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RELIABILITY INDICATORS ANALYSIS FOR DISTRIBUTION NETWORK IN ELEKTROVOJVODINA

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Abstract:

This paper will show reliability indicators analysis in Elektrovojvodina for year 2002. In literature, as well as in practice, this indices are known as:

- ENS = Energy Non Supplied (Total undelivered energy caused by outage, during one year).
- SAIFI = System Average Interruption Frequency Index (Average power interruption frequency for each customer, during one year).
- SAIDI = System Average Interruption Duration Index (Average power interruption duration, in minutes, for each customer, during one year).
- CAIDI = Customer Average Interruption Duration Index (Average power interruption duration by outage).
- PO3H = Percentage of outages not solved for 3 hours (Number of outages in percents, which are not taken care of in 3 hours).
- PO24H = Percentage of outages not solved for 24 hours (Number of outages in percents, which are not taken care of in 24 hours).

In the end, there is a survey of the most often causes of customer outages and comparison of reliability indicators for Elektrovojvodina and other electric utilities around the world.

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INTRODUCTION

Reliability of electrical distribution systems was treated in a study of Faculty of Electrical Engineering in Belgrade in 1999. , with the same title. In this study, which was requested by EPS, the theme of reliability was backed up, for the first time, by exact results from one domestic distribution company. These results make it possible to compare distribution parts of Elektrovojvodina, as well as to compare Elektrovojvodina with others distributors in Europe and all over the world.
Reliability indicators, shown in this survey, are derived for Elektrovojvodina in year 2002, as follows:

- outages of all power transformers 110/x kV (93 transformers)
- outages of all power transformers 35/x kV (149 transformers)
- outages of overhead and underground networks 10 kV, 20kV and 35 kV (10.411 km)

Outages of 20(10)/0,4 kV transformers, as well as low voltage network outages are not shown in this analysis. At this moment, we haven't got the data needed for this kind of analysis. Power interruptions, caused by planned and unplanned maintenance turn-offs, are not presented in this article. The work on reliability indicators analysis for distributive network of Elektrovojvodina, was continued for year 2003. Up to the delivery date for this paper, outage elaboration for middle voltage networks was not finished, and presentation of these results will follow.
In most European countries, which have applied or are on the threshold of applying electrical energy market, the relation between the distributors and customers has become much different. Besides the possibility of choosing their producer, the customers can choose the electrical energy supplier. Under these conditions, because of competition, treaty relationships are established, which define the requests for fulfilment of particular quality conditions in delivery of electrical energy. After years of practical usage of these requests in European, American and Japanese electrical power industries, the indicators for network performance evaluation and supplier comparison are defined.
In the USA, special attention is paid to the quality of electrical energy delivery, so that the service quality indicators (SQI Metrics) are established by expert institutions (ANSI, IEEE, NESC). In this paper, we will give an example, presenting the participation of particular indicators in the complete evaluation of quality of electrical energy delivered in Massachusetts.

Table I – Indicators

Performance indicator	Participation
SAIDI	22,5%
SAIFI	22,5%
Lost work time accidents	10 %
Telephone answering rate	12,5 %
Service appointment rate	12,5 %
On-cycle meter readings	10 %
Consumer division cases	5 %
Billing adjustments	5 %

It can be generally said, that in the earlier period (1990.), greater importance was given to the reliability indicators, and today customer service quality indicators are equally important. This leads to a conclusion that this theme should be seriously dealt with in the following period, during which, our distribution companies would take the same direction.

1. UNDELIVERED ELECTRICAL ENERGY BECAUSE OF DISTRIBUTIVE NETWORK OUTAGES

The quantities of undelivered electrical energy (ENS in kWh) are shown in Table II. They are sorted by distribution parts, and by participation of parts of the distribution network, whose outages caused power interruptions. Absolute values of undelivered electrical energy by distribution parts are not comparable, because of significant differences in size. Hence, we introduced a relative factor ratio of undelivered energy to total delivered energy, by distributions. This indicator is marked as RENS, and it is stated in thousandths (‰).
By usage of RENS indicator, very convincing comparison between distribution parts can be carried out, and it can be seen that significant differences exist, ranging from 0,23 ‰ to 0,84 ‰. The analysis could be take even further, and for example take that the value of undelivered kWh is 3 dinars/kWh. In that way, the value of undelivered energy in the year 2002. is calculated, for the whole Elektrovojvodina, and equals 13.064.127 dinars (186.630 €).

Table II - ENS (kWh) i RENS (‰)

ED	ET 110/x	ET 35/X	MV network	ENS	Delivered energy [MWh]	RENS
NS	108.436	123.730	662.972	895.138	1.981.326	0,4518
SU	97.862	93.961	607.942	799.765	1.126.796	0,7098
PA	264.757	170.058	550.236	985.051	1.166.622	0,8444
ZR	51.115	0	467.586	518.701	789.705	0,6568
SO	84.127	0	227.906	312.033	784.056	0,3980
RU	4.272	2.930	259.284	266.486	705.618	0,3777
KI	49.029	0	165.413	214.442	348.590	0,6152
SM	1.890	0	82.291	84.181	360.819	0,2333
VR	42.032	0	43.808	85.840	352.027	0,2438
SE	56.218	0	136.814	193.032	245.419	0,7865
EV	759.738	390.719	3.204.252	4.354.709	7.860.977	0,5539

Data from the Table II is shown on figures 1. and 2. On figure 1. the quantities of undelivered energy (ENS in MWh), are shown for the distribution parts as well as for Elektrovojvodina totally.

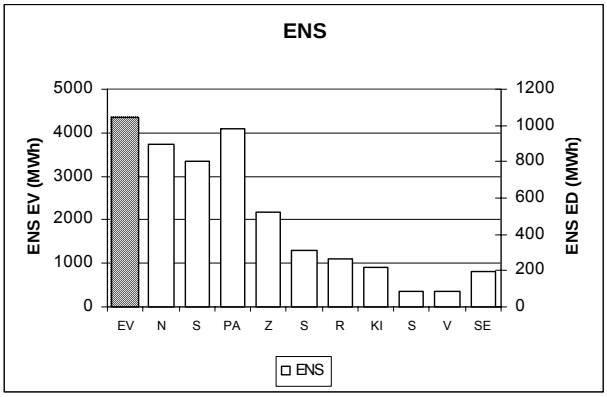

Fig. 1. Graphic presentation of undelivered energy ENS (MWh) by distribution parts and EV

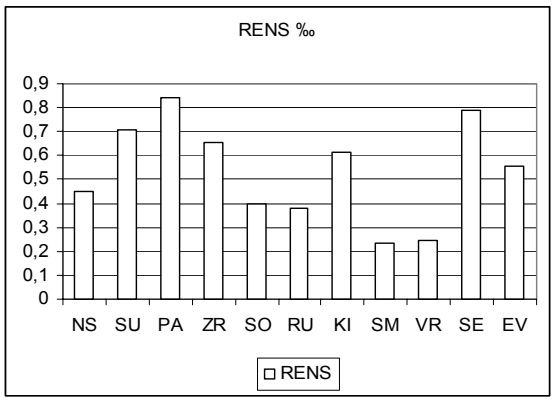

Fig. 2. Graphic presentation of relative ratio of undelivered energy RENS (‰)

Relative ratios of undelivered energy RENS (‰), by distribution parts and for Elektrovojvodina totally, are shown on figure 2.

The figure 3. shows the participation of particular parts of the network in the total undelivered energy.
ENS:
ET 110/x = 759.738 kWh = 17,45 %
ET 35/x = 390.719 kWh = 8,97 %
MV network = 3.204.252 kWh = 73,58 %

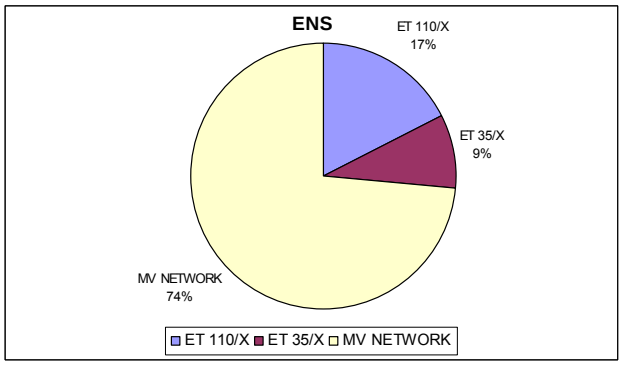

Fig. 3. Participation of network parts in the total undelivered energy

2. SYSTEM AVERAGE INTERRUPTION FREQUENCY INDEX (SAIFI)

SAIFI is the second indicator of distribution network reliability. It shows how often is the average customer left without electrical power, observed for the year 2002. Table III shows the SAIFI indicator by distribution parts and by participation of network parts.

Table III - SAIFI (outages/customer)

ED	ET 110/x	ET 35/x	MV network	SUM
NS	0,751	0,755	1,987	3,493
SU	2,340	0,591	3,406	6,337
PA	3,811	1,444	3,194	8,450
ZR	1,326	0	4,465	5,791
SO	3,757	0	3,013	6,770
RU	0,265	0,083	3,001	3,349
KI	3,710	0	7,067	10,777
SM	0,266	0	1,322	1,588
VR	1,599	0	1,798	3,397
SE	1,872	0	2,851	4,723
EV	1,867	0,504	2,976	5,347

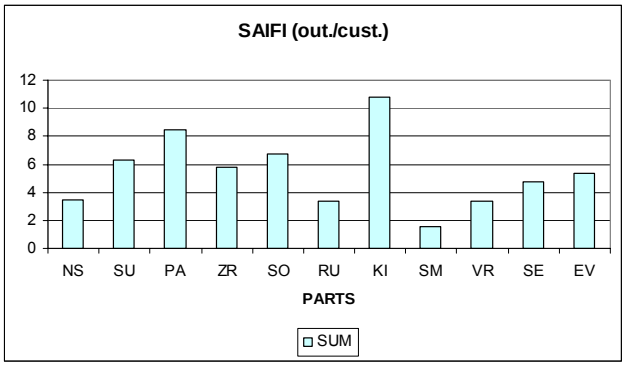

Fig. 4. Graphic presentation of SAIFI indicator by distribution parts for year 2002.

As can be seen in the Table III and in Figure 4., in the year 2002. each customer, had an average of 5,34 electrical power supply interruptions. In the distribution part, which has the worst indicator, each customer had an average of 10,77 electrical energy supply interruptions during the year 2002. The distribution part with the best SAIFI indicator, had an average of 1,588 electrical power supply outages. The Figure 4. presents the graphic chart of SAIFI indicator by distribution parts, for the year 2002.

On the pie chart, on Figure 5., the participation of particular network parts in the total outage frequency of each customer, is shown. From the chart it can be seen that more then a half (55 %) of interruption is caused by outages in the MV network.
SAIFI:
ET 110/x = 1,867 = 34,9 %
ET 35/x = 0,504 = 9,4 %
MV Network = 2,976 = 55,6 %

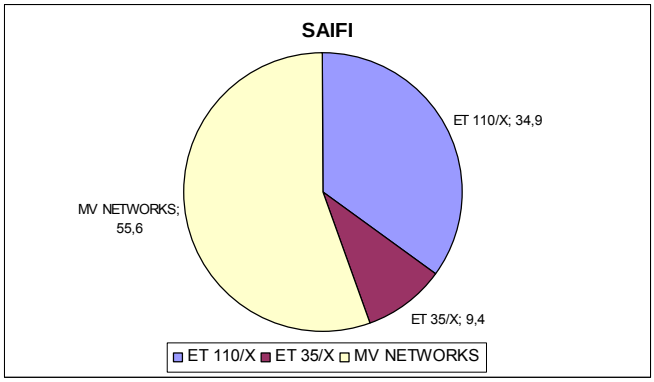

Fig. 5. Participation of particular network parts in the SAIFI indicator

3. SYSTEM AVERAGE INTERRUPTION DURATION INDEX (SAIDI)

The third indicator, by which the reliability of electrical energy delivery is evaluated, is called SAIDI. It shows the total time each customer (averagely) was left without electrical energy, during the year 2002. In the whole Elektrovojvodina, all outages of ET 110/x kV, ET 35/x kV and MV network, have caused a power supply interruption of each customer in duration of 234 minutes, during the year 2002.

Table IV - SAIDI (min)

ED	ET 110/x	ET 35/x	MV network	SUM
NS	26,87	34,14	112,73	173,74
SU	53,66	48,01	193,15	294,82
PA	130,2	73,69	132,45	336,34
ZR	28,29	0	256,63	284,92
SO	62,28	0	148,42	210,7
RU	4,09	1,32	163,69	169,1
KI	63,02	0	341,54	404,56
SM	2,93	0	90,44	93,37
VR	49,47	0	96,34	145,81
SE	92,83	0	161,12	253,95
EV	50,44	26,63	157,51	234,58

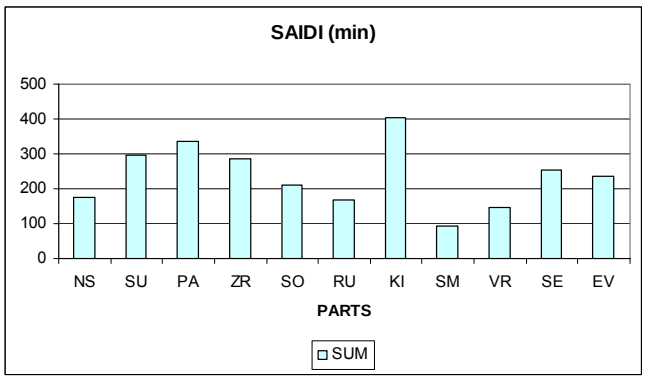

Fig. 6. SAIDI indicator graphic presentation, by distribution parts in year 2002.

In Table IV and on Fig. 6. the SAIDI indicator is presented, by distribution parts, participation of network parts and total for year 2002.
In the distribution part with the worst SAIDI, 404 minutes of electrical power supply interruption has been recorded, for each connected customer. In the distribution part with the best SAIDI indicator, it was 93 minutes in the whole year 2002.

On the pie chart, shown on Figure 7. the participation of the particular network parts in the customer interruption duration during the year 2002., is shown. As can be seen from the chart, 2/3 of supply interruptions is caused by MV network outages.
SAIDI:
ET 110/x kV = 50,44 min = 21,5 %
ET 35/x kV = 26,63 min = 11,35 %
MV network = 157,51 min = 67,14 %

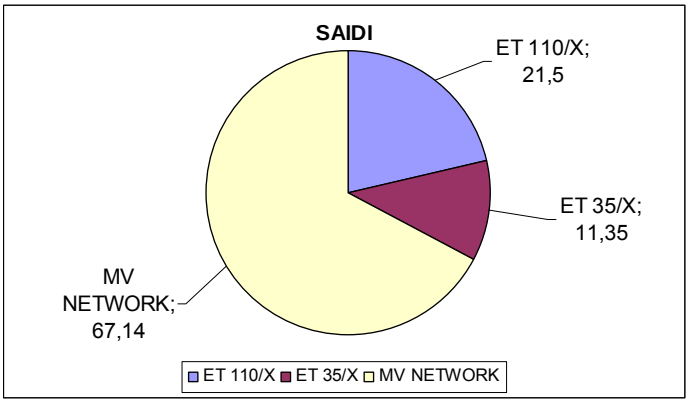

Fig. 7. The participation of particular network parts in power supply outage duration

4. CUSTOMER AVERAGE INTERRUPTION DURATION INDEX (CAIDI)

CAIDI is the name of the fourth indicator for evaluation of quality of distribution network service, and it shows how long did it take, averagely, to restore the customer electrical power supply after the interruption.
Observed on the level of Elektrovojvodina, the power supply interruption per outage, has lasted 43 minutes averagely. Wen observed by distribution parts, this indicator doesn't deviate much, and ranges from 31 minute for the distributive part with the best indicator, to 58 minutes for the distributive part with the worst indicator.

Table V - CAIDI (min)

ED	ET 110/x	ET 35/x	MV network	SUM
NS	35,79	45,18	56,73	49,74
SU	22,92	81,26	56,71	46,52
PA	34,16	51,01	41,47	39,80
ZR	21,32	0	57,48	49,19
SO	16,57	0	49,26	31,12
RU	15,41	15,96	54,54	50,49
KI	16,98	0	48,33	37,53
SM	11,01	0	68,41	58,79
VR	30,93	0	53,58	42,92
SE	49,59	0	56,51	53,77
EV	27,00	52,85	52,93	43,87

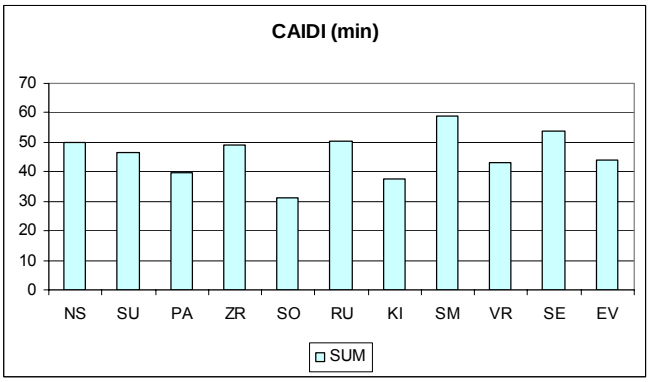

Fig. 8. Graphic presentation of CAIDI by distribution parts in year 2002.

Particular parts of the network had different influence on the average outage duration. The average outage duration of MV network lasted the longest time, on the level of Elektrovojvodina, as well as in distribution parts. This is explained by outages caused by storms, as well as by time prolonging because of failure spot location process, and because of inability to supply the energy from other direction.

5. PERCENTAGE OF OUTAGES NOT SOLVED FOR 3 HOURS (PO3H)

The reliability indicator, which is marked as PO3H, represents the percentage of power supply outages which last longer than 3 hours.
From the table presentation (Table VI), it can be seen that about 7 % on the level of Elektrovojvodina, last longer than 3 hours. One distribution part in the year 2002. had no outages longer that 3 hours.

The worst PO3H indicator had the distribution part, where more than 12 % of outages lasted longer than 3 hours. The Figure 9. shows the graphic presentation of PO3H indicator for the year 2002.

Table VI - PO3H (%)

ED	ET 110/x	ET 35/x	MV network	SUM
NS	0	4,54	10,15	9,04
SU	0	15,38	6,69	6,76
PA	2,56	8,16	12,13	10,79
ZR	0	0	1,39	1,33
SO	0	0	4,38	3,87
RU	0	0	12,9	12,58
KI	0	0	5,36	4,88
SM	0	0	12,98	12,82
VR	0	0	0	0
SE	0	0	6,38	5,94
EV	0,64	8,26	7,64	7,18

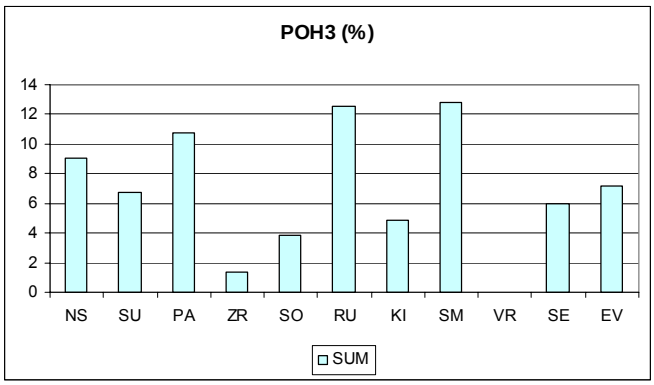

Fig. 9. Graphic presentation of PO3H indicator (%) by distribution parts for year 2002.

The extremely high participation of 93 %, in the outages longer than 3 hours, happen in the MV networks. This is explained by influence of bad weather conditions (storms), on outages of overhead network, as well as by difficult failure spot discovery, for overhead and underground cable network.
PO3H:
ET 110/x = 1 = 0,63 %
ET 35/x = 10 = 6,25 %
MV network = 149 = 93,12 %

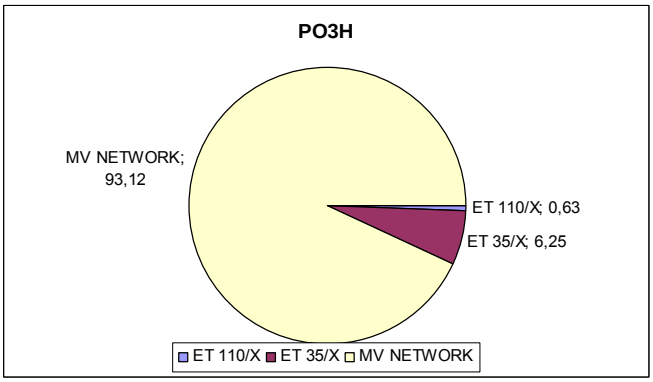

Fig. 10. Participation of particular network parts in the outages lasting longer than 3 hours

During the year 2002., there were no power supply interruptions lasting longer than 24 hours.

6. OUTAGE CAUSES

It is interesting that the analysis of outage causes of ET 110/x and 35/x kV, showed that there is a really small number of transformer outages, because of direct failures on or in the transformer.
The most often cause of ET 110/x kV outages is the unreliable work of 20 kV switches on feeders.It happens because of siwtch age and big problems in their maintenance. The biggest problem is inability of carrying out the indoor servicing, because of spare parts shortage, and also because of unsatisfactory equipped and trained personnel, working on the switch maintenance jobs.
For a remarkably high number of outages, on ET 110/x kV, and on ET 35/x kV, the cause of outage is unknown.This happens, because automatic event registration and remote communication isn't implemented on the most of 110/x kV stations, and on all 35/x kV stations.
The great part of outages in middle voltage network has been caused by a few typical causes.
In overhead leads, the most common cause of outage is insulator destruction, rough weather with windstorms, rain and thunder, and birds as eart-fault causes.
In middle voltage undergound lines, the most common cause of cable destruction or cable terminal destruction, as well as cable tearing because of insufficient attention during work.

7. COMPARISON WITH OTHER ELECTRICAL ENERGY DISTRIBUTORS IN THE WORLD

In electrical energy distributors worldwide, the most often used distribution network reliability indicators are: SAIFI, SAIDI and CAIDI. In one survey, from 205 companies in the USA in year 1995., when asked which network reliability indicators they use in their reports, the answer was as follows: SAIFI 83%, SAIDI 87 %, CAIDI 81 %.

For comparison with the results of other distributors some reliability indicators values, reachable from literature, will be presented.

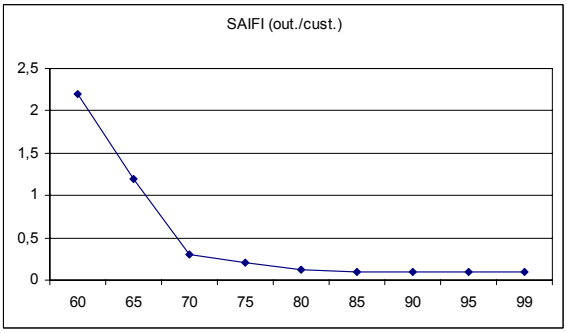

Fig. 11. SAIFI indicator graphic presentation for Japan, in period 1960.-1999.

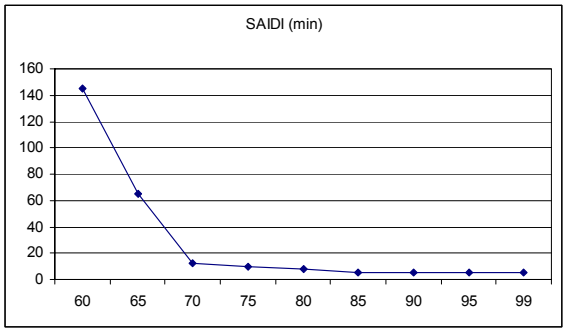

Fig. 12. SAIDI indicator graphic pressentation for Japan, in period 1960.-1999.

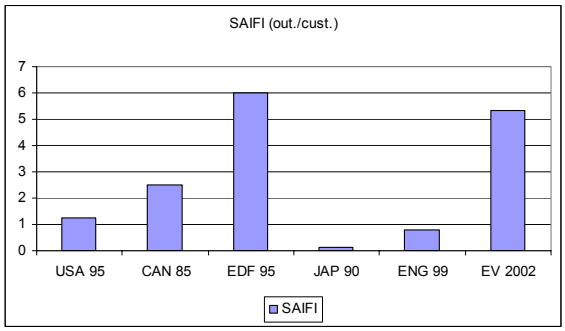

Fig. 13. Comparative presentation of SAIFI indicator for EV and 5 world distributors

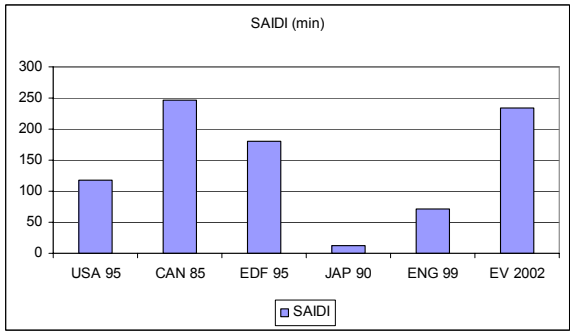

Fig. 14. Comparative presentation of SAIDI indicator for EV and 5 world distributors

8. CONCLUSION

By comparison of gathered reliability indicators for the network of Elektrovojvodina, and the data for the most developed electric utilities around the world, it can be concluded that Elektrovojvodina's results are comparable in value with the values for EDF in year 1995. Compared with the data from Japan, the customers of Elektrovojvodina are, however, a few tens of times, by frequency and by duration of outages, in worse position.

This comparison is even more unfavorable for Elektrovojvodina, if it is known, that in the most of presented Electrical Power Industries, reliability indicators include outages of MV/LV substations, outages of LV network, as well as planned customer outages due to maintenance on all voltages network.

For Elektrovojvodina, with currently available data, we are not able to estimate the influence of the part of the network that is not included, on the evaluated reliability indicators. Used database, for processed parts of the network, is very accurate, therefore, any estimation would jeoperdize a picture for which we can say is credible.

9. REFERENCES

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