THE RELATIONSHIP BETWEEN RELIABILITY INDICES AND DAILY LOAD CURVE

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ABSTRACT

Generally, the moment of interruption occurs stochastically. The most important task in respect of reliability is to find the relationship between interruption and its starting moment. Actually, there is a relationship between the moment of interruption beginning and the daily load curve. Interesting conclusions can be drawn by observing contribution of each interruption to the reliability indices (SAIFI, SAIDI) and by comparing it to daily load curve and moment of interruption beginning. Probability of interruption with more difficult consequences is higher within heavily loaded network than during light load regimes. Also, the interruptions that happen out of working hours usually have longer duration. Accordingly, it is possible to take some actions for improving reliability. This paper deals with the relationship between reliability indices and the daily load curve calculated on the real network.

INTRODUCTION

The main task of the power system is to insure adequate power supply to its customers with given quality and low costs. Power system ability to serve electricity to its final customers is usually referred as reliability.

According to IEEE Std 1366-2003 power supply interruption is supply abruption of one or more customers connected to the distribution system. Since power interruption is of stochastic nature, it is interesting to find out what is the relationship between interruption and its starting moment. Even though starting moment of interruption is related to daily load curve and customers' habits, observation of direct relationship between interruption and its starting moment is not sufficient due to different interruption consequences. On the other side, by definition power reliability indicators such as SAIFI and SAIDI are reflecting outage consequences. Planned interruptions usually occur during working hours and they are related to regular maintenance activities. Analysis of occurrence of unplanned interruptions within the load curve can result with improvements of reliability indicators and customer's service quality.
For that purpose real data set of whole year 2007 is used, along with outages and load curve of distribution area of Split (Elektrodalmacija) within Croatian Distribution System Operator.

RELIABILITY INDICES SAIFI AND SAIDI

Different interruptions cause different consequences. So it is not appropriate simply to compare interruptions and its starting moments since 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 (joint 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 [2]. The most commonly used indicators are SAIFI, SAIDI and CAIDI. 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. According to above mentioned standard [1] the following definitions are valid:

Interruption: the loss of service to one or more customers connected to the distribution portion of the electric power system. It is result of one or more components outages, depending on system configuration. Interruption can be classified as a part of momentary or sustained event.
Sustained (long) interruption: any interruption that lasts more than 3 minutes [3].
Planned interruption: a loss of electric power with a component deliberately taken out of service at a selected time, usually for the purposes of construction, preventive maintenance or repair.
Unplanned interruption: an interruption caused by an unplanned outage (i.e. fault).
System average interruption frequency index (SAIFI) indicates how often the average customer experiences a sustained interruption over a predefined period of time. This is given in (1) and (2):

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

or

$$SAIFI = \frac{\sum_i N_i}{N_T} = \frac{CI}{N_T} \quad (2)$$

System average interruption duration index (SAIDI) indicates the total duration of interruption for the average customer during a predefined period of time. It is commonly measured in customer minutes or customer hours of interruption. This is given in (3) and (4):

$$SAIDI = \frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customers Served}} \quad (3)$$

or

$$SAIDI = \frac{\sum_i r_i N_i}{N_T} = \frac{CMI}{N_T} \quad (4)$$

where:

- i - interruption event
- r_i - Restoration Time for each Interruption Event
- CI - Customer interrupted
- CMI - Customer Minutes Interrupted
- T - Total
- N_i - Number of Interrupted Customers for each Sustained Interruption event during Reporting Period
- N_T - Total Number of Customers Served for the Areas

These indices are actually measures of unreliability, as they increase when reliability becomes worse.

RELATIONSHIP BETWEEN LOAD AND RELIABILITY

The analysis of relationship between interruption and its starting moment can be further developed with inclusion of daily load curve. For this kind of analysis in this paper real yearly data set is taken from distribution area of Split (Elektrodalmacija) within Croatian Distribution System Operator (HEP ODS).

HEP ODS Elektrodalmacija Split

Distribution area of Split called Elektrodalmacija is geographically the largest distribution area within Croatia, covering 5030 km^2, with the second largest number of customers (250 000) and load level (peak load of 500 MVA; annual consumption of about 2300 GWh). For relevant data collection, recording and analysis HEP ODS is using software system called DISPO, that is developed in accordance to the norms IEEE Std 1366-2003 [1] and EN 50160 [3].

Data analysis

Within the area of Elektrodalmacija in 2007 DISPO registered more than 4300 interruptions. Around 300 samples 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 [1].

Remaining 4000 records were used for detailed analysis of its starting moment. In this paper SAIFI hourly values ($SAIFI_{hour}$) are introduced for every hour during the day (24 values). **Hourly SAIFI** presents sum of contribution of each interruption started in given hour on total SAIFI value:

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

where:

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

In other words, it is sum of SAIFI values of each interruption that started in given timeframe.

Hourly SAIFI values were calculated and given graphically on the Figure 1. Diagram given in Figure 1 is compared to average daily load curve in 2007 given on Figure 2.

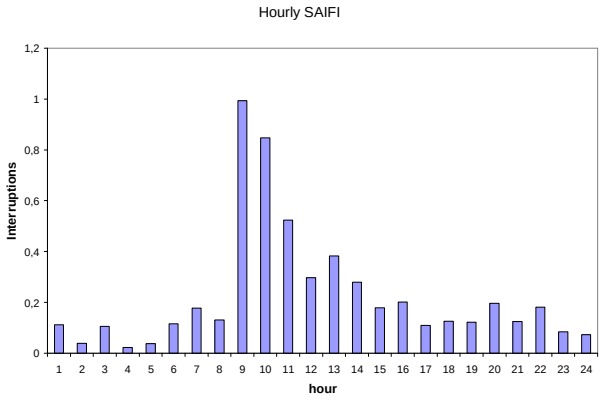

Figure 1 Hourly SAIFI of Elektrodalmacija in 2007 – all interruptions

Obviously, in between 9:00 h and 14:00 h around 60% of total interruptions started. It can be related to the fact that within this timeframe large number of planned interruptions occurs.

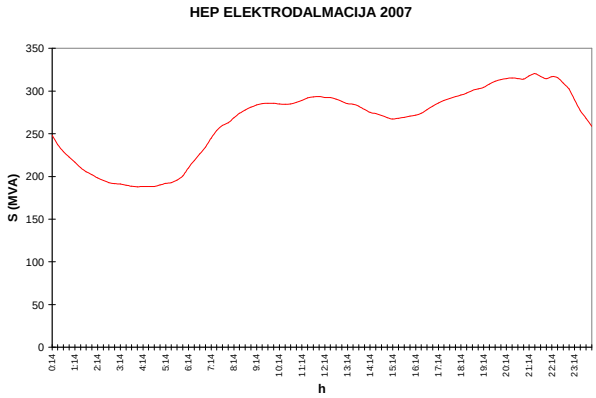

Figure 2 Average 15-minute daily load curve of Elektrodalmacija in 2007

Comparing Figure 1 and Figure 2 it is obvious that there is no strong correlation between SAIFI values and daily load curve. That's why only unplanned interruptions are taken into account (1300 out of total 4000). Hourly SAIFI values for unplanned interruptions are given on the Figure 3.

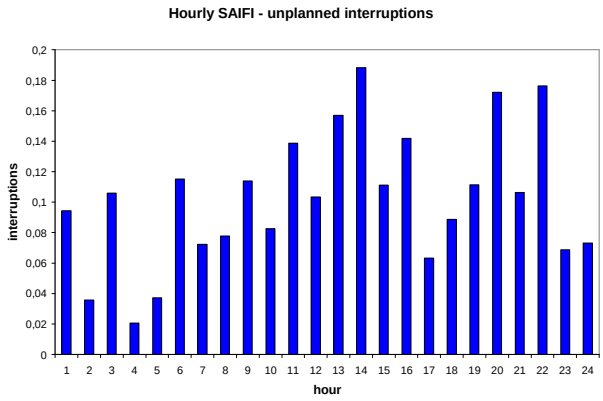

Figure 3 Hourly SAIFI for unplanned interruptions of Elektrodalmacija in 2007

Similarly to above mentioned hourly SAIFI, **hourly SAIDI** represents sum of contribution of each interruption started in given hour on total SAIDI value. In other words, it is sum of SAIDI values of each interruption that started in given timeframe.

Hourly SAIDI values for unplanned interruptions in the area of Elektrodalmacija in 2007 are given in Figure 4.

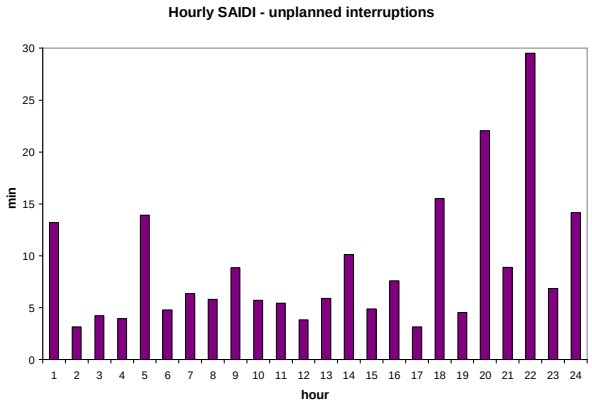

Figure 4 Hourly SAIDI for unplanned interruptions - Elektrodalmacija in 2007

Comparison of three-hour values

Obviously, there is certain correlation between indicators and daily load curve, but it is different for SAIDI and SAIFI values. More precise relationship can be obtained by observing three-hour timeframes of daily load curve and respecting indicators values. In this way local extremes are avoided. **Three-hour SAIFI (SAIDI)** is defined as sum of SAIFI (SAIDI) values of all interruptions that started in given three-hour timeframe:

$$SAIFI_{3\text{-hour}} = \sum_{k=1}^{m} SAIFI_k \qquad (6)$$

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

Three-hour values are given on the Figures 5 and 6.

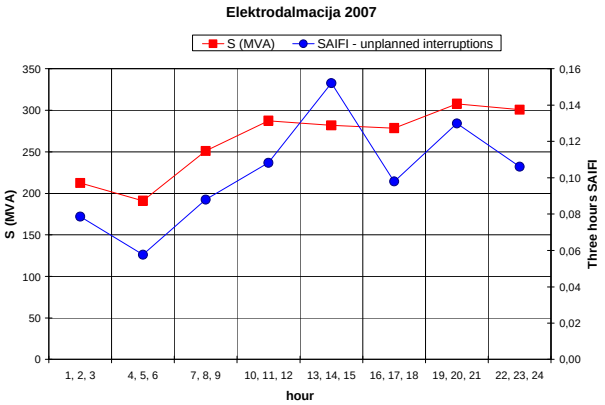

Figure 5 Three-hour values of daily load curve (S) and SAIFI for unplanned interruptions

Figure 5 shows that it is more likely to have unplanned interruptions with more difficult consequences during heavily loaded power system and vice versa. It is clear that the hourly SAIFI curve is well followed and correlated to daily load curve, with the exception of in between 13:00 h and 15:00 h when obviously some difficult interruption happened (it could happen any time). If longer time horizon is taken into analysis (i.e. few years) this correlation would be better.
It is interesting to compare results from Figure 5 to the one given in Figure 6. 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.

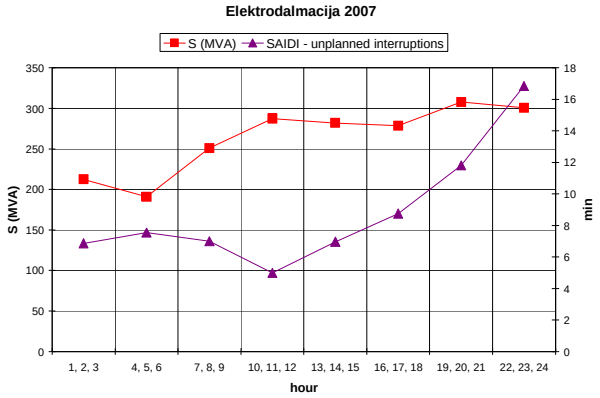

Figure 6 Three-hour values of daily load curve (S) and SAIDI for unplanned interruptions

As given on the Figure 6 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, hourly and three-hourly SAIDI values show that interruptions that happened within working hours are lasting shorter and are having less difficult consequences.

MEASURE FOR RELIABILITY IMPROVEMENTS

Constant changes of power system load are having significant influence on power system reliability. Higher load is accelerating equipment ageing [5]. Due to load changes mutual capacitance between different circuits and networks are changing as well. Distribution networks and its circuits are usually mutually connected through switched out switching equipment. If switching is allowed, there could be different possibilities of alternative power supply. In that case, power supply is determined by exchange capacity between two neighboring power circuits (networks). Alternative supply is usually limited during heavily system load regimes and much weaker that in the regimes with lighter loads. Obviously that with adequate network investments and balanced network load outage probability can be significantly decreased (increased reliability).
Depending on network topology and capacity, load changes can have measurable influence on system reliability.
Tariff system that is stimulating load balancing and load management can also have positive impact on system reliability.
Better organization of emergency staff out of working hours can also decrease fault duration and its consequences.
Remote control system and other types of automatics can decrease fault probability and its duration and consequences.
These are just some of possible activities that could be taken in order to improve system reliability with respect of load curve specifics.

CONCLUSION

In this paper the relationship between reliability indices and daily load curve in real network is analyzed. Hourly SAIFI and hourly SAIDI values are introduced as new reliability indicators. Indicators are calculated in more details for unplanned interruptions and are compared to daily load curve. Direct relationship between these two values is notified. The reliability indices changes are calculated per hour and three-hour blocks during the day. 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.
Knowledge on relationship between reliability indices and load curve can have very positive impact on power system control and distribution network development.

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