*: a successful deployment of LRCDA implementation needs a top management support, commitment and involvement. Management should go all-out for an evolving mechanism for multi-level communication to all employees, explaining importance and benefit of the program, promoting motivation and continuous improvement and ensuring total employee involvement.
- *Employee Empowerment*: one of the essential principles of LRCDA, such as of Lean and TPM, is the encouraging operators to assume more responsibility and authority for decisions affecting their production equipment. Employee empowerment means the extent to which employees producing a product or offering a service have a sense of controlling their work, receiving information about their performance and being rewarded for affecting performance enhancement in the workplace.
- *Continuous improvement*: it refers to continuous improvement of processes and systems, which in term manifests as improvement on many fronts, such as productivity, quality, cost, schedule and process flow.
- *Training and Multi-skilling*: adequate training and education of employees at all levels should be treated as a strategic initiative for successful model implementation. The training objective must include systematic development of knowledge, skills and attitude required by an individual to perform adequately the job responsibilities. The top management must identify the training needs, set training targets and prepare appropriate training and schedule plans.
- *Autonomous operator maintenance*: the top management should encourage operator to work alongside maintenance workers to perform tasks

that prevent deterioration of production equipment and endeavor to build the sense of ownership of the equipment. The autonomous maintenance practiced by operators helps to maintain high machine reliability, avoid defects and maintain high quality of production.

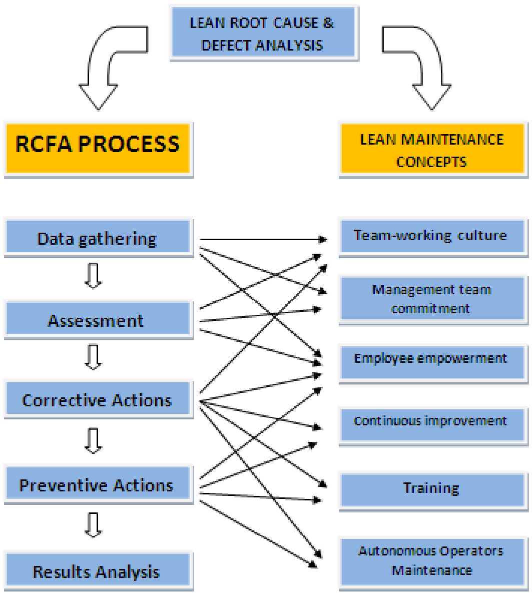

Figure 3: LRCDA elements connection

As RCFA methodology, the LRCDA is a logical sequence of phases the leads the investigator through the process of isolating the facts surrounding the event or the fault. After the problem defining, the analysis determines the best actions, corrective and preventive, to will resolve the problem and its recurrence.
The LRCDA consists of six main steps:

1. Work team creation: the first step of LRCDA is the creation of a dedicated work management team that includes the figures of all the main departments: production, maintenance and quality. In addition to project management, the team have the role of motivations promoter, cross-functional team culture promoter, inter-department synergy creator and promoting training and skill enhancements for production and maintenance workers.
2. Data gathering: the second step is to make a data collection that is necessary to understand the problem and identify the root causes. It is possible to report by defect observing, process flow studies and examination, statistic documents, consulting the workers, consulting experts and asking questions.
3. Assessment: it is the defining and identify of the defect and its main causes. To assessment implementing it is possible to choose in several methods. Selecting the right method can speed the entire process up, as required in Lean Maintenance. The best methods to use are: Ishikawa diagram, Pareto Analysis and the Fault-tree analysis.

   The assessment consists, in general, of 4 steps:
   - identify the defect;
   - defining the root causes and related significances;
   - cause classifications;
   - identify the reasons of root causes.
4. Corrective actions: after causes definition, it is required a corrective actions planning, formulated in Action Plan and related cost, to reduces the probability that a problem will recur. Following the TPM principles, in this phase it is very important a strict collaboration between Operations and Maintenance. In this connection, operators should participate in the maintenance actions to simplify the maintenance workers job, through check and inspections.
5. Preventive actions: strictly correlated to corrective actions are the preventive actions. It is necessary introduce a preventive action plan to avoid the defect causes recurrence. In this step, the operators could be have an important role, indeed, the prevention could be done by them through an Autonomous Maintenance. The operators could perform tasks that prevent deterioration of production equipment and improve their performance. The organization should train the operators to perform autonomously routine check, inspection, cleaning, lubrication and adjustment, with a preset frequency.
6. Results analysis: the last step is to measure the results of the LRCDA implementation and evaluate its efficiency in terms of defect, scraps, WIP and related costs reduction.

The LRCDA process flow is illustrated in Figure 4.

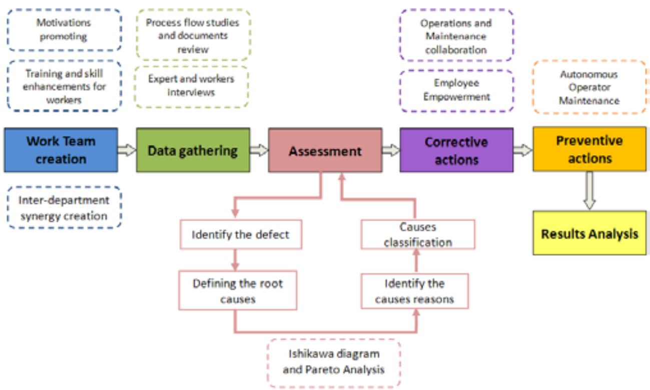

Figure 4: LRCDA process flow

The model indicators determination is necessary because of indicator importance to helps you to understand where you are, which way you are going and how far you are from where you want to be; it could also alert you to a problem before it gets too bad and help you recognize what needs to be done to fix the problem. To evaluate the performance of LRCDA, the main objective must be considered, than the production defect reduction. For this reason, to understand the result of the model implementation it has been established the Defect Indicator as:

$$DefectIndicator = \frac{Numberofdefects}{Totalproduction} \quad (1)$$

The indicators are selected also to understand in which way the model is going and the changes that the model is providing to system. For LRCDA it is important to evaluate the integration level between maintenance and production during the procedure developing.
To measure this integration could be used indicators that observe the autonomous operator maintenance degree in a predetermined period, such as:

$$\frac{Numberofequipmentscheckedbyoperator}{Overallequipment}; \quad (2)$$

$$\frac{Operatorworktimedevotedtomaintenance}{Overalloperatorworktime}; \quad (3)$$

$$\frac{Number\ of\ equipment\ failures\ detected\ by\ operator}{Overall\ equipment\ failures}. \quad (4)$$

Moreover, whit intent to measure the collaboration degree between production and maintenance could be useful to observe in a predetermined period:

$$\frac{Number\ of\ meetings\ with\ prod.and\ maint.partecipation}{Overall\ meeting} \quad (5)$$

Following the concepts of employee empowerment and commitment, it is also essential to evaluate the Employee Satisfaction that is a measure of how happy workers are with their jobs and working environment. They must feel part of a family or a team. Keeping morale high can be of tremendous benefit to any company, as happy workers are more likely to produce more, take fewer days off, and stay loyal to the company. There are many factors involved in improving or maintaining high satisfaction rates, which wise employers would do well to implement. To measure Employee Satisfaction, it is possible to submit them to a questionnaire shown in Figure 5, where Level 1 is the maximum satisfaction level and so forth.

FACTORS	LEVEL			
1) Satisfying time work organization	1	2	3	4
2) Equal distribution of work	1	2	3	4
3) Responsibility and tasks definition	1	2	3	4
4) Relationship with head	1	2	3	4
5) Motivations passed by top management	1	2	3	4
6) Top management methods to enocourage shared activities	1	2	3	4
7) Relationship with colleagues	1	2	3	4
8) Work place quality	1	2	3	4
9) Equipment quality	1	2	3	4

Figure 5: Questions helping to define Employee Satisfaction

The LRCDA model is a dedicated process to root causes research with intent to remove the production defects. The difference between LRCDA and other similar techniques, such as the RCFA, is that LRCDA is treated not only as a problem solving method but as work style that leads all the employee to a common objective achievement. In addition to rework time saving and total cost saving, the expected results coming from LRCDA implementation are the strict collaboration between operations and maintenance workers, the employee commitment and the autonomous operator maintenance introduction. The LRCDA model advantages are shown below in detail:

- the LRCDA is a model focused on reduction of random and recurring production defects;
- the LRCDA is a model focused on research and analysis of all or, at least, the main root causes of defects;
- the LRCDA has the intent to avoid the recurrence of the root causes with a continuous improvement and consequently lower the maintenance costs;
- the LRCDA may often be the fastest and least expensive way to find sources of defects;
- the LRCDA provides a reduction of scraps and WIP;
- the LRCDA reduces rework times;
- the LRCDA reduces cost due to scraps and WIP;
- the LRCDA improves the equipment effectiveness and the maintenance efficiency and effectiveness;
- the LRCDA provides a real collaboration between operations and maintenance;
- the LRCDA provides an autonomous operators maintenance;
- the LRCDA provides a training to improve the knowledge and skills of all people involved.

5 LRCDA Model Implementation

LRCDA model has been implemented in a power cables factory with intent to reduce partial discharges (PD) phenomena in medium voltage (MV) cables. Partial Discharges are electrical discharges refered to a small area of the insulation/screen system and not the overall thickness between conductor and metallic screen. They occur when gas cavities or conducting inclusions or intrusionsare in insulation material (see Figure 6) and cause a progressive deterioration of the insulation in the location of the voids and could lead to cable failure.

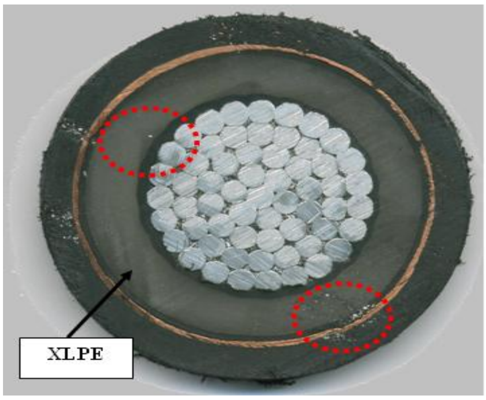

Figure 6: An example of PD causes

After work team creation composed by figures that represent all factory's departments (maintenance, production and quality), it has been studied the PD situation in MV cables. The 2011 and 2012 situations is shown below in Table 1, where:

- MV(tons) = MV cables tons produced;
- YTD MV= MV cables tons produced year to date;
- Partial Discharge = number of PD faults come out from MV cables production.

	2011	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2012
MV (tons)	4325,9	267	488	404	282	796	504	174	574	452	466	772	-	5.180
YTD MV	-	267	755	1.159	1.442	2.238	2.741	2.916	3.490	3.942	4.407	5.180	5180	5.180
Partial Discharge	34	4	2	1	4	7	6	1	6	5	6	4	-	46

Table1:MV tons production and number of PD faults in 2011-2012

The PD Rate Indicator estimated has been calculated as:

$$PDRateIndicator = \frac{PDfaults}{100\, TonsMVcablesproduced} \quad (6)$$

andas illustrated in Table 2, the estimated average values for 2011 and 2012 are respectively of 0,79 and 0,89.

PD Rate Indicator	2011	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2012
PD / 100 Tons cables produced	0,79	1,50	0,41	0,25	1,42	0,88	1,19	0,57	1,04	1,11	1,29	0,52	-	0,89
YTD (PD/100 Tons produced)	-	1,50	0,79	0,60	0,76	0,80	0,88	0,86	0,89	0,91	0,95	0,89	0,89	0,89

Table 2: PD Rate Indicator

In 2012 it has been estimated a total cost due to PD faults in MV cables of € 73.009,44. These costs have been calculated from the sum of more rates, fixed and variable costs, and are illustrated below in Table 3:

- scrap cost [€ / m];
- extra working [h/fault];
- extra WIP cost [€];
- total time to solve problem [month].

<u>Scrap cost</u>: for each fault, after its locating, a part of 250 meters is cut from the piece that automatically becomes a production scrap. This is a loss and then a cost of 3,17 €/m.

<u>Extra working</u>: when a fault occurs, consequently extra work is producing, indeed are maked more operations consisting of: extra spooling, extra use of forklift, extra PD tests (on the average two times more).It is estimated about of 20 h/fault.

<u>Extra WIP cost</u>: these kind of costs are due to three several factors,

1. Drums immobilization, they are deducted to the production.
2. Occupation of space inside the plant.
3. Extra use of forklift to drums handling.

<u>Total time to solve the problem</u>: it represents the total time from fault detecting to fault extrapolation and delivery to the end costumer.

PD COST/YEAR	
PD faults / month	4
scrap m / fault	250
Scrap cost [€/m]	3,17
Extra working hours / fault	20
€/h	35
Extra WIP / fault [m]	3000
Extra WIP cost / month [€]	228,24
Time to solve problem (month)	6
Total cost of extra WIP	1369,44
Cost / fault [€]	1492,5
Cost / year [€]	73.009,44

Table 3: PD faults costs in 2012

The next step has been to analyze all the possible PD causes. The first stage consists to observe the MV cables with PD fault produced during 2012; this work has been composed of three working phases shown below:

1. the early stage is to do an extra test of the defective cable and try to localize, with help of a specific tester machine, the PD fault. After that, it is important to cut the piece with the fault inside;
2. the next stage is to "open the piece", i.e. it is required to take off the jacket and the aluminium layer;
3. finally, there is the possibility to check and analysis the part of cable that is composed just from the semiconductives (external and internal), insulation material and conductor.

Thereafter, following this procedure each defective cable, two different situations have been observed:

1. The first one has been that several pieces were defected on the external semiconductive, they had some incisions, grooves and deep scratches, as shown below in Figures 7-8. These kind of faults were classified as "mechanical damages".

Figure 7: Example of mechanical scratch (1)

Figure 8:Example of mechanical scratch (2)

2. The second situation has been that the pieces had not scratched, then it has been necessary a more deep study to understand the problem. For this reason, it has been done an silicon oil test on the pieces following this method: the cable is subjected to high voltage with intent to generate the partial discharge which leads to breakdown, therefore the piece is dipped in silicon oil and in this way it's possible to observe inside the insulation material. The partial discharge produces a sort of vortex into insulation and from the starting point of this vortex it's possible to understand from which side (external semiconductive, insulation or internal semiconductive) of the piece the partial discharge is born. An examples in Figures 9-10.

Figure 9: PD phenomenon starting from external semiconductive

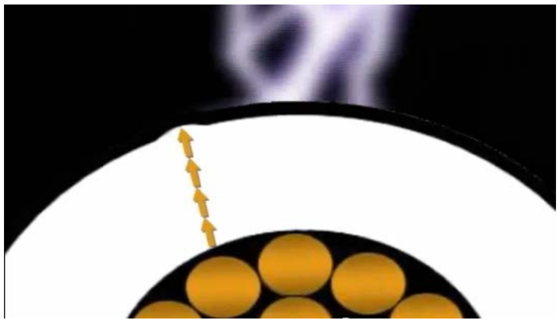

Figure 10:PD phenomenon starting from internal semiconductive

Normally this kind of problems come from air bubbles inside the insulation material, lumps on insulation screen and mixed compounds. These faults have been classified as "production process problems".
After cables examination, the data have reflected a very important results because it's clear that the most part of the faults were mechanical damages, 71,74% of total faults, as shown in Figure 11.
After these results, indeed, the study has been focused on these faults type and first of all to delete the causes of mechanical damages.

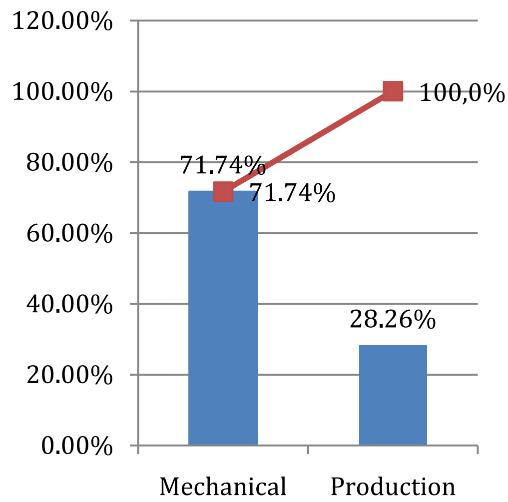

Figure 11: Pareto chart of fault type classification

Resuming what has been illustrated previously, according to studies done on the cables with PD faults, it is resulted that there two categories of faults during the production:

1. Mechanical damages on external semi conductive.
2. Process problems as air bubbles, lumps on screen or mixed compounds.

For this reason it has been clear that the attention had to be focalized on two definite production phases: insulation process phase and the starting phases of jacketing process (as shown in Figure 12).

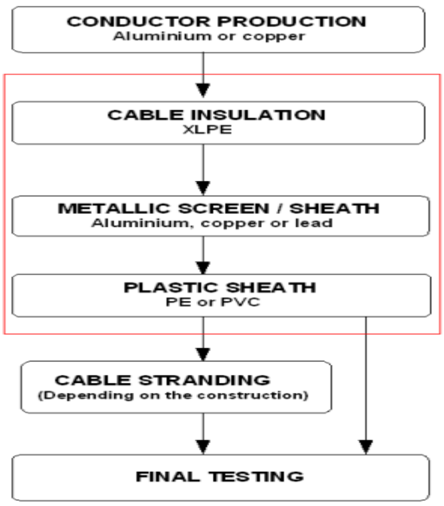

Figure 12: Main phases of process to analyze

Starting from this important assumption, it was essential to study all the steps of this two working phases and to check every component and resource used during both (machinery, components and human power). Specifically:

- drums;
- rollers;
- cooling pipe (insulation process);
- curing pipe (insulation process);
- insulation materials rooms;
- extruders (insulation process);
- pay off of jacketing line.

With the intent to a better research and capture the causes of the PD phenomena and the relationships between cause and effect, it has been drawn up an Ishikawa diagram, called also Fishbone or Cause and Effect diagram.

The basic concept in the this diagram is that the name of a basic problem is entered at the right of the diagram at the end of the main 'bone'. This is the problem of interest. At an angle to this main bone are located typically three to six sub-bones which are the contributing general causes to the problem under consideration. Associated with each of the sub-bones are the causes which are responsible for the problem designated. This subdivision into ever increasing specificity continues as long as the problem areas can be further subdivided. The practical maximum depth of this tree is usually about four or five levels. When the fishbone is complete, one has a rather complete picture of all the possibilities about what could be the root cause for the designated problem.The diagram can be used by individuals or teams; probably most effectively by a group. A typical utilization is the drawing of a fishbone diagram on a blackboard by a team leader who first asserts the main problem and asks for assistance from the group to determine the main causes which are subsequently drawn on the board as the main bones of the diagram. The team assists by making suggestions and, eventually, the entire cause and effect diagram is filled out. Once the entire fishbone is complete, team discussion takes place to decide what are the most likely root causes of the problem. These causes are circled to indicate items that should be acted upon, and the use of the fishbone tool is complete. The drawing up of this Ishikawa diagram focused on PD faults has been assisted by a team composed of Quality Manager, Production Manager and Technical Engineer.

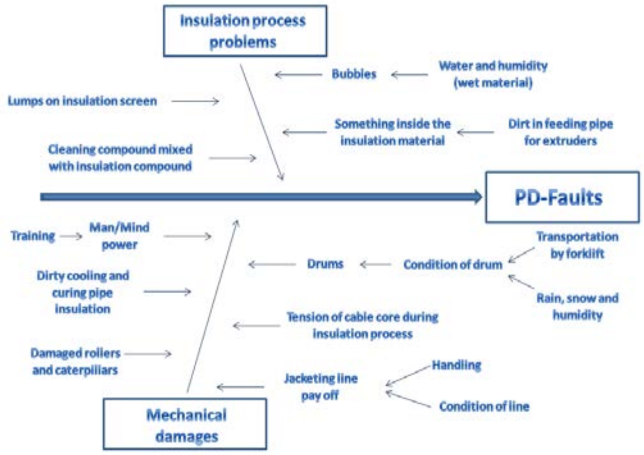

Figure 13:Ishikawa diagram focused on PD faults problem

Following the previous studies, the causes have been subdivided in two macro categories used to faults classification, mechanical damages and insulation process problems (see Figure 4.40). Associated with each macro categories are the sub-causes of the problem designated, and so forth. As shown in Figure 4.36, the mechanical damages represent about 71% of total and for this reason, the following analysis and next corrective actions are focused just on the main reasons and causes of this damages type. The most important causes are described below in detail.

Drums: they are subject to wear and breakage and these can be happened for two main reason: a wrong handling by forklift, corrosion and rust due to the drums storage on the outside and then they are subject to every atmospheric agent, like rain, snow, wind and humidity. All that causes a lot of damages on drums: sloping flanges, bangs on bottom and scratches (see Figure 14-15).

Figure 14:Example of scratch on drum

These kind of damages could be produced, during the production, especially during the take off of insulation process and the pay off of jacketing line, very deep scratches on the external semiconductive. For this reason an improper drums maintenance is one of the main cause of the mechanical damages and so it is one of the mother lode of PD faults on MV cables.

Figure 15:Example of drum sloping flanges

<u>Rollers and caterpillars</u>: they are essential components of the main process lines, insulation and jacketing, during power cables production. They have an important role because they give the right direction to the semifinished cable during its line crossing and avoid overburden, excessive flexing and traction. Moreover, in some cases, the caterpillars have the function of modeling tool with intent to give to the semifinished cable the predetermine dimension, a spherical form.

Figure 16:Example of damaged rollers

The main problem in this case is the bad condition of rollers and caterpillars, indeed it’s important to check accurately if the rollers and belts are damaged/consumed (an example is shown in Figure 16), blocked/jammed or with accumulated dirt on the surface because these cause scratches on the cable and then could create PD faults.

<u>Curing pipe</u>: The curing follows on directly from the extrusion process; it therefore refers to continuous curing or continuous vulcanization. The curing process itself starts due to the heating of the PE molten mass containing peroxide which has been extruded at approximately 200 °C. Vulcanization is a chemical process for converting rubber or related polymers into more durable materials via the addition of sulfur or other equivalent "curatives" or "accelerators". These additives modify the polymer by forming crosslinks (bridges) between individual polymer chains.Vulcanized materials are less sticky and have superior mechanical properties. From the vulcanization process comes out the by-product. A by-product is a secondary product derived from a manufacturing process or chemical reaction, so it is not the primary product or service being produced.The by-products could be very dangerous during the insulation process. After an high use of the line and an elevated length of insulated core, the by-product could be amassed in some points of the curing pipe reducing the crossing opening of the cable (see Figure 17).

Figure 17: By-product mass in the CCV curing pipe

The cable indeed, with a rocking movement, could touch the by-product mass and could be scratched itself. For this reason, the curing pipe should be inspected periodically and it is considered one of the possible causes of mechanical damage.

Insulation materials rooms ("Clean rooms"): in the "clean rooms" are located the insulation materials octabins. From them, the granulate passes to the extruder, used for melting, filtering and transporting the XLPE through the extrusion head. They are characterized by a controlled environment; air is passed trough "ultra filters" for keeping the contaminant level low and maintaining overpressure with respect to outside air in order to avoid any ingress of external contaminant. Humidity is controlled in order to avoid moisture contamination of the pellets and also the temperature is controlled in order to avoid condensation as boxes are opened. For this reason, to avoid the problem of dirt and humidity in the insulation, that causes air bubble, lumps on screen or a mixture between cleaning compound and insulation compound, it's necessary that the rooms must be with closed and isolated doors, working filters and keep tidy from every powder or dirt come from outside. Another important thing to check inside this rooms is the extruders feeding pipes that must be cleaned outside of every powder or dirt, cleaned inside of every residual materials and not damage to avoid the penetration of materials.

After PD fault causes inspection, a corrective action plans was planned with intent to remove or, at least, reduce each critical factor of MV cables production. The objective was to schedule and implementall the corrective actions during the last three months of 2012, from October to December, for a more safe production of MV cables during 2013.

The action plan is shown below in Table 4. Each main PD fault causes has been planned a corrective actions specifying also the action responsibility and date or the period.An important thing to underline is that, for the responsibility, it has been followed a specific idea: do not overload the maintenance men work, but try to share this corrective maintenance job with the operators and create a good collaboration to simplify both labors.

FAILURE	CORRECTIVE ACTION	RESPONSIBILITY	DATE
Drums	1)Drums maintenance: to repair every damaged drum removing sharp edge and corrosions. 2) To make aware the forklif driver to a slower drum handling	1) EFKAVA (Maintenance men) 2) Production manager	1)Starting date: 10/11/2012
Rollers and caterpillars	Rollers and belts maintenance: to repair or replace every flawed component.	Maintenance	27-28/11/2012
Cooling and curing pipes	CCV-line maintenance: to check the pipes by a small camera, than to remove all dirt inside them with 800 bar water pression.	Maintenance and Delete (External company)	27/11/2012
Man power	To make aware all the operators about the problems and how to work better giving them accurated information.	Production manager and shift foreman	November
Clean rooms	1)To use the material octabins in a air conditioning room with a temperature around 20-25 C. 2) To clean or replace the feeding pipes if necessary. 3)To clean the floor and to replace every damage part of the feeding machine.	Operators	December
Pay off of jacketing line	1)To make aware the operators to a more carefull and slower drum and cable handling	Operators	December
	2) Jacketing line maintenance: to check rollers and caterpillars, to clean the floor and to eliminate all the sharp edges.	Operators	December

Table 4: Action plan schedule

Drums Maintenance: the drums condition was very bad and consequently it was one of the main causes of cable scratches. For this reason, first of all it has been very important to start the corrective actions from drums maintenance. The starting point has been to create a collaboration between production and maintenance workers and share this action between both to develop a faster and easier job; following this supposition, the "instruction for drums maintenance" have been formulated as illustrated in Table 5.

Instruction for drums maintenance	
The drums must be marked with three numbers (1,2,3) putting a paper with the number on the drum. Each number indicates the maintenance priority and the usage for production.	
Number	**Maintenance priority (Level of drum damage)**
1	Maximum priority/High damage, do NOT use in production.
2	Medium priority/Medium damage, use in production only if drums with number 3 are not available
3	Low priority/Low Damage, use in production only if drums with green paper are not available
Every damage on the drums must be painted in **red color** with a spray in order to make maintenance job easier. After maintenance each single drum will be marked with **green color** paper and will be available for production.	

Table 5: Instruction for drums maintenance

The drums maintenance cycle has four main steps:

1. the shift foremen have checked the drums, examining every damage and painting in red color with a spray in order to make the repair service easier; moreover they have marked the drums with three number (1,2,3), that represent the maintenance priority (as shown in Table 5), using a "red paper";
2. after check, the "free" drums, i.e. the drums not used in production, have been accumulated by forklift in a specific storage, close to reparation place, according to maintenance priority numbers (see Figure 18);
3. in third step, following the priority numbers, the maintenance men have started the reparations and fixing up of the drums damages (see Figure 19);

4. at the end of maintenance, the shift foremen have to confirmed the right reparation marking the drum with a green paper that represents the possibility to use this drum in production.

Figure 18: Drums storage according to maintenance priority number

Figure 19:Example of drum damage reparation

Another important thing to underline is that to avoid the drum damages reducing their main cause, i.e. a wrong handling by forklift, according with the production manager, it has been composed a "suggestions document" to give to the forklift driver, with intent to improve the drums handling.

Rollers and caterpillars maintenance: this has been the easier and faster action to make but, not for this reason, the lesser important. The job has taken only two days, 27-28 November 2012, and it has been done by maintenance men. They have checked all the damages on every production process line (insulation and jacketing lines) and consequently have repaired or replaced the rollers, the belts and small rollers of caterpillar which were damaged and not working.

Cooling and curing pipes maintenance: to execute CCV line cooling and curing pipes maintenance it has been necessary the help of an external qualified companywith the maintenance manager collaboration. The company has specialized equipment to check and clean very long pipes (around 70 meters).The pipe check is done using a robot camera (see Figure 20) that goes inside the pipe and, at same time, sends the images on a monitor realizing also a recording on a compact disk. Moreover, they clean the pipes with a water high-pressure method using a rotating machinery that removes dirt and by-product material from the pipe sides.

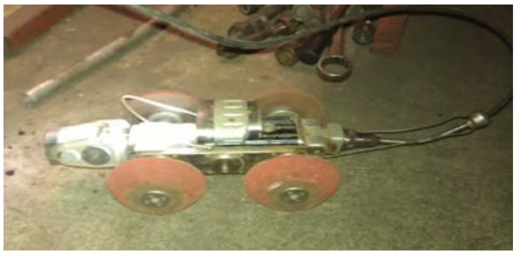

Figure 20: Robot used to check the insulation pipes

With this tool it has been possible to observe that inside the curing pipe were a lot of by-product material on the pipe sides (see Figure 21). This is very dangerous for the cables because it could be scratch the external semiconductive during the insulation process.For this reason, it has been necessary to clean the pipe with high-pressure method using a pressure of 800 bar and, for the accessible points, the maintenance men have removed the material by a manually operation.

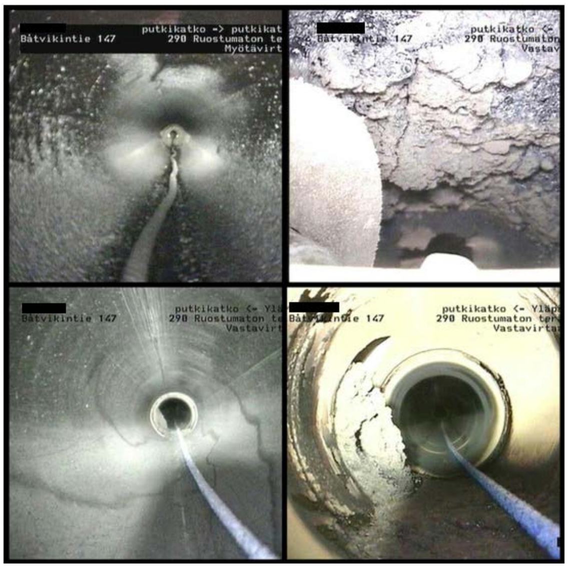

Figure 21: By-product material inside the curing pipe

Preventive actions: The last step for a good LRCDA implementation is the generation of preventive actions. Following identification of the problem causes for a particular causal factor, achievable recommendations for preventing its recurrence should be generated. After our studies, it's clear that the main PD phenomena causes comes from the insulation line and its process. For this reason, it has been developed an Autonomous Maintenance (AM) or routine maintenance performed by the insulation line operators. In this way, the line operators have received a training for their specific maintenance activities that typically are cleaning, inspection, minor adjustments and lubrication, so all this tasks have become operator's responsibility. With intent to implement an easier and faster preventive maintenance, a CCV line check sheet has been formulated.The operators have to fill in the check sheet marking OK or NOT-OK with an "X" each tools and machinery and it must be done every 2 weeks during a setup. After the compilation, they have to consign it to the shift foreman who has to contact the maintenance manager to repair the failures in case of damages or problems occurrence.

6 Results analysis

The expected results, in addition to a cost saving which is later illustrated, concern more aspects of Lean Enterprise such as: quality improvement, scraps reduction in terms of cable meters, WIP reduction that leads extra spooling reduction, extra forklift use to WIP handling reduction, fewer immobilized drums due to WIP and re-working reduction in terms of fewer PD test on the same piece, rework time saving, autonomous operator maintenance, a better coordination between maintenance and production, delivery delays elimination and consequently improvement of customer satisfaction.With intent to measure the project expected results in terms of cost saving in 2013, it has been estimated a PD rate indicator, which is a statistical measures that give an indication of output quality, in this case focused on PD faults in MV cables, during the past, present and future.

PD RATE INDICATOR	2011	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2012
PD / 100 Tons cables produced	0,79	1,50	0,41	0,25	1,42	0,88	1,19	0,57	1,04	1,11	1,29	0,52	-	0,89
YTD (PD/100 Tons produced)	-	1,50	0,79	0,60	0,76	0,80	0,88	0,86	0,89	0,91	0,95	0,89	0,89	0,89
Target 2013		0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	

Table 6: PD Rate Indicator and Target 2013

As shown in Table 6, the estimated average values for 2011 and 2012 are respectively of 0,79 and 0,89. Moreover it has been established a target to achieve in 2013. The PD Rate Indicator Target 2013 is to reach the average value of 0.40. This hypothesis comes from the assumption that the project has been focused on all the possible corrective actions with intent to reduce the mechanical damages, i.e. about 70% of total PD causes, and these actions have ended well, then it is reasonable to aspect that the quality indicator will improve, at least, of 50% and so from 0,89 (the average indicator value in 2012) to an average value in 2013 of 0,40 (see Figure 22).

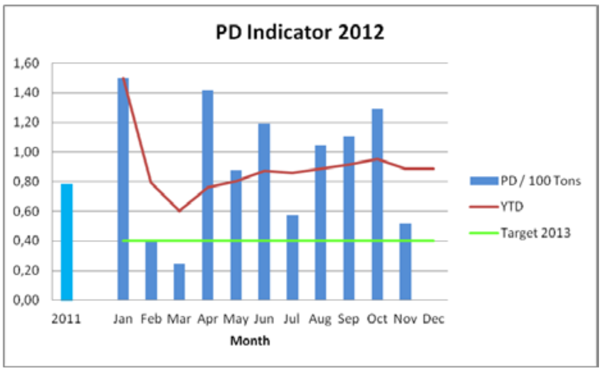

Figure 22: PD Rate Indicator graphic

The presumed improvement of PD Rate Indicator entails the PD faults number decrease and consequently a scraps and WIP reduction measured in terms of cost saving. As illustrated in detail in the Table 3, a cost/PD is estimated in €1492,5. Multiplying this value with the average PD rate indicator value (PD/100 tons) it is possible to estimated the PD costs (€/100tons). The results are shown in Table 7:

	2011	2012	2013
Cost/PD (€)	1492,5	1492,5	1492,5
PD/100 tons	0,79	0,89	0,4
PD costs (€/100 tons)	1179,075	1328,325	597

Table 7:PD costs (€/100 tons)

Consequently to LRCDA method implementation and the PD Rate Indicator improvement, the PD costs, calculated as €/100tons, will be cut drastically from 2012 to 2013. The PD costs reduction will generate an yearly cost saving in 2013 of €40.870,62. The details are illustrated in Table 8, where:

- MP (tons) = Yearly Master Production about MV cables tons;
- Cost/year (€)=
  MP(tons)/100×PD costs (€/100 tons)+Total cost of WIP
  where:
  Total costs of extra WIP = €1369,44;
- Cost saving (€) =
  Cost/Previous Year (€) – Cost/Actual Year (€).

	2011	2012	2013
MP (tons)	4325,9	5180	5154
Cost/year (€)	52375,05	73.009,44	32138,82
Cost saving (€)		-20.634,39	40.870,62

Table 8: Cost saving estimation

Finally, it is possible to observe that the cost due to PD fault should decrease from €73.009,44 in 2012 to €32.138,83 at the end of 2013 with an expected cost saving of about €40.870,62.

The first achieved results, relating to January and February 2013, are rather positive, since the PD rate indicator is decreased from 0,89 to 0,47, although the LRCDA model has been tested in a factory just for the first time and it has been introduced in the plant from few months and it requires more time to concepts and tasks assimilation by top management and employee. MV cables production and number of PD faults in January and February 2013 are shown in Table 9:

	2011	2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2013
MV (tons)	4325,9	5.180	380	480											860
YTD MV	-	-	380	860											860
Partial Discharge	34	46	2	2											4

Table 9: MV tons production and number of PD faults in 2013

According to MV production and PD faults, it is possible to observe that PD Rate indicator is following a descending trend (as shown in Table 10 and Figure 23) and we hope to go closer the predetermined Target 2013 of 0,40 at the end of the year.

QUALITY INDICATOR	2011	2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2013
PD / 100 Tons cables produced	0,79	0,89	0,53	0,42											0,47
YTD (PD/100 Tons produced)	-		0,53	0,47											-
Target 2013			0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	

Table 10: PD Rate Indicator 2013

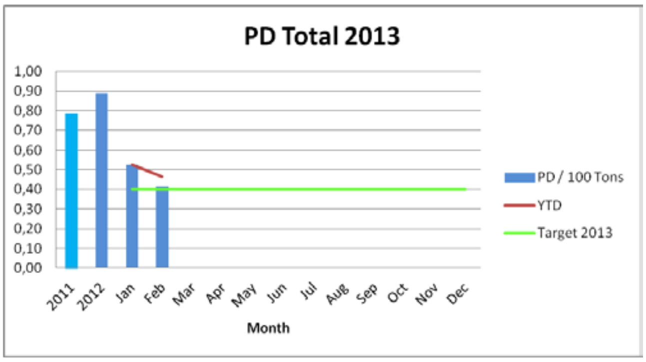

Figure 23: PD Rate Indicator 2013 trend

The achieved cost saving in 2013 (see Table 11) is quite good and satisfying, considering that it has been achieved a cost saving of€2956,78.

	January 2012	January 2013	February 2012	February 2013	YTD 2013
MP (MV cable)	267	379	488	480	
PD faults	4	2	2	2	
PD rate indicator	1,5	0,53	0,41	0,42	
PD unit cost (€)	1492,5	1492,5	1492,5	1492,5	
PD cost (€/100)	2238,75	791,02	611,92	626,85	
WIP Cost/month(€)	114,12	114,12	114,12	114,12	
Cost/month(€)	6091,58	3112,16	3100,36	3123	
Cost saving achieved (€)	/	2979,42	/	-22,64	2956,78

Table 11: YTD achieved cost saving 2013

Comparing expected cost saving with achieved cost saving (see Table 12), it is observed that achieved saving YTD are quite less than expected saving but in any case the first procedures model test provides good results in terms of cost saving and a better collaboration and synergy between production and maintenance.

	COST SAVING (€)	
	Expected	Achieved
January	3714,83	2979,42
February	238,36	-22,64
YTD	3943,19	2956,78

Table 12: Results analysis

7 Conclusions

The achieved results do hope for the future but it is important to underline that in order to provide a continuous improvement in terms of product quality and process flow, it is required that the planned actions and their standard procedures (drums, roller, caterpillar and process line maintenances) will be over and over again implemented, moreover related motivations and attentions will be constant also in future. Remembering that interventions done and planned concern and are focused on root causes of mechanical damages, if target will not reach at the end of 2013 and the partial discharge phenomena in MV cables will be still significance, then LRCDA method could be focused also on the second causes macrocategory, i.e. insulation process problems, with the intent to reduce and delete overall PD root causes.

The first results from this preliminary study and implementation seem to indicate that the expected benefits of this model correspond to real and practical benefits, in terms of production defect reduction and cost saving related. For sure the data achieved must be completed with more data coming from enough tests to validate the model in power cables field, its indicatorsand to understand how much LRCDA could be better than other similar procedures and how much LRCDA could give more than others and for how long LRCDA could be implemented and developed in a factory with a constant motivation by top management and employee. After the model validation in this specific sector, a future work could be to expand LRCDA and its main concepts in several branches, in order to make LRCDA a solid model to develop and perform in every field.

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