RELIABILITY INDICATORS FOR QUALITY MARK OF DELIVERD ELECTRICAL ENERGY

Jovan Čarnić, PD Elektrovojvodina doo, Novi Sad, SCG
Miroslav Bačlić, PD Elektrovojvodina doo, Novi Sad, SCG

ABSTRACT

This paper shows reliability indicators for delivered electrical energy applied in Elektrovojvodina. This analyze include failures of power-transformers 110/x kV/kV (PT 110/x), power-transformers 35/x kV/kV (PT 35/x) and power supply network 20 and 10 kV (MV net) with power-transformers x/0.4 kV. It's also shown structure of outages causes in consideration of cause and duration of the failures.
Elektrovojvodina network is separated in local branches – different sizes, number of customers, network length. For each branch is made complete analyze per month and year. Analyze include period from 2002 to 2005.
On the analyze results, we can compared quality criteria and give next steps for increasing reliability of network.

INTRODUCTION

Quality of electrical energy is estimated with several criteria. Reliability indicators depend of utility company is: voltage quality, continious supplying, harmonic presence etc. This paper detailed work on reliability criteria based on continious supplying of electrical power.
Sistem reliability is defined like: Sistem posibility to deliver energy in determined quality and quantity. This sistem atribute we can show with probability and some marks, criteria, like here.

RELIABILITY INDICATORS

Data need for reliabilty analize are colected from failure reports (for every month, year), phisical capasity of the power network and some other data. The biggest problem for data processing is deficiency of precision number of customers supplied from fider and substation region. This problem is exceded with estimation of customer number based of outages power, customer area atributes, property of electrical objects, etc.

Failure evidency is made for each fider. Total failure number not include interrupts on LV network and failure caused by MV/LV power-transformer, but this caind of a failures are included in analize for total number cusomer with interruption and unsuplied energy.
Total number of failures include interrupts caused by procedure of fider sectionalization for searching exact point of failure. Reason for this action is that some costumers closer to power source get power earlier then others, which get power after rapair. Some fiders have connect with some neghboring fiders and than after reconfiguration all custumer can get power after short time.
Reliability criteria are separated in two groups: economical and non-economical reliability indicators. Economical reliability indicators are based on money equivalent for injury caused by interrupt of power. In our practice are not jet established wais for counting demage of supply intrerrupt and real price of electrical power. For that reason this paperwork will analize just non-economical reliability indicators.

Non-economical reliability indicators

Non-econimical reliability indicators take demage admist failure just implicitly, without money amount. At this point, we can defined up limits for reliability indicators and tried to real indicators fell in limits with maintance and repairs of network.
Non-economical relibility indicators are separated to:

Basic reliability indicators. This group consist of;

f – Outages frequency. This indicator shows number of failures or interrupts in month or year.

TABLE 1 – Number of outages in year

Year	2002	%	2003	%	2004	%	2005	%
PT 110/x	138	6.6	136	5.8	143	5.2	174	5.4
PT 35/x	100	4.7	85	3.6	87	3.2	78	2.4
MV net	1865	88.7	2127	90.6	2516	91.6	2964	92.2
Sum	2103	100	2348	100	2746	100	3216	100

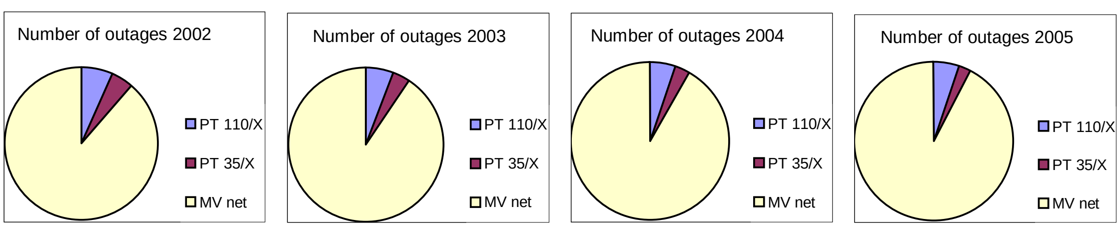


Figure 1 – Number of outages per year

Table 1 and figure 1 shows increasing number of failures PT 110/x and MV net and decreasing of PT 35/x. Reason for this trend is company policy for network expansion, aspiration in unique voltage levels, without 35 kV and 10 kV voltage level. Phisical capasity of the power network and tendency of network expansion is shown in table 2, where we can see reason for previous conclusion.

TABLE 2 – Phisical capasity of the power network

Year	2002	2003	2004	2005
PT 110/x [MW]	2788.5	2820	2863	2980.5
PT 35/x [MW]	990.03	981.93	971.93	973.43
PT x/04 [MW]	4190.73	4280.7	4346.5	4448.19
MV net [Km]	8959.2	9011.44	9111.19	9239.68

d - Interrupt duration. This parameter include all interrupts, no mater on outage power and customer type. We can see that dominate part in intrrupt duratation cames from failures in MV. That data is expected, because MV network has much more elements and length.

TABLE 3 – Duration length - min

Year	2002	2003	2004	2005
PT 110/x	6054	4420	4137	6342
PT 35/x	5285	4822	3472	4340
MV net	115448	163137	182143	219960
Sum	126787	172379	189752	230642

Nj – Number of customers without power in failures. This parameter includes all customers with interrupt in power suppluing durring the year, no mater for number of interrupts or outages duratation. – table 4. We can see that number of customers with interrupt is several times bigger then naumber of all supplied customers – table 5. That mean that some customers was without power several times durring the yaer. That number of failures per customer will be explain in next text.

TABLE 4 – Number of customers without power in failures

Year	2002	2003	2004	2005
PT 110/x	1432987	1267296	1309738	1640879
PT 35/x	345556	237893	265034	207771
MV net	2253725	2520573	2883865	3448482
Sum	4032268	4025762	4458637	5297132

Table 5 presented number of customers with at least one interrupt of power supply, no mater for number oh interrupts, just from interrupts in MV net.

TABLE 5 - Number of customers with at least one interrupt of power supply

Year	2002	2003	2004	2005
Total number of customers	844673	851740	863088	873996
Customers without power	585277	603557	468206	646349

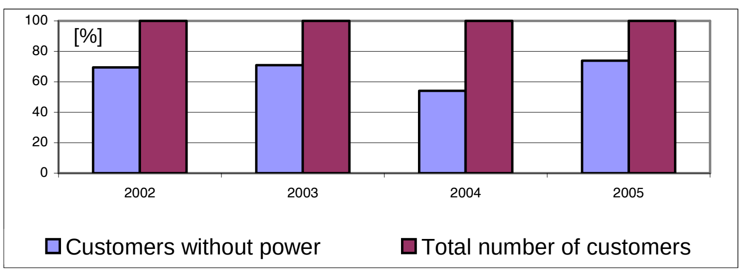


Figure 2 – Participation of customers without power

On this reliability criteria, we can make conclusion that dominate impact to failure number, interrupt duratation and number of customer without power is caused by failures in MV network. Total impact of MV net interrupt is larger then 90% of all failures. Because of that, ih next text exposure will based just on MV network.

Reliability indicators based on failure number of customers with interrupt. In table 6 are shown values of reliability indicators durring the whole period of analize. Detaled analize is presented by branches in next tables.

TABLE 6 – Reliability indicators

Reliability indicator	2002	2003	2004	2005
SAIFI (out./cust.)	2.67	2.92	3.34	3.99
CAIFI (out./cust.)	3.85	4.18	6.16	5.34
SAIDI (min/cust.)	125.3	154.4	175.8	215.6
CAIDI (min/cust.)	61.9	52.9	72.4	53.9
ASAI	99.46	99.37	99.4	99.38
ASUI	0.54	0.63	0.6	0.62
PO3H (%)	10.6	8	7.8	7.6
PO24H (%)	0.053	0.048	0.039	0.067

SAIFI - System Average Interruption Frequency Index. It shows how often is average customer left without electrical power – table 6. In the year 2005 each customer, had an average of 3.99 electrical power supply interruptions.

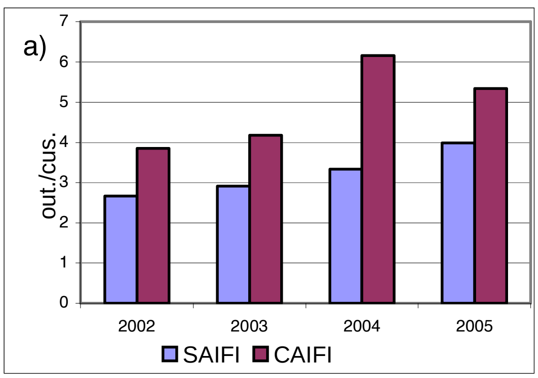
TABLE 6 – SAIFI, system average interruption frequency index

Year	NS	SU	PA	ZR	SO	RU	KI	SM	VR	SE	EV
2002	1.30	2.70	2.52	4.23	3.84	3.14	7.60	0.73	2.12	3.07	2.67
2003	1.28	2.74	2.98	4.61	4.23	3.64	7.42	1.34	2.11	4.46	2.92
2004	1.28	3.61	3.31	4.94	3.81	6.3	7.76	0.91	2.64	3.95	3.34
2005	1.93	3.49	3.23	6.89	5.82	6.75	6.23	1.73	3.14	5.59	3.99

CAIFI - Customer Average Interruption Frequency Index. CAIFI shows how often is the average customer with at least one interrupt left without electrical power during the year – Table 7. In the year 2004 each customer with interrupt had an average of 6.16 interrupts of electrical power supply. Figure 7a presents relation between SAIFI and CAIFI. From the figure it can be seen that CAIFI is bigger the SAIFI, because in CAIFI are calculated only customer with electrical power supply interruptions.

TABLE 7 – CAIFI, customer average interruption frequency index

Year	NS	SU	PA	ZR	SO	RU	KI	SM	VR	SE	EV
2002	2.87	3.55	3.78	5.40	4.09	3.55	8.05	1.70	2.46	3.76	3.85
2003	2.65	3.65	4.48	6.05	4.00	4.36	8.10	3.74	2.46	5.01	4.18
2004	3.30	5.66	5.96	7.53	5.76	9.74	9.49	4.71	4.77	6.90	6.16
2005	3.26	4.93	4.90	8.69	5.26	7.29	6.69	4.06	3.01	6.54	5.34



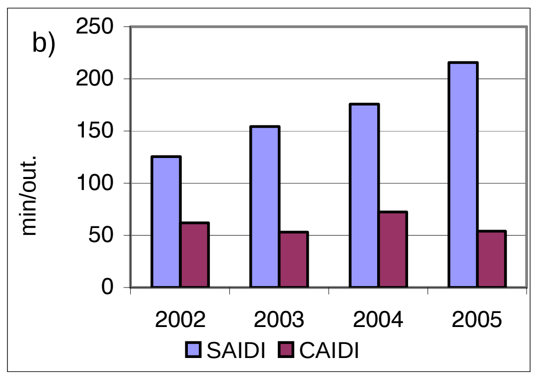


Figure 3 – Reliability indicators for 2002 – 2005 period

SAIDI - System Average Interruption Duration Index. It shows the total time each customer (average) was left without electrical energy, during the year – table 8. During the year 2004 all outages of MV net have caused a power supply interruption of each customer in duration of 175.8 minutes.

TABLE 8 – SAIDI, system average interruption duration index

Year	NS	SU	PA	ZR	SO	RU	KI	SM	VR	SE	EV
2002	77.7	120.2	118.1	171.4	156.2	167.6	351.4	52.0	74.4	143.9	125.3
2003	73.9	121.1	204.7	203.3	177.3	273.4	345.6	62.8	97.85	146.0	154.4
2004	81.1	142.4	240.6	180.6	166.3	423.4	305.9	54.4	77.9	207.2	175.8
2005	117.6	177.8	200.9	319.3	255.4	416.1	349.2	98.7	126.2	324.5	215.6

CAIDI - Customer Average Interruption Duration Index. CAIDI measures how long it takes a utility to restore service after an interruption and it's scored by adding up the duration of each service interruption in a year and dividing the total by the total number of customer service interruptions, thereby deriving the average outage duration for that year – table 9.Figure 7b presents relation beetven SAIDI and CAIDI. From the figure it cen be seen that SAIDI is several times longer, because average customer had several interruption (SAIFI) during the yaer with average durability CAIDI.

TABLE 9 – CAIDI, customer average interruption duration index

Year	NS	SU	PA	ZR	SO	RU	KI	SM	VR	SE	EV
2002	59.7	44.5	46.9	40.5	40.6	53.3	46.3	71.1	35.1	46.9	47.0
2003	57.6	44.2	68.6	44.1	41.9	75.0	46.5	46.8	45.2	32.7	52.9
2004	104.4	43.5	96.6	35.6	58.7	94.6	51.0	95.7	37.9	55.3	72.4

2005	60.9	50.9	62.2	46.3	43.8	61.6	56.1	56.9	40.3	58	53.9

ASAI - Average Service Availability Index. It shows which period of time system is in function. In 2005 year, service was 99.3 % of time in function – table 10.

TABLE 10 – ASAI, average service availability index

Year	NS	SU	PA	ZR	SO	RU	KI	SM	VR	SE	EV
2002	99.32	99.49	99.46	99.54	99.54	99.39	99.47	99.19	99.60	99.46	99.46
2003	99.34	99.49	99.21	99.49	99.52	99.14	99.47	99.47	99.47	99.62	99.37
2004	99.28	99.55	99.17	99.58	99.5	99.23	99.55	99.32	99.66	99.4	99.4
2005	99.3	99.42	99.29	99.47	99.5	99.29	99.36	99.35	99.53	99.34	99.38

ASUI - Average Service Unavailability Index. It shows which period of time system is out of function. In 2005 year, service was 0.62 % of time out of function – table 11.

ТАБЕЛА 11 – ASUI, average service unavailability index.

Year	NS	SU	PA	ZR	SO	RU	KI	SM	VR	SE	EV
2002	0.68	0.51	0.54	0.46	0.46	0.61	0.53	0.81	0.40	0.54	0.54
2003	0.46	0.51	0.79	0.51	0.48	0.86	0.53	0.53	0.53	0.38	0.63
2004	0.72	0.45	0.83	0.42	0.5	0.77	0.45	0.68	0.34	0.6	0.6
2005	0.7	0.58	0.71	0.53	0.5	0.71	0.64	0.65	0.47	0.66	0.62

PO3h – Percent of Outages not solved for 3 Hours, represents the percentage of power supplay outages which last longer than 3 hours – table 12. Here, we must take to knowlege and distance beetven failure point and nearest team service. Table 12 presents that branch VR – Vrbas has smollest PO3H, because teritory of branch Vrbas is smaller then other.

TABLE 12 – PO3H, percent of outages not solved for 3 hours

Year	NS	SU	PA	ZR	SO	RU	KI	SM	VR	SE	EV
2002	18.9	1.2	18.6	0.7	6.3	29.2	3.5	7.6	0	7.8	10.6
2003	9.9	1.6	14.3	3.9	7.4	15.3	6.4	7.9	0	2.9	8.0
2004	14.2	0.9	12.6	0.6	5.3	14.2	3.6	9.6	0	4.7	7.8
2005	9.4	3.9	12.8	1.6	5.3	13.7	6.2	11.3	3.4	3.8	7.6

PO24h – Percent of Outages not solved for 24 Hours. This indicators shows number of hard failures, or failures which can't be rapared in short time. Fortunately, number of that outages is small, just several durring the year.

TABLE 13 – PO24H percent of outages not solved for 24 hours

Year	NS	SU	PA	ZR	SO	RU	KI	SM	VR	SE	EV
2002	0	0	0	0	0.45	0	0	0	0	0	0.054
2003	0	0	0	0	0.37	0	0	0	0	0	0.048
2004	0	0	0	0	0.38	0	0	0	0	0	0.039
2005	0.2	0.22	0	0	0	0	0	0	0	0	0.067

Reliability indicators based on power and unsupplied energy. This indicators are based on exactly number of unsupplied energy to customers. The quntities of undelivered electical energy and it participation by parts of service netvork is shown in table 14.

This indicator shows how many energy will be delivered to customers without any interrupt. Constant rising of ENS – Energy Not Suplied is caused by growing network, worth weather conditions, older network, etc.

TABLE 14 – ENS, energy not supplied

Year	2002	2003	2004	2005
PT 110/x [MW]	762	758	714	1152
PT 35/x[MW]	392	252	196	208
MV net [MW]	2077	2599	3074	3651
Sum	3231	3609	3984	5011

AENS - Average Energy Not supplied, show average non-supplied energy per each customer during the year – table 15.

TABLE 15 – AENS, average energy not supplied

Year	2002	2003	2004	2005
PT 110/x [kW]	0.902	0.890	0.827	1.318
PT 35/x[kW]	0.463	0.297	0.227	0.237
MV net [kW]	2.459	3.051	3.561	4.178
Sum	3.824	4.238	4.616	5.733

ACCI - Average Customer Curtailment Index, presents unsupplied energy per each customer with at least one interrupt – table 16. From table 16 it can be seen that diference betven ENS by customer is smaller than AENS, because number of a outages is diferent too.

TABLE 16 – ACCI, average customer curtailment index

Year	2002	2003	2004	2005
PT 110/x [kW]	nema pod.	0.601	0.545	0.702
PT 35/x[kW]	nema pod.	1.049	0.741	1.002
MV net [kW]	0.92	1.03	1.07	1.06
Sum	nema pod.	0.9	0.89	0.95

OUTAGES CAUSES

During the reliabilty analize of service, it's also collected data about outages causes. With that caind of data we make a list of possible outage causes for 10 and 20 kV network, and for 2002 – 2005 year period. All posssible outage causes are sorted in 25 categories – table 17. This categories are formed on a most frequently outage causes. Some similar causes are put in one category, because in year period maybe just one or two happend.

TABLE 17 – Outage causes

Outage cause	2002	%	2003	%	2004	%	2005	%
Insulator destruction	256	13.7	291	13.7	472	18.8	694	23.4
Cable destruction	489	26.2	517	24.3	458	18.2	500	16.9
Unknown	207	11.1	289	13.6	372	14.8	511	17.2
Earth-fault	209	11.2	256	12.0	264	10.5	271	9.1
Line failure	69	3.7	93	4.4	108	4.3	158	5.3
Pass fault	65	3.5	44	2.1	132	5.2	114	3.8
Wire break	97	5.2	110	5.2	109	4.3	93	3.1
Substation MV/LV failure	38	2.0	61	2.9	70	2.8	93	3.1
Circuit breaker failure	54	2.9	52	2.4	78	3.1	75	2.5
Pass earth-fault	63	3.4	44	2.1	38	1.5	73	2.5
Surge arrester failure	32	1.7	51	2.4	28	1.1	67	2.3
Birds	101	5.4	80	3.8	78	3.1	62	2.1
Fuse change	19	1.0	19	0.9	34	1.4	44	1.5
Turn – off for repair	16	0.9	23	1.1	32	1.3	35	1.2
Transformer fault	43	2.3	35	1.6	39	1.6	31	1.0
Switch fault	41	2.2	39	1.8	44	1.7	31	1.0
Short circuit	18	1.0	47	2.2	73	2.9	29	1.0
Protection fault	11	0.6	10	0.5	15	0.6	27	0.9
Trees	20	1.1	30	1.4	40	1.6	21	0.7
LV fault	5	0.3	11	0.5	4	0.2	18	0.6
Overloaded	7	0.4	7	0.3	12	0.5	7	0.2
Fire in substation	0	0	0	0.0	1	0.0	5	0.2
Curren measuring transformer fault	0	0	0	0.0	3	0.1	2	0.1
Wrong manipulation	2	0.1	17	0.8	3	0.1	2	0.1
Substation 110/20 fault	0	0	1	0.0	9	0.4	1	0.0

As can be seen from table 17 dominate outage causes is insulator destruction, cable destruction, unknown cause, line failure, earth fault cause, until all other causes is ¼ of total number. Table 18 shows number of cause per month for 4 years period.

TABLE 18 – Number of outages per month for 2002-2005 year period

month	1	2	3	4	5	6	7	8	9	10	11	12
2002	98	76	113	135	193	223	284	236	190	153	85	79
2003	139	122	143	153	216	220	295	176	199	223	127	114
2004	115	108	128	169	170	336	466	264	210	288	153	109
2005	132	138	215	178	408	409	397	293	311	227	133	123

Also we can analize dependece some outages causes from month durring the year.

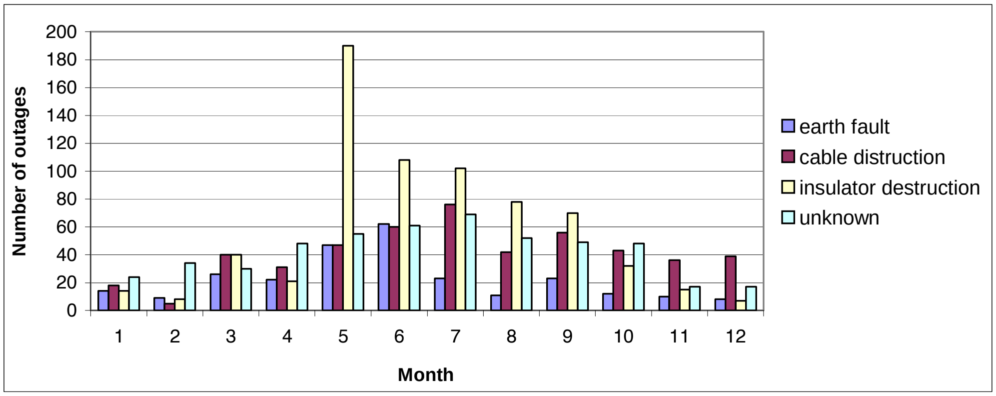


Figure 4 – Number of outages per month for 2005 year

On the bar-chart shown on figure 4, and table 18 we see that the majority number of failures is in summer season. That presentation is in the first place caused by insulator destruction and cable destruction. Reason for big deference beetven summer and winter number of failiers is in weather conditions. During the summer on fields is much more field works, more dust which cause smering of insulators and with morning dew or rain cause overjump voltage and in some causes insulator destruction. Overjumps voltage and insulator destructions is also caused by weather conditions – windstorms, heavy rain, tunder and flashes specialy in may, june, july and august. Considerable part of outages is caused by birds and tree contact with wires which cause earth-fault.

In summer season number of cable distruction is larger too, which is caused by low load, less heating, smaler evaporation of capilar wather in insulation specialy in older type of cables with papier insulation. Many cable destruction cames from cable terminal destruction, specialy on crosovers from cable to overground network. Also one of possible cause of cable destruction is insufficient attention durring the work.

Number of unknown causes is also larger in summer season. In that category are classified outages with unknown exsactly cause of outage and after fiew minutes power is restored without new problem. Posible cause of that outages is windstrorm and flashes.

On the base of collected data for outages, outage causes, phisical capasity of the power network, we can analyze number of outages per km – table 19. Before that kind of analyze we must regroup outage cause in two groups. One group is outage causes for overground network and other is outage cause for cables. In first group fall down: insulator destruction, earth-fault, line fault, birds, and tree contacts. In second group is just cable destruction's.

TABLE 19 – Frequency failures of cable and overground network

Year	2002	2003	2004	2005
Cable (km)	2432	2462	2502	2590
Overground network (км)	6527	6549	6609	6649
Cable failure number	489	517	458	500
Overground network failure number	752	860	1071	1299
Outages frequency for cables (out./km)	0.2	0.21	0.18	0.19
Outages frequency for overgroud network (out./km)	0.11	0.13	0.16	0.19

In total number of overground network failures not included unknown outages and outages caused by passing earth-fault. Reason for that is unknown exactly place of failure and for that this result must be accept with reserve.

CONCLUSION

The outages records analyzes shows that a number of failures variable depend on weather conditions and seasons. This conclusion is specialy based on year 2002 – very dry during summer, without windstorms – small number of outages and year 2005 with many rainy days and windstorms large number of outages.
Also analyzes shows that reliability of cable network is smaller than overground. That result is very important for further network development.
For increasing network reliability, maintenance must be improved where it’s posible (overground network).
More precisious data about network phisical evidence, number of customers and power of outage objects will be welcome for further analize. Authors will insist on that praoblem and data in next period.

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