DAILY FLUCTUATIONS OF ELECTRIC RELIABILITY INDICES

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ABSTRACT

The relationship between reliability and daily load curve is presented in CIRED 2009 paper. The beginning moment of unplanned (forced) interruption occurs stochastically. Also, reliability has dynamic (fluctuating) nature during daily hours. For observing this phenomenon additional indicators like three-hourly (3-h) SAIFI and SAIDI where used. Now, input data have been collected for three years from real network and the results confirm the first assumptions. 3-h SAIFI is giving strong relationship between reliability and load variation and 3-h SAIDI value is correlated with heaviness of interruption, maintenance controlling and development policies. It became obvious that probability of interruption with more difficult consequences is higher within heavily loaded network than during light load regimes. At least, the 3-h CAIDI was and could be useful for this research too.

Knowledge on daily fluctuation of electric distribution reliability can have positive impact on maintenance strategy, distribution network development and power system control.

This paper presents the analysis of reliability value fluctuations during the day using real three years data set taken out from the real power network, with the aim to help to improve reliability indices and final customer satisfaction.

INTRODUCTION

Reliability is defined as power system ability to insure adequate electricity delivery. There are many different reliability indices used to measure and compare system reliability. Almost all reliability indices are used for given timeframe, usually for one year time horizon. These values are taken as constant values that present or predict system reliability in given timeframe. Within this paper reliability is analyzed in shorter, daily time domain. Knowing daily reliability indices fluctuations one can actively and more efficiently impact on system reliability.

Power supply interruption, as defined by IEEE Std 1366-2003 [2], is interruption of one or more customers. Beginning moment of forced interruption is of stochastic nature. So, the relationship between interruption itself and its beginning moment needs to be clarified [1]. Although beginning moment is related to daily load curve and customers' habits, it is not adequate to observe only direct relationship between interruption and its beginning moment since each interruption has its specific, different importance for given power system area. On the other hand, reliability indices, such as SAIFI and SAIDI, by definition assume specific importance of given interruption in the system. Planned interruptions usually appear during working hours since it mostly related to system maintenance and construction. Accordingly, planned interruptions are not relevant for this kind of research.

For the purpose of this paper yearly interruption data sets for 2007, 2008 and 2009 are used, as well as average daily load curve for Croatian power system, distribution area of Elektrodalmacija Split which supplies around 270000 customers with its peak load of 500 MVA.

CHOOSING RELIABILITY INDICES FOR DAILY OBSERVING

One of the classic reliability definitions is: "Reliability is probability that element or system will operate adequately in given time and operating conditions". It is well known that reliability is changing, especially due to ageing, but it is always observed through longer period of time [7].

Practically all reliability indices are only of static (constant) nature for given time domain. But, using different indices in this paper, such as **SAIFI** (1), **SAIDI** (2) i **CAIDI** (3), daily reliability fluctuations will be analyzed with refer to the daily load curve.

$$\text{SAIFI} = \frac{\sum \text{Total Number of Customers Interrupted}}{\text{Total Number of Customers Served}} \quad (1)$$

$$\text{SAIDI} = \frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customers Served}} \quad (2)$$

$$\text{CAIDI} = \frac{\sum \text{Customer Interruption Duration}}{\text{Total Number of Customers Interrupted}} \quad (3)$$

or

$$\text{CAIDI} = \frac{\text{SAIDI}}{\text{SAIFI}} \quad (4)$$

For monitoring the movement of reliability throughout the day it is necessary to analyze relationship between interruptions itself, interruption beginning moment and daily load curve.
Different interruptions cause different consequences, so it is not appropriate simply to compare interruptions and its starting moments. I.e. interruption that caused power supply outage of several households is not comparable to the one that hits 5000 households. Also, the interruption that lasted for 5 minutes is not of the same importance to the one that lasted 2 hours. Number of disconnected customers should be related to the total number of customers. So, there are three main aspects to clarify: how many customers are suffering from the power outage; how many customers there are in total and how long the interruption lasted. Similarly, if the system is analyzed through the system load, it would be of importance to know the interrupted load as well as total system load.

For this purpose it is suitable to use reliability indicators such as SAIFI and SAIDI, and the impact of each interruption to the SAIFI and SAIDI values. International working group CIGRE/CIRED (common working group C4.07) has come out with suggestion to use IEEE indicators (IEEE Std 1366-2003) since there is no existing adequate IEC standard [3]. The most commonly used indicators are SAIFI, SAIDI and CAIDI.

CAIDI (Customer Average Interruption Duration Index), is defined using SAIFI and SAIDI, as it is shown in (4), and it can also be interesting for this kind of research. CAIDI gives average value per customer influenced by the interruption, and not for system as a whole.

While interpreting these indicators it is important to keep in mind that they refer to average values of all customers. In other words, these indicators for one customer can be significantly different that the average values.

Adapted indicators

SAIFI, SAIDI and CAIDI indicators will be analyzed on the daily horizon using principle of each interruption contribution to the total value of each indicator. These contributions are to be sorted by each interruptions beginning moment.

In this paper **three hourly indices** are used for every three-hour during the day (8 values) because better relationship can be obtained by observing three-hour timeframes of daily load curve and respecting indicators values than hourly values [1]. In this way local extremes are avoided.

Three-hour SAIFI is defined as sum of SAIFI values of all interruptions that started in given three-hour timeframe:

$$SAIFI_{3\text{-hour}} = \sum_{k=1}^{m} SAIFI_k \quad (5)$$

where:

- k - interruption event that started in given three-hour timeframe
- m - number of interruptions that started in given three-hour timeframe
- $SAIFI_k$ - SAIFI value of interruption that started in given three-hour timeframe

In the same way**, three-hour SAIDI**, and **three-hour CAIDI** are:

$$SAIDI_{3\text{-hour}} = \sum_{k=1}^{m} SAIDI_k \quad (6)$$

$$CAIDI_{3\text{-hour}} = \sum_{k=1}^{m} CAIDI_k \quad (7)$$

Input data set

Within the area of Elektrodalmacija in three years (for 2007., 2008. and 2009.) was registered more than 10000 interruptions collected by information system made for this purposes. A few hundred records are taken out from that since DSO was not responsible for these interruptions (force majeure, supplier's request for interruption, third party activities, faults at remote third subjects...) or since the interruptions were extremely difficult (MED) according to [2]. Since that planned interruptions are not interesting for this analyze only 3000 forced interruptions are taken into account (about 1000 per year). For Elektrodalmacija Split the average daily load curve (average of 365 days in 2007 and average of three years) are used too.

It is important to follow and check other files as well, in order to avoid wrong records that can significantly impact final study results (i.e. significant deviation of interruption duration or number of interrupted customers).

STUDY RESULTS

First year results

Three hour values of $SAIFI_{3\text{-h}}$ i $SAIDI_{3\text{-h}}$ for forced interruptions, as well as average daily load curve for 2007 are shown on Figures 1 and 2.

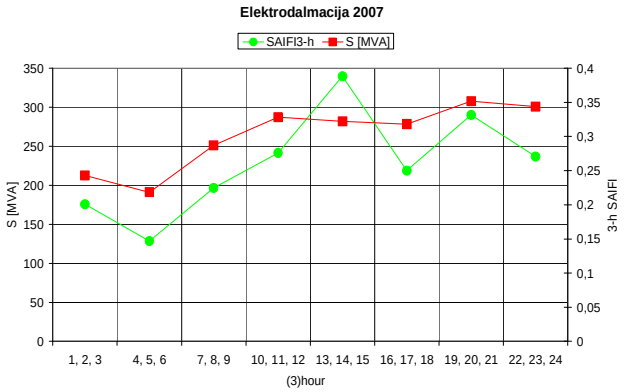

Figure 1. Three-hour values of daily load curve (S) and SAIFI for forced outages in 2007

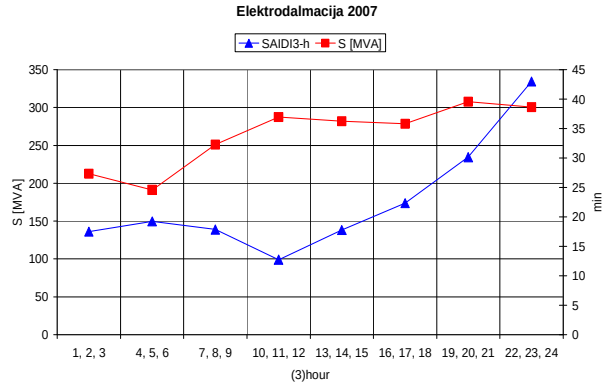

Figure 2. Three-hour values of daily load curve (S) and SAIDI for forced outages in 2007

Obviously there is a certain relationship between reliability indices and daily load curve. But, it is different for three-hour SAIFI then for three-hour SAIDI, as shown in [1].

Figure 1 shows that it is more likely to have forced outages with more difficult consequences during heavily loaded power system regimes than during lightly loaded regimes and vice versa. It is clear that the hourly SAIFI curve is well followed and correlated to daily load curve, with the exception of time slot in between 13:00 h and 15:00 h when obviously some difficult outages happened (it could have happened any time). This correlation would be stronger if longer time horizon is taken into analysis (i.e. few years).

It is interesting to compare the results given in Figure 1 to the one given in Figure 2. Interruptions that happened in between 13:00 h and 15:00 h and increased SAIFI values obviously lasted shortly and did not significantly influenced SAIDI values.

As given in the Figure 2 interruptions that happened out of working hours are of longer duration. That is obviously directly connected to organization and availability of emergency staff within the company. From the other side, three-hourly SAIDI values show that interruptions that happened within working hours are lasting shorter and are having less difficult consequences.

Three year results

It is expected that taking into account longer timeframe (larger data set) would assume "stronger" relationships. Accordingly, data sets for 2008 and 2009 (in total 3000 values on forced outages) are also analyzed. It is correlated to the average daily load curves of 2007, 2008 and 2009, as shown on the Figures 3 and 4.

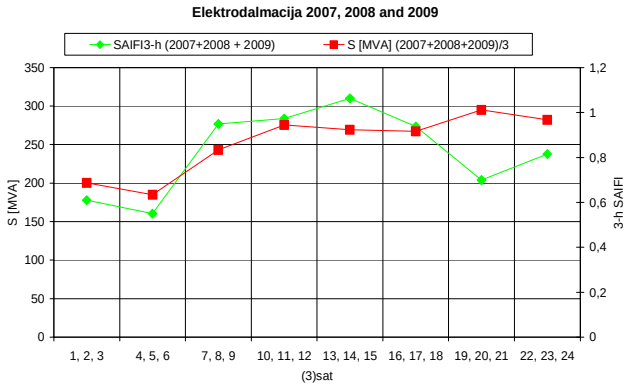

Figure 3. Three-hour values of daily load curve (S) and SAIFI for forced outages in 2007, 2008 and 2009

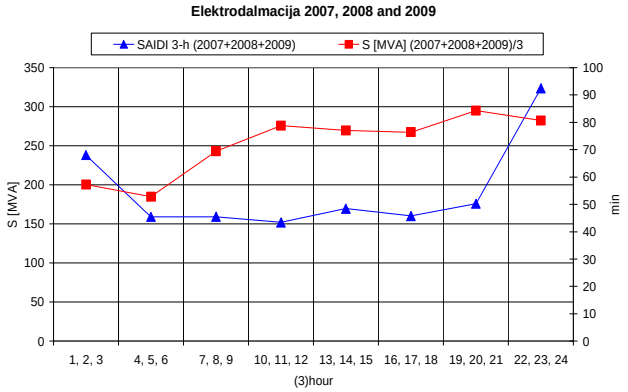

Figure 4. Three-hour values of daily load curve (S) and SAIDI for forced outages in 2007, 2008 and 2009

Three year results shown on Figure 3 and Figure 4 confirm first assumptions what was concluded for Figures 1 and 2.

Figure 3 proves that three-hour SAIFI values "follow" daily load curve. There is certain deviation due to relatively limited input data set. Figure 4 shows that the outages that started during the night are lasting longer than the other outages.

Three-hour CAIDI

Three-hour CAIDI analysis is also given here. The average values represent interrupted customers and not the system as a whole. The results are compared with three-hour SAIDI values, as shown on the Figure 5.

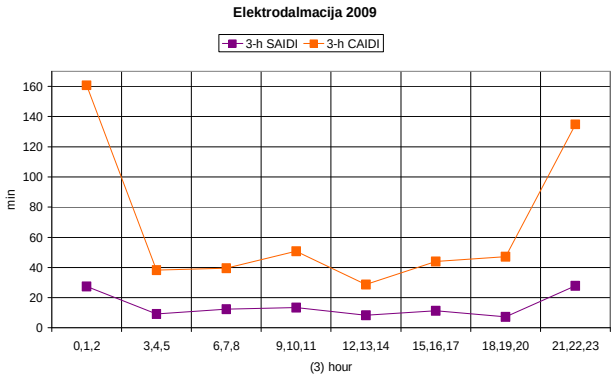

Figure 5. Three-hour values of CAIDI and SAIDI for forced outages in 2009

Clearly, the problem of longer duration of the night outages (outages that happen during the night regimes) is more significant if analyzed through three-hour CAIDI than three-hour SAIDI values. It proves that CAIDI values could also be interesting and indicative for this kind of analyses.

ADDITIONAL OBSERVATIONS

Based on the findings given in this paper it is easier to define the measures for improvement of reliability and customers' service quality. Some of these measures are given in [1].

Forced outage is of stochastic nature and it is expected to have certain deviations from the mean value. Indicators used in this paper are especially influenced on input data quality.

Finally, to calculate these indicators there is no need to collect additional input data, because this is just another way of observing the same data set. Only data for SAIFI and SAIDI calculations were used. With this method it is possible to calculate and compare historical results with future (foreseen) data of interruption registered in standard way.

By observing these curves, its shapes and results it is possible to evaluate the effect of some measures or policies. It is clarified that the respond on outage is not conformed during day hours. It was well known before, but this curves are direct result of that policy. Actually, now we can measure and compare that respond.

CONCLUSION

Reliability has dynamic (fluctuating) nature during daily hours. It is clarified that the respond on outage is not conformed during day hours.

After observing the three years data set it became obvious that probability of interruption with more difficult consequences is higher within heavily loaded network than during light load regimes. Also, the interruptions that happen during off-peak hours usually have longer duration, particularly during the nights. Activities with respect to load balancing and better maintenance organization especially out of working hours time could significantly improve reliability indices and consequently power quality and customer service. With this method it is possible to measure and compare the effect of those activities.

Knowledge on daily dynamic of electric distribution reliability can have positive impact on maintenance strategy, distribution network development and power system control.

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