REDUCING ELECTRIC POWER LOSSES WITH THE IMPLEMENTATION OF LEAN SIX SIGMA CONCEPT

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***Abstract**:*
In the process of electric power distribution losses occur. One type of losses are technical losses that occur during transformation of electric power from the higher to the lower voltage levels in certain components of the electric power distribution system, or in the network of medium and low voltage. Another type of losses is commercial losses due to defective measuring devices, or due to customer abuse. Technical losses in well organized distribution systems are in the range from 5-6% from a total electric power transferred, while the commercial losses are below 0.5%. In distribution systems that are not well organized and where there is customer abuse total losses of electric power can surpass 20% from a total electric power transferred.
This work analyzes the process of electricity distribution from the place of transfer to the place of electricity delivery on a customer's measurement place. In the process, the flow of values through the process is being followed, and the opportunities for process improvement, i.e. loss reduction, are being sought. For this, Lean and Six Sigma tools are used in order to reduce losses, and the variation that occurs in the process of electric power distribution.

1. INTRODUCTION

The process of electric power distribution begins on the place of electric power transfer from transmission lines which are on 110 kV to the substations which transform electric power from 110 to 35 kV (or 20 kV depending on the substation). That electric power is then transmitted to the substations which transform electric power from 35 (20) kV to 10 kV, further, that energy transforms in substations from 10 kV to 0.4 kV, that is, to a voltage state in which it is being delivered to the end customer. On the place of electric power transfer (from a national organization for electric power transmission – in Serbia EMS – 'Elektro mreža Srbije' – Serbian Electric Network) measuring devices are read (usually on the first day of the month at 7:00 AM). Thus transferred power is transmitted by the system to substations and to the end customer where the consumption is read every month on certain days. The read information on the customer's consumption (higher and lower rate, active, reactive and apparent power) give the process output, that is the amount of electric power that is invoiced and charged from the customers (homestead or economic organization). The difference between the transferred amount of electric power at the place of input into a distribution system (the place of electric power transfer) and invoiced electricity distributed to the customers represents total losses of electric power in distribution systems.

According to official information brought out by the management of EPS (Elektro privreda Srbije - Electric Power Industry of Serbia), that company annually losses 61 million Euros because of the losses of electric power in distribution systems. One part of the losses is technical losses, which are, in well optimized distribution systems, in the range below 6%. Total losses of electric energy in EPS, depending on the economic association, are in the limits from 12% to 25%. If, from the total losses of electric power in EPS technical losses, estimated to 6% are deducted, it is arrived to the conclusion that commercial losses are in the range from 6% to 19%. It is obvious that the issue is great losses and unnecessary wasting of resources of EPS. For this reason, one of the priority projects on the level of EPS is precisely the project of reducing losses.

The losses of electric power vary from month to month, and from year to year regarding the values mentioned above. This means that in the process of electric power distribution there are general causes of the variation that lead to loss occurrence. In order to reduce, or, at the end, eliminate electric power losses, it is necessary to begin with a systematic treatment for 'curing' the process of electric power distribution, that is, all the processes where there are possibilities for electric energy losses to occur.

This work uses Lean Six Sigma concept for solving the problem of electric energy losses in the processes of electric energy distribution [Sto, 2007], [Kub, 2009]. With the implementation of DMAIC – Define Measure Analyze Improve Control methodology (standard methodology in Six Sigma concept) it is possible to define a problem, measure categories, characteristics that affect the losses, analyze the characteristics, and determine the roots of causes, implement corrective measures, and finally, control whether they give the expected effects. In this way the roots of the causes that lead to electric power losses will be removed.

On the other hand, Lean concept can enable simplification of the processes that affect the occurrence of electric power, and provide the flow of data and information without obstacles and broken connections.

Both Six Sigma and Lean concepts have been implemented in the realization of the project of electric power losses in an economic association within EPS. This work discusses the implemented concept and the results that can be achieved with the implementation of this process.

2. VALUE STREAMS IN THE PROCESS

The value stream mapping is a Lean method of process mapping for understanding the flow of activities' sequences and information used for the production, or service delivery. [Sto-1, 2007], [Sto-2, 2007]. Those who perform expert Lean work use value stream mapping to:

- Identify main sources of time that does not add value in the value stream;
- Predict a future state with less wasting;
- Identify the raw materials and energents used in the processes in relation to the necessary ones;
- Identify the pollution caused and ecological waste in the value stream;
- Develop and implement a plan for the future Lean activities.

Analyzing these flows in value streams can reveal, in the company, essential opportunities for reducing cost, improving ecological performances, and health and safety in electric power distribution. Dealing with ecological issues and the inclusion of the staff for ecology and employee health when future efforts for improvement are being planned in Lean value stream can also help the company fulfill the requirements of the supervisory institutions for minimizing the wasting and, avoid the need for costly repair.

The figure 1 shows the map of electric power flow from the place of transfer to the place of reading and charging the delivered electricity the assumption of technical losses is given. The assumption should only indicate the places where the losses of electric power occur in the technical part of the system. The economic association makes transfer of electric power from EMS on several transfer places. From that place to a customer's measurement place losses occur in the network of middle and low voltage (on the stream value diagram assumed values 1.4%, 1.2%, 1.1% and 0.8%). During transformation from voltage levels from 110 kV to 35 kV and 10 kV the assumed losses are 1.5%. During transformation from middle to low voltage level there are also electricity losses and they are estimated to 1.5%. The experts in distribution industries can precisely determine these values and affect them in various ways; for example, by optimizing distribution of load, by optimizing the place where lines with dual feed separate by network reconfiguration, and by regulating voltage. The loss that occurs at the customer's measurement place is a commercial loss which reaches values from 8 – 18% depending on the economic association, branch or business office. It is obvious that the losses are great, and their cost is 61 million Euros, as EPS reports.

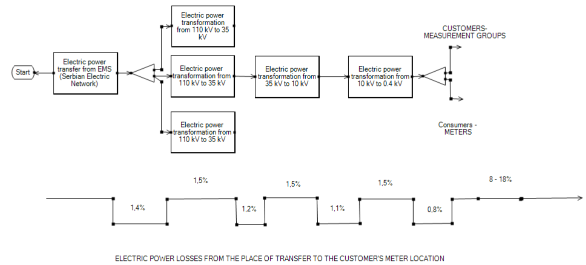

Figure 1- Electric power losses from the place of transfer to the customer's measuring place

3. THE PROCESSES THAT AFFECT ELECTRIC POWER LOSSES

The first step in the process of reducing commercial electric power losses in economic associations for electric power distribution is to identify the processes where there are causes leading to electric power loss. The processes are:

- The process of meter-reading
- The process of control preparation, control, and measurement place relocation
- The process of systematic meter replacement

In these three processes, which are justifiably believed to generate the greatest number of causes that lead do electricity loss at the customer's measurement place, great number of data is collected. These data represent a true 'gold mine' from which necessary information can be extracted, and decisions can be made on corrective measures that should lead to reducing, and finally, eliminating all unnecessary electric power losses in economic associations for electric power.

For a better understanding of where the inconsistencies that lead to electric power losses occur, it is necessary to record maps of these three processes. The maps of these processes are shown in figures 2, 3, and 4.

To the map of the process of meter-reading, the characteristics measured in the process were added, and in this way a map of the process of measurement was also created. All inconsistencies that occur in certain activities, that is, the inconsistencies registered by the reader during a measurement place reading, were identified on this map. In the П03.3.2 activity each of the 20 pre-defined inconsistencies, objections that affect the commercial electric power loss was collected.

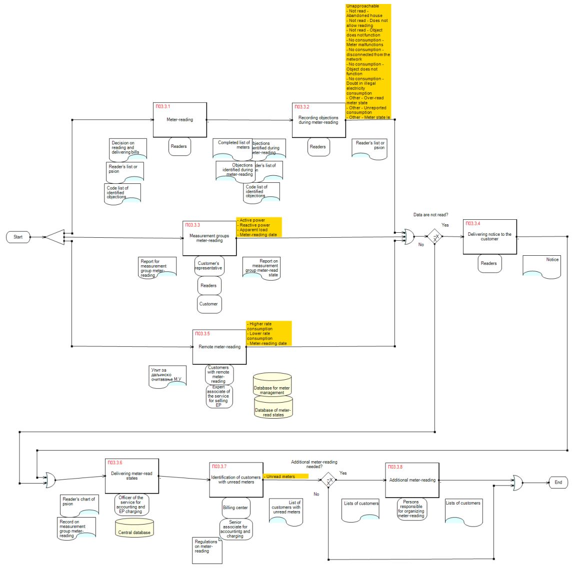

Figure 2- The map of the process of meter-reading

The process of meter-reading was analyzed, and it was confirmed that there is the Π03.3.6 activity, issuing listings to the proper authorities. This actually means that a certain referee, from a parent database, lists the entered data on 20 objections (inconsistencies) that the readers identified during the reading, and forwards these listings to a proper authority. Here, the problem was identified. The procedure was not defined. Further, it was not defined who was responsible, when and how proper authorities were informed, and which these authorities were. It has also been established that there was no evidence whether there would be feedback from the 'proper authority', when and in what form. This was the reason for reexamining whether this activity belongs to the meter-reading process, or to some other process. The participants in the Brainstorming Session did not deny that the entered data on objections (inconsistencies) should set in motion a certain following action, but they were not sure whether the existing way of the process flow guarantees the effects of such actions. It will be shown later that the activity was removed from the process of meter-reading, and that a new process that collects and analyzes all data that affect electric power loss was designed.

The same approach was implemented concerning the **Process of Control Preparation, Control, and Measurement Place Relocation** and the **Process of Systematic Meter Replacement**. Measurement maps in these processes are not shown because of the scope of the work.

In the *Process of Control Preparation, Control, and Measurement Place Relocation* as-it-is there is a sub process called *Control Processing*. This sub process is realized by a higher officer and the officer for measurement place control. They are experts for preparation and measurement place control. They have seen that there is a need for collecting and processing data that are collected by an installation team who control measurement places. For this reason, they introduced several activities related to documentation review and extracting data. In this way, their focus was shifted from the expert part of the work to the administration part. A special problem was that their activities were not connected with the activities in the process of meter-reading, and data were not stored in the parent database.

The team that worked on the project for reducing losses with the implementation Lean Six Sigma concept observed that certain activities did not belong to the described process. This led to redesigning Control Processing (activities marked in red on the figure 3). The redesigned activities and with new tasks were transferred to a newly designed process, *The Process of Reducing Electric Power Losses*.

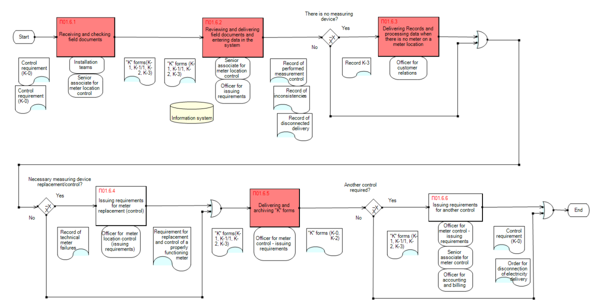

Figure 3- Redesigned *Control Processing* sub process

The Process of Systematic Meter Replacement as-it-is was analyzed in the same way, and redesigned into the process as-it–should-be.

The performed analyzes of the existing processes that affect the electric power loss indicated that the processes were not interrelated and that they did not share data and information that were relevant for reducing electric power losses. What is particularly important, and what the existing processes did not have, is data analysis of these processes using quality methods and tools. It is known that without data analysis using quality methods and tools, it is not possible to improve a process, which means that it cannot be expected that a reduction of electric power will occur. These losses will only vary within certain limits on a high level.

The solution to the existing problem of EPS, and economic associations for electric power distribution can be found in designing a new process that would connect the existing processes, and introduce the activities of data analysis and determining corrective actions according to the information obtained in the analyses. Such newly designed process is shown in the figure 4. This process can be seen as a 'central circular subway line that connects all other subway lines'. In the process management language, it means that the process of reducing electric power losses connects all three existing processes that affect the electric power losses. This process (picture 5):

- Collects all relevant data and documents that occur in the three processes;
- Processes and analyzes data using quality tools and methods;
- Separates the vital minority of significant categories that leads to loss;
- Determines the roots of causes that lead to losses;
- Defines corrective measures
- Forwards corrective measures to appropriate services that should realize them;
- Collects feedback from the authorities;
- Analyzes the effectiveness of measures taken, and, if needed, defines the effectiveness of an additional corrective measure;
- Prepares reports for the proper authorities and monitors trends of electric power losses.

On the process map shown in the figure 5, it can be seen in which activity data and documents are taken from the three processes, and in which activities the information are delivered about the required corrective measures that should be undertaken by the proper authorities. This exchange of data and information is uniquely defined; from which activity of one process to which activity of another process.

In this way recorded and redesigned existing processes, and the new designed process enable for the same to be documented. This means that manuals about processes (now there are 4 processes that affect the electric power loss), procedures, work instructions, forms, and check lists for each activity (where needed) have been created. Since the process has been redesigned, all employees who realize certain activities in these processes have passed training programs for introducing with the new processes and documentation they need in order to perform their activities for the first time without making errors. In addition to introducing with the documentation where it is described how to perform activities and in what order, work instructions and check lists have also been used for practical training which took place in the Training Cabinets that all branches of the economic association have.

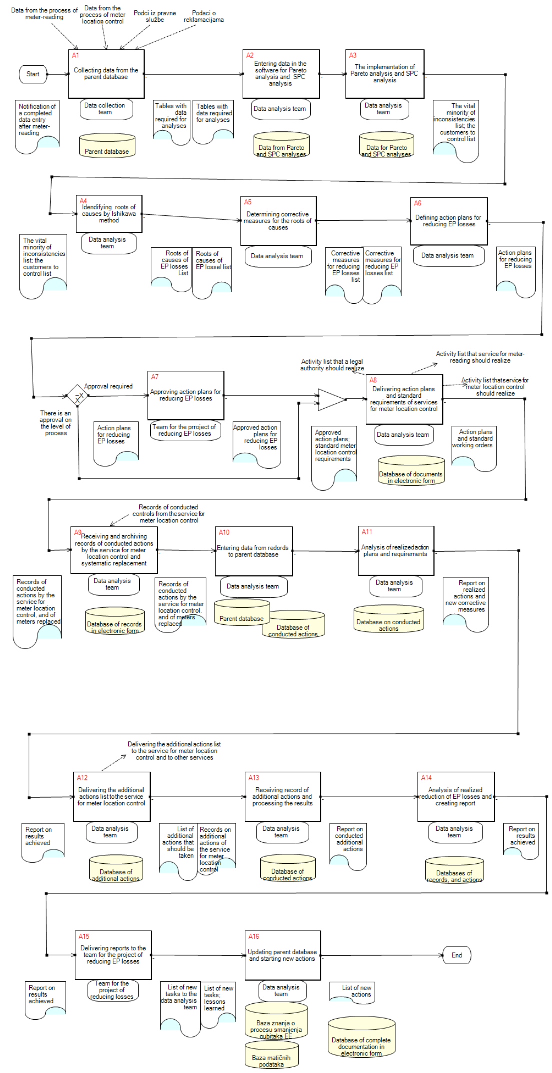

Figure 4- The process of reducing electric power losses

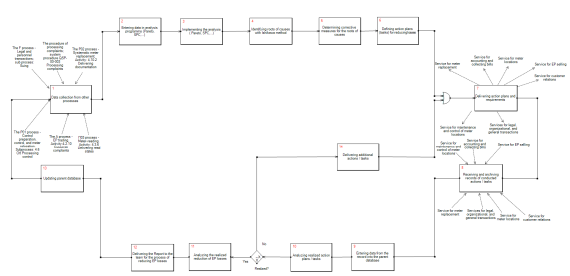

Figure 5- The process of reducing electric power losses, and connections with other processes

In the cabinets for practical training all types of measurement places and meters were placed, so that the employees could, in real conditions, acquire skills they need for performing their tasks. All employees who participate in the activities where there is a possibility for the electric power losses to occur have passed the training. This means that all readers, all members of installation teams, and all other qualified personnel that in any way participate in these processes have passed the training. After completing the training, and passing the test (practical and theoretical part), the trainees were given certificates that they are competent to perform activities in the processes that affect the electric power loss. It is planned to check the competency of all employees who were given certificates every 6 months.

4. DATA ANALYSIS USING QUALITY METHODS AND TOOLS

In the process of reducing electric power losses there are activities by which data from other processes are first collected, and then analyzed using quality methods and tools [Sto,2007], [Wes,2009]. The first step in analyzing the losses is to determine which 20% of substation areas participate in 80% of electricity losses. For this, it is necessary to measure, on the output place of every substation area, the amount of electricity delivered to the customers connected to that substation. From the parent database, the data on total invoiced amount of electricity to the customers connected to a certain substation can be obtained. The difference between the monthly amount of electricity output from the substation, and the invoiced amount of electricity to the customers who spent that electricity makes it possible to calculate the percentage of electricity losses in the substation for a certain month. Thus, it is in this vital minority of 20% substations that the possibilities for reducing electricity loss of 80% should be looked for.

The economic associations for distribution of electric power plan to install measuring devices on outputs of substations. As a starting point, the areas where there is a reasonable doubt that great electric power losses occur were chosen (e.g. city areas without central heating). Only when a greater number of substations in one area is provided with the possibility to measure the monthly amount of electricity at outputs, and compare those data with the electricity invoiced to the customers Pareto analysis can be implemented. One such analysis with the assumed data is shown in the figure 6.

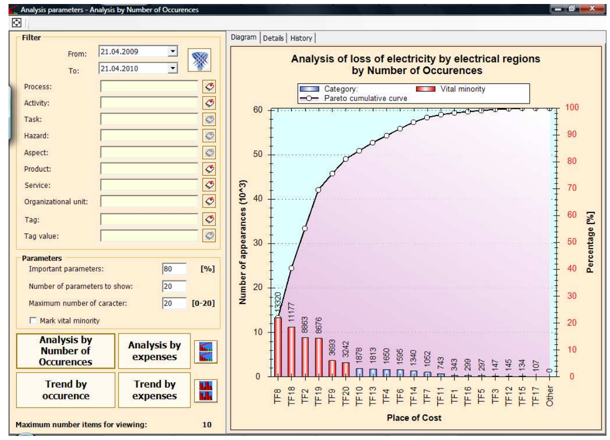

Figure 6 - The analysis of electricity loss by substation areas

On the Pareto diagram it can be seen that it is possible to extract the 20% of substation areas (TF8, TF18, TF2, TF19 and TF20) where 80% of losses occur. These substation areas should be in the focus of the efforts to reduce electricity losses. It would be wrong to focus on the 80% of substations that make 20% of electricity losses.

The next step is to analyze the inconsistencies that occur in the 20% of substation areas identified in the first analysis. Since in the period of realization of the project the data for Pareto analysis of the losses by substation areas were not available, the analysis of objections, inconsistencies, which were collected in the process of meter-reading, was begun (figure 2). On the figure 7, the analysis of objections identified during meter-reading by the number of occurrences in one branch of an economic association for electric power distribution for the time period from August 2009 to January 2010.

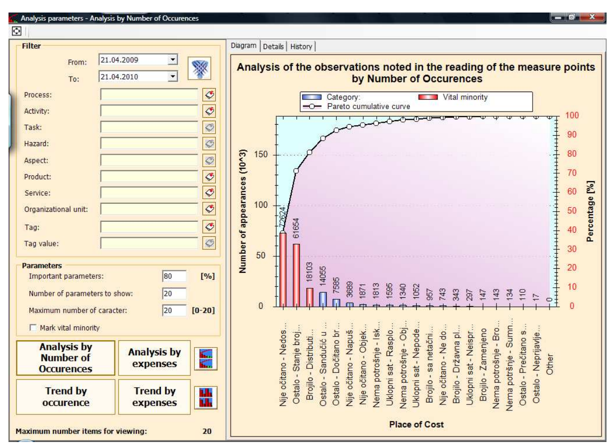

Figure 7 The analysis of objections identified during meter-reading by the number of occurrences

On the Pareto diagram it can be clearly seen that 3 out of 20 objections, inconsistencies, make the vital minority, and that they occur in 80% of cases. These objections, inconsistencies, have the greatest effect on the electricity loss. The good news is that the focus should be on identifying the roots of causes that lead to the occurrence of these objections, inconsistencies, and to take up corrective measures that will reduce or eliminate them. By removing the inconsistencies the electricity losses will be reduced. During the monitoring of these data in the following period some other inconsistencies will appear as a vital minority. For them, corrective measures will also be defined and after implementing the same, their causes will also be removed. The procedure is continued with the rest of inconsistencies until it is arrived to the status where there are no inconsistencies, that is, until excellence is achieved.

Another analysis that can identify a doubt that illegal abstraction of electricity occurs is a statistical control of the parameters of electricity distribution. To achieve this, it is best to monitor the consumption of one customer (higher rate, lower rate, total consumption) for a longer period (best from the moment of connecting to the electric power system). For monitoring electricity expenditure for one customer, it is best to use individual control chart with moving range [Whe, 1992]. The figure 8 shows individual control chart with moving range for one customer's consumption during the summer period for a five-year-period.

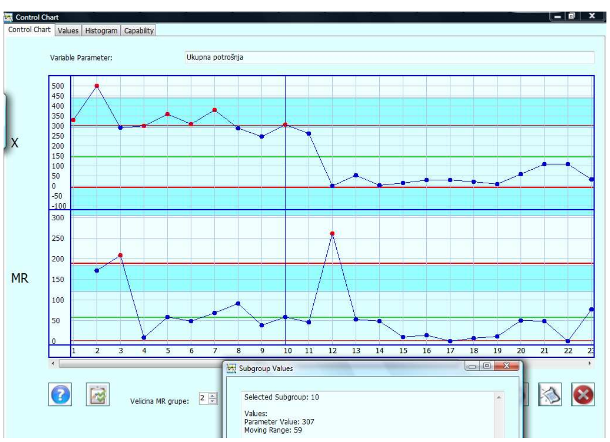

Figure 8 Individual control chart of one customer's electricity consumption in the summer period

On the individual control chart with moving range for total electricity consumption it can be seen that the customer's consumption in the summer period from July 2006 (point 10 on the control chart) is more than 300 kWh. From September 2006 there is a sudden drop in electricity consumption and the consumption decreases for the summer period to the values of about 50 kWh (see the right part of the control chart).

If summer and winter consumption are put together, and if consumption is monitored during a five-year-period, individual control chart with moving range is obtained, as shown in figure 9. This control chart has 60 data. It is shown in two parts. It can be seen that from the end of winter season in 2005 there is a sudden drop in electricity consumption which stays on a much lower level during the next 4 years, in contrast to the middle monthly consumption (282 kWh).

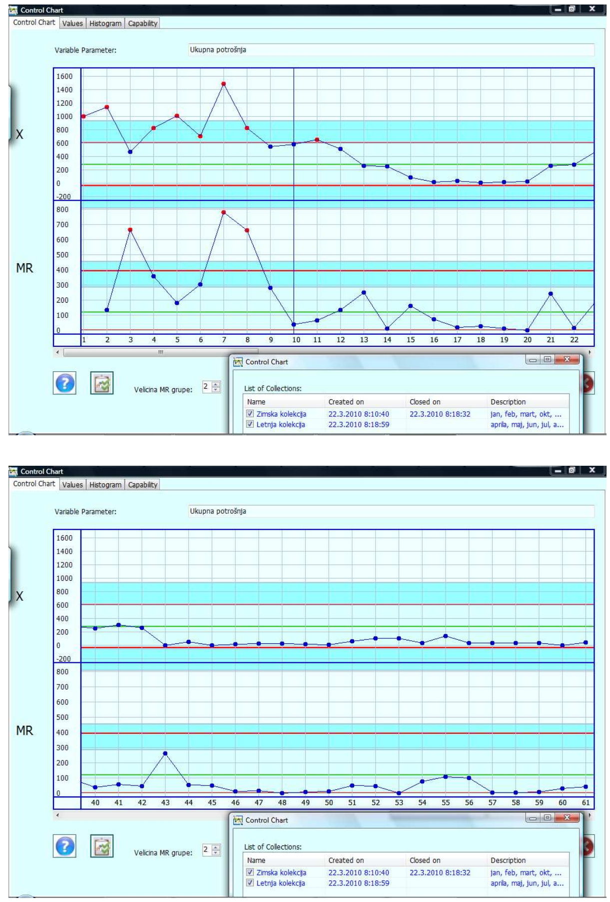

Figure 9 Individual control chart with moving range for a five-year-period consumption

Apart from the analysis of total consumption on the individual control chart with moving range, the consumption in the higher and in the lower rate can be also analyzed. These analyses are not shown because of the scope of the work.

This example clearly illustrates the ability of an individual control chart with moving range to determine whether there is a 'virus' in the process of electricity consumption that leads to a drastic drop in electricity consumption, or whether the customer started consuming electricity a few times less on a monthly level. The measuring place control can give an answer to that question.

In the same way, all customers connected to a substation extracted as a vital minority where 80% of losses occur can be monitored. Individual control charts of electricity consumption for customers of that substation area can determine more precisely who these

’suspicious’ customers are. In this way the number of necessary controls will also be reduced, and the embarrassing situation of doubting conscientious customers will be avoided as well.

The data on electricity consumption for each customer exists in the parent database. All that should be done is to create an interface among the existing data and the software for processing these data via the control chart, as it was done in the given example. The data from the parent database were transferred to the SPC .Net program developed by CIM Group d.o.o. company.

After the vital minority of inconsistencies had been identified, or after the customers suspected of illegal electricity consumption, the following step was to determine the roots of causes, and to define corrective measures. For this purpose Ishikawa diagram is used. Without getting into a detailed explanation, Ishikawa diagram for the electricity loss consequence is shown in figure 10.

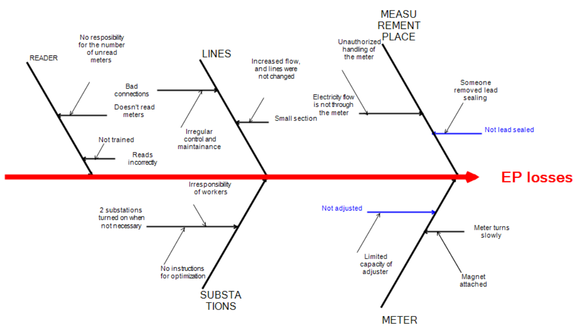

Figure 10 Ishikawa diagram for electricity losses

This Ishikawa diagram is on a global level, that is, the main categories that influence electricity loss have been determined. In the same way Ishikawa analyses that lead to electricity losses are created. All this was done in the process of reducing electric power losses realized by CIM Group d.o.o. in co-operation with associates of an economic association for electric power distribution. However, the scope of the work does not allow for everything achieved to be shown.

5. CONCLUSION

The process of electric power distribution as-it-is has a great number of possibilities for losses to occur. This process contains general causes of the variation that lead to electric power losses. General causes of the variation mean that they are inherent in the process itself. In order to improve the process, it is not enough only to remove specific causes of the variation (consequence of employees’ errors), but also the process itself should be re-examined and redesigned. The analyses conducted during the realization of the project of reducing electric power losses in an economic association showed that it is necessary to redesign the existing processes and also to introduce a new process. The new process connected the existing processes, ensured centralized collection and analysis of data. It also ensured identifying roots and defining corrective measures. Monitoring of the realization of the measures taken enabled for their effectiveness and efficiency to be tracked. This is the way that provides the possibility for reducing electric power losses to the level of the best organized distribution companies in the world.

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