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APPLICATION OF STATISTICAL METHODS IN THE PROCESS OF AUTOMATIC VOLTAGE REGULATION

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SUMMARY

Process approach, as a quality management principle, is an approach which provides permanent process management, with intention of continual improvement, based on the results of an objectively measured process performance analysis.
The results of the process performance analysis provide information about level of control and confidence of the process, and that is the base for decision making on quality improvement actions.
Level of control and confidence of the process is defined by quantifying collected data, through the use of adequate statistical methods.
As an example of statistical methods application in process management, automatic voltage regulation process transforming 110/20 kV is chosen, on the consumption area of *Power Distribution Novi Sad*.

1. PREFACE

Distribution of electric energy in whole, as well as its consisting processes, including the automatic voltage regulation, has a distinct process character by all definitions of process, whether some of the processes are managed manually, or the process is managed through local automatics, or the process management is realized by application of adequate special software.
The advantage of the process approach is in providing of permanent management, regardless of mode of process management, which means that processes must always be under control and confident within acceptable limits.
Are the processes under control, and at what level? Are they confident? It is hard to say if one can not quantify bulk of indicators of measured values, which can only be obtained by applying adequate statistical methods.
On the other hand, applying of statistical process control provides us with sense of how much is care of certain processes effective, in other words how well is our job done.

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Of course, application of statistical process control requires certain conditions, which are above all:

— to accomplish measuring in certain points in the process;

— acquisition of measured values;

— and, of course, possibility of data availability.

All these conditions are fulfilled by the fact that 110/20 kV power substations are incorporated in the remote controlled system, whose SCADA software generates daily reports containing all required and measured values. Collection of measured values of voltage in one period of time, as a performance of automatic voltage regulation, does not enable significant possibilities to qualify process seriously in form of quantified measures of that process. That is the reason why in this case

– "histogram" method and

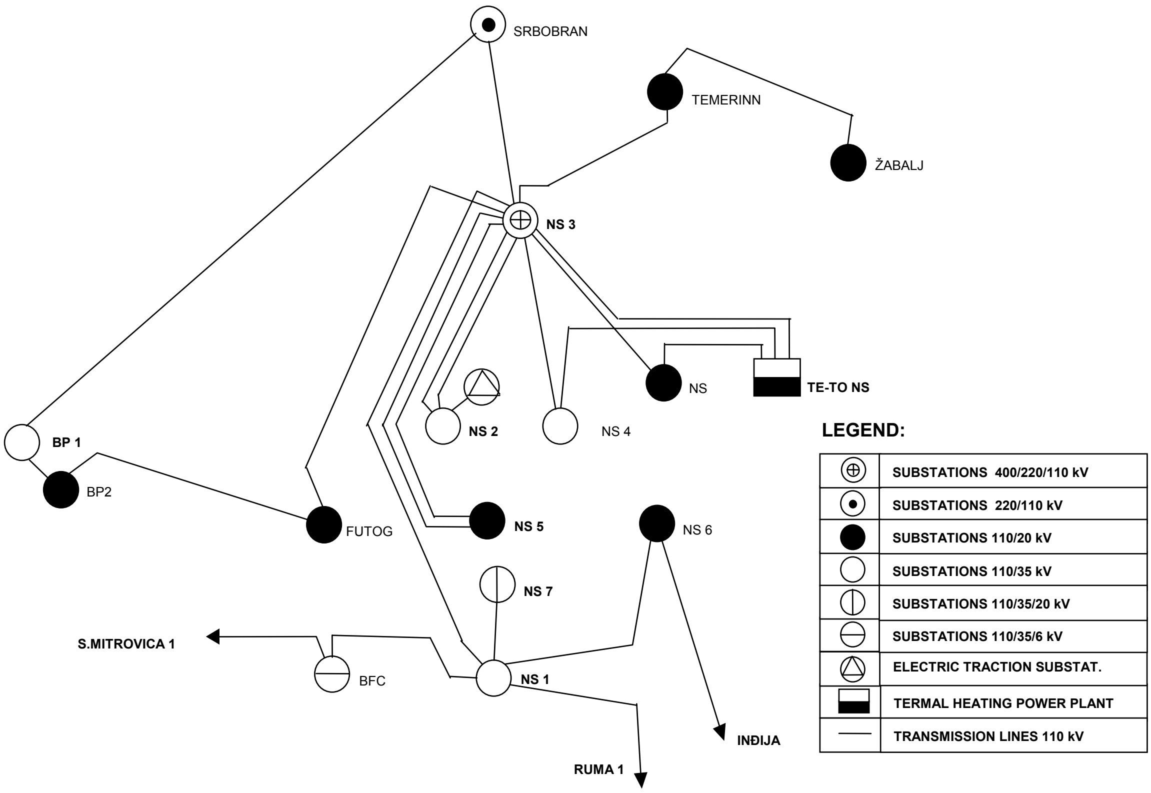
– X/σ control chart method,

are applied to estimate process status, its level of control and confidence, using quantitative indicators.

2. SCOPE OF STATISTICAL PROCESS CONTROL APPLICATION

Statistical process control method is applied to the process of automatic voltage regulation in transforming 110/20 kV, on the consumption area of *Power Distribution Novi Sad*.

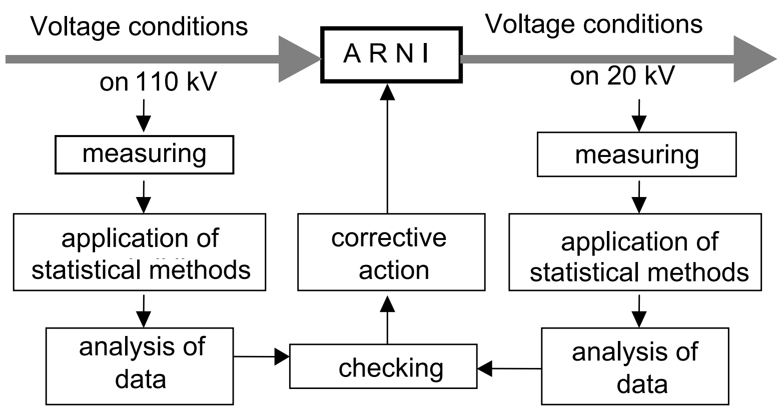
Power Distribution Novi Sad has eight power substations 110/20 kV in its distribution network, with total of thirteen transformer units, which provides measuring of receiving 110 kV voltage, and measuring of the voltage in the process of distribution of electric energy at 20 kV level. (Picture 1).



Picture 1: 110 kV network ED Novi Sad

Automatic voltage regulation process is provided by usage of compound automatic regulators in each transformer unit 110/20 kV.

Analyses of measured values of voltage are carried out independently at 110 kV voltage level and at 20 kV voltage level. By comparing these results, quantified effects of regulation are obtained, as well as possibility of automatic voltage regulation process improvement. (Picture 2)



Picture 2: Automatic voltage regulation process

3. CHARACTERISTICS OF MEASURED VALUES OF VOLTAGE

Hourly values of voltage on 110 kV and 20 kV are derived from daily reports.
Collection of measured values, in both cases, is more or less under the influence of variations. These variations are the result partly of special causes variations, and partly of common causes variations.
Nature of the special causes variations is that they can be removed in most cases by intervention of the person responsible for activities in this process, while common causes variations require some kind of action on the system itself, which is much more complicated request.

4. ANALYSIS OF MEASURED VALUES OF VOLTAGE

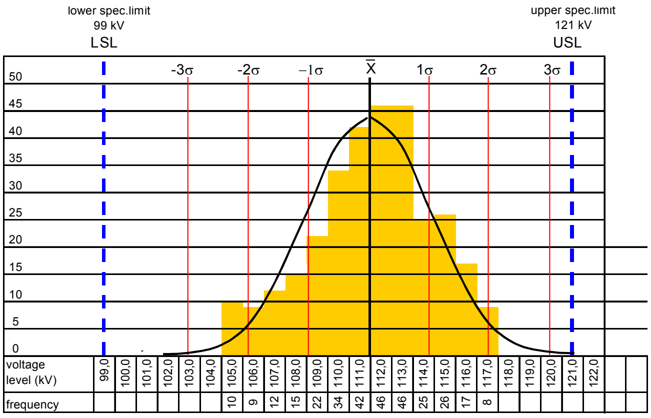
Objective of the analysis of measured values is to obtain quantified measures, which estimates process control and confidence of the process.
"Histogram" method gives us the "picture" of the process, based on which a conclusion could be made of nature of the variation of measured values of voltage, as well as location of the process in regard to the specified limits.
Collection of measured values, in processes which we consider to be more or less under control, is in most cases greatly under special causes variations influence. Each process is believed to be under control at level in which actual distribution of measured values of voltage in histogram is adjusted to theoretical – "normal" distribution. Higher level of adjustment of actual values to "normal" distribution is when there is tiny or small presence of special causes variations, which increase probability of that process to be under control.
Unlike "histogram" method, in which process is observed statically, control chart method, as tool for analysis of process variations, gives us possibility to identify moment and place in which special causes variations happened. That is the way to identify nature of the special causes variations easier, and even identify actions needed to resolve them.
Illustration of these methods on concrete example is contribution to development of an analysis model, whose results enables:

- evaluation of process control level;
- evaluation of process confidence level;
- evaluation of process effectiveness based on input and output performances status;
- undertaking actions based on data, which will improve process.

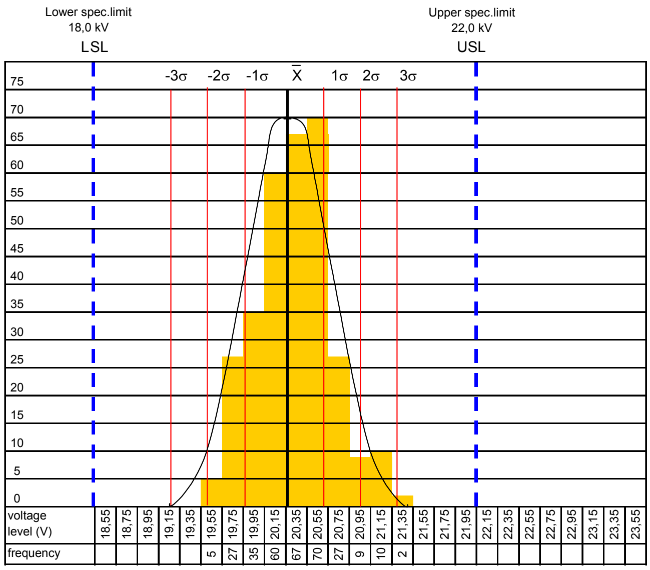
4.1. "Histogram" method

Classifying and sorting of measured values of 110 kV and 20 kV voltage, results in obtaining frequency of measured values within intervals. Based on this data, it is easy to calculate central tendencies measures, in this case that is variation mean and other variation measures, as well as standard deviation of the process, for voltage state on 110 kV and 20 kV side

Based on these values, frequency of actual distribution and frequency of theoretical distribution according to Gauss or “Normal” distribution could be obtained.



Picture 3: 110 kV voltage histogram



Picture 4: 20 kV voltage histogram

Actual and theoretical distribution relation could best be seen on graphs (Picture 3 and Picture 4).

Actual distribution is presented by histogram, and theoretical by normal distribution curve.

Less is the presence of special causes variations, better is the actual distribution, that is histogram, adapted to theoretical normal distribution curve.

Intention to quantitatively express process characteristics, whenever it is possible, leads us to application of χ^2-test, which essentially is hypothesis test of compatibility of actual distribution to normal distribution.

χ_0^2 is quantitative value of the actual and theoretical distribution ratio.

$\chi_{(a,r)}^2$ is table value for certain level of significance (here it is 1%) and for certain degree of freedom.

These values relationship, which are related:

$$\chi_0^2 \leq \chi_{(a,r)}^2$$

clearly shows us if processes are under control or not, and analysis results are given in Table 1.

Table 1: χ^2 test results

χ2 test results	χ_o^2	$\chi_{(\alpha,r)}^2$
on 110 kV	29,676	26,217
on 20 kv	34,997	21,666

In this example could be clearly seen that measured values on 110 kV and 20 kV side are more or less influenced by special causes variations. They must be explored, diagnosis must be made when they occur, where they occur and what is their nature.

4.2. “Control chart” method

By sequencing “pictures” of the process – shown in histograms, in process “movie”, using X/σ control chart where on the mean diagram could be seen when and/or where special causes variations significantly are present, and those are mostly points out of control limits.

Control limits are calculated values and they are directly dependent on nature and character of the process, according to following relations:

$$\begin{matrix} LCL_{\bar{x}} \\ UCL_{\bar{x}} \end{matrix} = \bar{\bar{X}} \pm A_3\,\bar{\sigma}_p$$

where A_3 is constant dependant on size of the subgroup, that is number of samples.

Greater the possibility of potential process control is, the smaller is the span between upper (UCL) and lower (LCL) control limit.

Comparing diagrams of 110 kV and 20 kV voltage level means, (Picture 5 and Picture 6), we could be satisfied with the state of the process.

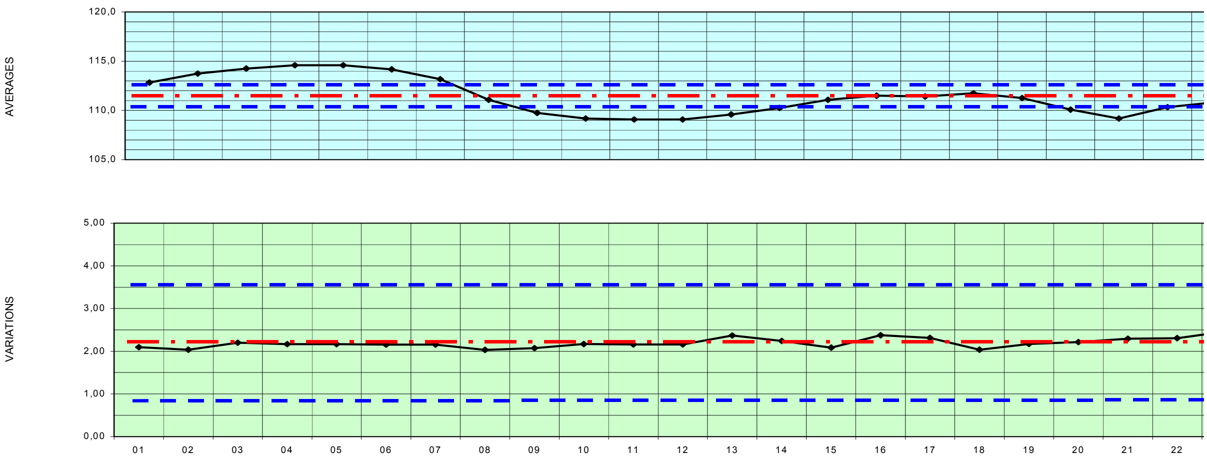
Automatic voltage regulation influence to the state of 20 kV voltage level is evident, because of improving 110 kV state is very obvious.

ELEKTROVOJVODINA — CONTROL CHART FOR VARIABLES $(\overline{X}/\sigma)$ — Date: 18.04.2003.

Part of the company: ED Novi Sad | Object: 110 kV network | Voltage level: 110 kV | Measuring spot: TS 110/20 kv | Specified limits: 99 - 121 kV

Data collected by: Dragan Cvetinov | Data collection method: SCADA | Measuring device: | Measuring unit: 1 kV

Vreme (h)		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
Measuring spot: NS5-ET1	1	113	114	115	115	115	115	114	112	111	110	110	110	111	111	112	112	112	112	112	111	110	111
NS5-ET3	2	115	115	116	116	116	116	115	113	112	111	111	111	112	113	113	113	113	113	113	112	111	112
NS6-ET1	3	109	110	110	111	111	110	109	107	106	105	105	105	105	106	107	107	107	108	107	106	105	106
NS6-ET2	4	109	110	110	110	110	110	109	107	106	105	105	105	105	106	107	107	107	108	107	106	105	106
NS7-ET1	5	112	113	114	114	114	113	112	110	108	108	108	108	108	109	110	110	110	111	110	108	107	109
NS9-ET1	6	112	113	113	114	114	113	112	111	109	109	109	109	109	110	111	111	111	111	111	109	108	109
NS9-ET2	7	111	112	113	113	113	113	112	110	109	108	108	108	109	109	110	110	110	110	110	109	108	109
FUT-ET1	8	115	116	117	117	117	116	115	113	112	111	111	111	112	112	113	114	114	114	113	112	111	112
FUT-ET2	9	115	116	117	117	117	116	115	113	112	111	111	111	112	112	113	114	113	114	113	112	111	112
BP2-ET1	10	114	115	115	115	115	116	115	112	110	110	109	109	110	111	112	113	113	113	113	112	111	113
BP2-ET2	11	114	115	115	116	116	116	115	112	110	110	110	110	110	111	112	113	113	113	113	112	112	113
TEM-ET2	12	115	116	116	117	117	116	115	113	112	112	112	112	112	113	113	114	114	114	113	112	111	112
ZAB-ET1	13	114	115	115	116	116	115	114	112	111	111	111	111	111	112	113	113	113	113	113	111	110	111
Sum		1354	1365	1371	1375	1375	1370	1358	1333	1317	1310	1309	1309	1315	1323	1333	1338	1337	1341	1335	1321	1310	1324
Average $(\overline{X})$		112,8	113,8	114,3	114,6	114,6	114,2	113,2	111,1	109,8	109,2	109,1	109,1	109,6	110,3	111,1	111,5	111,4	111,8	111,3	110,1	109,2	110,3
St.deviation (σ_p)		2,09	2,03	2,20	2,16	2,16	2,15	2,15	2,03	2,07	2,17	2,16	2,16	2,37	2,24	2,09	2,37	2,31	2,03	2,17	2,21	2,29	2,31



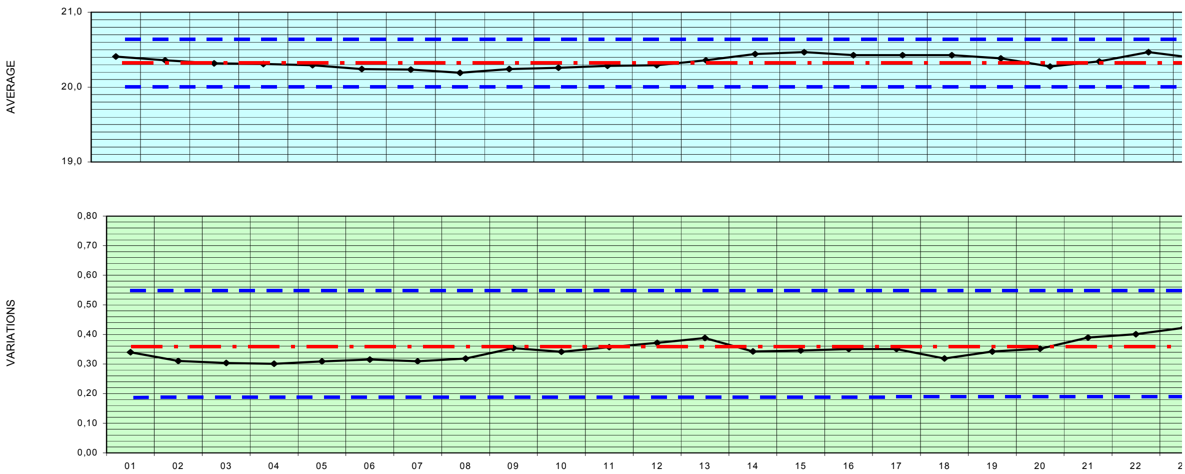
Pictire 5: X/σ control chart of 110 kV voltage, dependent on time

ELEKTROVOJVODINA — CONTROL CHART FOR VARIABLES $(\overline{X}/\sigma)$ — Date: 18.04.2003.

Part of the company: ED Novi Sad | Object: 20 kV network | Voltage level: 20 kV | Measuring spot: TS 110/20 kv | Specifed limits: 18 - 22 kV

Data collected by: Dragan Cvetinov | Data collection method: SCADA | Measuring device: | Measuring unit: 1 kV

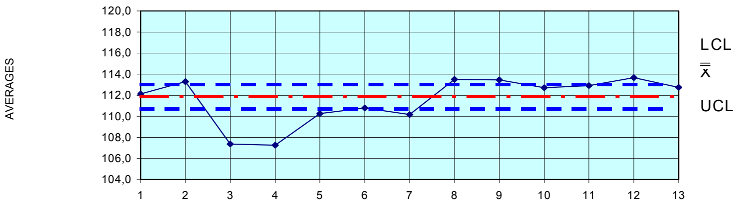
Vreme (h)		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
Measuring spot: NS5-ET1	1	19,8	19,8	19,8	19,8	19,8	19,7	19,9	19,7	19,6	19,7	19,8	19,7	19,8	20,0	19,9	19,8	19,8	19,9	19,8	19,7	19,9	20,0
NS5-ET3	2	20,1	20,1	20,1	20,1	20,1	20,1	20,0	20,0	20,1	20,1	20,0	20,0	20,1	20,2	20,2	20,2	20,2	20,2	20,2	20,0	20,1	20,2
NS6-ET1	3	19,9	19,9	19,9	19,8	19,7	19,6	19,7	20,0	19,9	19,9	20,1	20,2	20,2	20,2	20,0	20,0	20,0	20,0	20,0	19,8	20,0	20,1
NS6-ET2	4	20,2	20,2	20,1	20,2	20,2	20,1	19,9	19,6	19,7	19,7	19,6	19,6	19,7	19,8	20,1	20,1	20,1	20,2	20,1	19,9	19,8	20,1
NS7-ET1	5	20,6	20,6	20,5	20,5	20,5	20,5	20,6	20,6	20,8	20,7	20,6	20,6	20,7	20,7	20,7	20,8	20,8	20,7	20,8	20,7	20,8	20,9
NS9-ET1	6	20,5	20,4	20,3	20,2	20,2	20,2	20,2	20,2	20,3	20,3	20,3	20,3	20,3	20,5	20,5	20,3	20,3	20,3	20,3	20,3	20,5	20,6
NS9-ET2	7	20,8	20,7	20,8	20,6	20,5	20,5	20,4	20,4	20,4	20,6	20,5	20,5	20,6	20,7	20,8	20,6	20,6	20,6	20,4	20,4	20,6	20,7
FUT-ET1	8	20,5	20,5	20,5	20,6	20,6	20,5	20,4	20,1	20,2	20,2	20,2	20,2	20,2	20,4	20,6	20,6	20,6	20,6	20,6	20,3	20,4	20,6
FUT-ET2	9	21,1	21,0	20,9	20,9	20,9	20,8	20,9	20,8	20,8	20,8	21,0	21,0	21,2	21,2	21,2	21,2	21,2	21,2	21,2	21,0	21,2	21,4
BP2-ET1	10	20,6	20,5	20,4	20,4	20,4	20,4	20,4	20,4	20,5	20,5	20,5	20,5	20,6	20,6	20,7	20,5	20,5	20,5	20,5	20,5	19,9	19,9
BP2-ET2	11	20,4	20,3	20,2	20,2	20,2	20,2	20,2	20,3	20,3	20,3	20,5	20,6	20,5	20,5	20,5	20,6	20,6	20,5	20,3	20,5	20,6	20,7
TEM-ET2	12	20,4	20,3	20,3	20,4	20,4	20,3	20,2	20,2	20,3	20,3	20,3	20,3	20,4	20,5	20,4	20,4	20,4	20,4	20,4	20,2	20,3	20,4
ZAB-ET1	13	20,3	20,4	20,3	20,4	20,4	20,3	20,1	20,1	20,0	20,0	20,0	20,0	20,0	20,2	20,3	20,3	20,3	20,4	20,3	20,2	20,4	20,5
Sum		245	244	244	244	244	243	243	242	243	243	243	244	244	245	246	245	245	245	245	243	244	246
Average		20,4	20,4	20,3	20,3	20,3	20,2	20,2	20,2	20,2	20,3	20,3	20,3	20,4	20,4	20,5	20,4	20,4	20,4	20,4	20,3	20,3	20,5
St.deviation (σ_p)		0,34	0,31	0,30	0,30	0,31	0,32	0,31	0,32	0,35	0,34	0,36	0,37	0,39	0,34	0,35	0,35	0,35	0,32	0,34	0,35	0,39	0,40

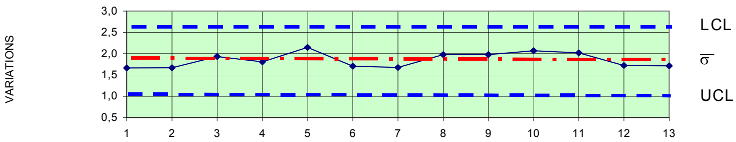


Pictre 6: X/σ control chart of 20 kV voltage, dependant on time

ELEKTROVOJVODINA	CONTROL CHART FOR VARIABLES (X/s)	Chart No.: 2003/02
Part of the company: ED Novi Sad	Object: 110 kV network	Voltage level: 110 kV
Data collected by: Dragan Cvetinov	Measuring spot: TS 110/20 kv	Specified limits: 99 - 121 kV
Date: 18.04.2003.	Data collection method: SCADA	Measuring unit: 1 kV

Measuring spot	NS5-ET1	NS5-ET2	NS6-ET1	NS6-ET2	NS7-ET1	NS9-ET1	NS9-ET2	FUT-ET1	FUT-ET2	BP2-ET1	BP2-ET2	TEM-ET2	ZAB-ET1		
Measuring time (h):	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
01	113	115	109	109	112	112	111	115	115	114	114	115	114		
02	114	115	110	110	113	113	112	116	116	115	115	116	115		
03	115	116	110	110	114	113	113	117	117	115	115	116	115		
04	115	116	111	110	114	114	113	117	117	115	116	117	116		
05	115	116	111	110	114	114	113	117	117	115	116	117	116		
06	115	116	110	110	113	113	113	116	116	116	116	116	115		
07	114	115	109	109	112	112	112	115	115	115	115	115	114		
08	112	113	107	107	110	111	110	113	113	112	112	113	112		
09	111	112	106	106	108	109	109	112	112	110	110	112	111		
10	110	111	105	105	108	109	108	111	111	110	110	112	111		
11	110	111	105	105	108	109	108	111	111	109	110	112	111		
12	110	111	105	105	108	109	108	111	111	109	110	112	111		
13	111	112	105	105	108	109	109	112	112	110	110	112	111		
14	111	113	106	106	109	110	109	112	112	111	111	113	112		
15	112	113	107	107	110	111	110	113	113	112	112	113	113		
16	112	113	107	107	110	111	110	114	114	113	113	114	113		
17	112	113	107	107	110	111	110	114	113	113	113	114	113		
18	112	113	108	108	111	111	110	114	114	113	113	114	113		
19	112	113	107	107	110	111	110	113	113	113	113	113	113		
20	111	112	106	106	108	109	109	112	112	112	112	112	111		
21	110	111	105	105	107	108	108	111	111	111	112	111	110		
22	111	112	106	106	109	109	109	112	112	113	113	112	111		
23	111	113	107	106	109	110	109	112	112	114	114	113	112		
24	112	114	108	108	111	111	111	114	114	115	115	114	113		
Sum	2691	2719	2577	2574	2646	2659	2644	2724	2723	2705	2710	2728	2706		
Average ($\overline{X}$)	112,1	113,3	107,4	107,3	110,3	110,8	110,2	113,5	113,5	112,7	112,9	113,7	112,8		
St.deviacion (σ_p)	1,7	1,7	1,9	1,8	2,1	1,7	1,7	2,0	2,0	2,1	2,0	1,7	1,7		





However, based on previous indications obtained by histogram analysis, this process must be seen from a different point of view as well. Rotation of the matrix of measured values of voltage by 90° gives us mean diagram. It clearly shows us the place where measurement was realized, which is significantly influenced by special causes variations.
(Picture 7 and Picture 8)
This means that verification of serviceability of regulation clutch and voltage regulator must be made, followed by checking of parameters for regulator adjustment, and finally check, and re-adjust if needed, regulator parameters.

5. ANALYSES RESULTS

Control charts can derive indicators which quantifies quality of the process and its confidence. (Table 2)
Let's pay attention to one representative indicator P_{pk}, which is in fact performance index of the process, and could be calculated using following relation:

ELEKTROVOJVODINA	CONTROL CHART FOR VARIABLES (X/s)	Chart No: 2003/02
Part of the company: ED Novi Sad	Object: 20 kV network	Voltage level: 20 kV
Data collected by: Dragan Cvetinov	Measuring spot: TS 110/20 kv	Specifed limits: 18 - 22 kV
Date: 18.04.2003.	Data collection method: SCADA	Measuring unit: 1 kV

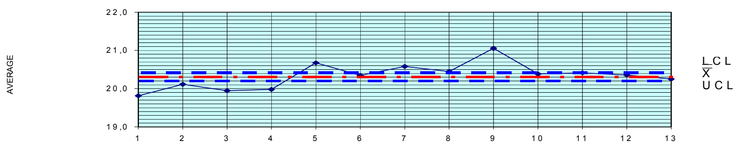
Measuring spot	NS5-ET1	NS5-ET2	NS6-ET1	NS6-ET2	NS7-ET1	NS9-ET1	NS9-ET2	FUT-ET1	FUT-ET2	BP2-ET1	BP2-ET2	TEM-ET2	ZAB-ET1		
Measuring time (h)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
01	19,8	20,1	19,9	20,2	20,6	20,5	20,8	20,5	21,1	20,6	20,4	20,4	20,3		
02	19,8	20,1	19,9	20,2	20,6	20,4	20,7	20,5	21,0	20,5	20,3	20,3	20,4		
03	19,8	20,1	19,9	20,1	20,5	20,3	20,8	20,5	20,9	20,4	20,2	20,3	20,3		
04	19,8	20,1	19,8	20,2	20,5	20,2	20,6	20,6	20,9	20,4	20,2	20,4	20,4		
05	19,8	20,1	19,7	20,2	20,5	20,2	20,5	20,6	20,9	20,4	20,2	20,4	20,4		
06	19,7	20,1	19,6	20,1	20,5	20,2	20,5	20,5	20,8	20,4	20,2	20,3	20,3		
07	19,9	20,0	19,7	19,9	20,6	20,2	20,4	20,4	20,9	20,4	20,2	20,2	20,1		
08	19,7	20,0	20,0	19,6	20,6	20,2	20,4	20,1	20,8	20,4	20,3	20,2	20,1		
09	19,6	20,1	19,9	19,7	20,8	20,3	20,4	20,2	20,8	20,5	20,3	20,3	20,0		
10	19,7	20,1	19,9	19,7	20,7	20,3	20,6	20,2	20,8	20,5	20,3	20,3	20,0		
11	19,8	20,0	20,1	19,6	20,6	20,3	20,5	20,2	21,0	20,5	20,5	20,3	20,0		
12	19,7	20,0	20,2	19,6	20,6	20,3	20,5	20,2	21,0	20,5	20,6	20,3	20,0		
13	19,8	20,1	20,2	19,7	20,7	20,3	20,6	20,2	21,2	20,6	20,5	20,4	20,0		
14	20,0	20,2	20,2	19,8	20,7	20,5	20,7	20,4	21,2	20,6	20,5	20,5	20,2		
15	19,9	20,2	20,0	20,1	20,7	20,5	20,8	20,6	21,2	20,7	20,5	20,4	20,3		
16	19,8	20,2	20,0	20,1	20,8	20,3	20,6	20,6	21,2	20,5	20,6	20,4	20,3		
17	19,8	20,2	20,0	20,1	20,8	20,3	20,6	20,6	21,2	20,5	20,6	20,4	20,3		
18	19,9	20,2	20,0	20,2	20,7	20,3	20,6	20,6	21,2	20,5	20,5	20,4	20,4		
19	19,8	20,2	20,0	20,1	20,8	20,3	20,4	20,6	21,2	20,5	20,3	20,4	20,3		
20	19,7	20,0	19,8	19,9	20,7	20,3	20,4	20,3	21,0	20,5	20,5	20,2	20,2		
21	19,9	20,1	20,0	19,8	20,8	20,5	20,6	20,4	21,2	19,9	20,6	20,3	20,4		
22	20,0	20,2	20,1	20,1	20,9	20,6	20,7	20,6	21,4	19,9	20,7	20,4	20,5		
23	19,9	20,1	19,8	20,3	20,8	20,5	20,6	20,7	21,3	19,7	20,4	20,5	20,4		
24	19,9	20,2	20,0	20,2	20,7	20,5	20,7	20,6	21,2	19,8	20,5	20,5	20,4		
Sum	476	483	479	480	496	488	494	491	505	489	490	489	486		
Average ($\overline{X}$)	19,8	20,1	19,9	20,0	20,7	20,3	20,6	20,4	21,1	20,4	20,4	20,4	20,3		
St.deviation (σ_p)	0,1	0,1	0,2	0,2	0,1	0,1	0,1	0,2	0,2	0,3	0,2	0,1	0,2		

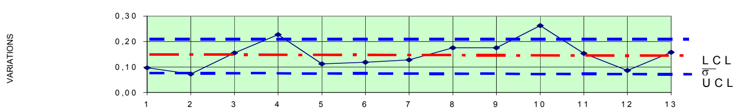
$$P_{pk} = \min\left\{\frac{LCL - \overline{\overline{X}}}{3\sigma_u}; \frac{\overline{\overline{X}} - UCL}{3\sigma_u}\right\}$$

If this index:

$$P_{pk} \geq 1$$

minimum level of process confidence is believed to be obtained, considering centering of the process related to the specified limits ± 10% (LCL and UCL).
In the example given, both on 110 kV and 20 kV sides, this index is greater than 1, but of great importance is that this index on 20 kV side is 39% greater than the same index on 110 kV side, which means that automatic voltage regulation has increased confidence of the process that much.





dependant on measuring spot

Table 2: Quality of the process indicators

ELEKROVOJVODINA	IMPROVEMENT EFFECTS	Chart No: 2003/02
Part of company: ED Novi Sad		Date: 18.04.2003.

No	PROCESS MEASURES	process measure sign	process on 110 kV	process on 20 kV	improvement effect	comment
1	Variation mean (kV)	$\bar{\sigma}$	2,20	0,35		
2	Process mean (kV)	$\bar{\bar{X}}$	111,46	20,34		
3	Upper control limit of mean (kV)	$UCL_{\bar{X}}$	113,33	20,64		
4	Lower control limit of mean (kV)	$LCL_{\bar{X}}$	109,59	20,05		
5	Upper control limit of spread (kV)	UCL_{σ}	3,55	0,56		
6	Lower control limit of spread (kV)	LCL_{σ}	0,84	0,13		
7	Standard deviation of the process (kV)	σ_n	2,24	0,35		
8	Total variation of the process (kV)	σ_u	2,84	0,36		
9	Total variation to standard deviation of the process ratio	σ_u/σ_n	1,27	1,01		presence of the special causes variations on 110 kV is 27%, and on 20 kV is 1%;
10	Capability of the process	$6\ \sigma_n$	13,46	2,12		
11	Performance of the process	$6\ \sigma_u$	17,07	2,14		
12	Capability index of the process	C_p	1,63	1,89	1,16	capability index of the process with removed special causses variations is increased by 16%;
13	Performance index of the process	P_p	1,29	1,87	1,45	performance index of the process in total is increased by 45 %;
14	Upper capability index of the process	CPG	1,42	1,56	1,10	upper capability index of the process is increased by 10%;
15	Lower capability index of the process	CPD	1,85	2,21	1,19	lower capability index of the process is increased by 19%;
16	Capability index of the process considering centering	C_{pk}	1,42	1,56	1,10	capability index of the process considering centering is increased by 10%;
17	Upper performance index of the process	PPG	1,12	1,55	1,39	upper performance index of the process is increased by 39%;
18	Lower performance index of the process	PPD	1,46	2,19	1,50	lower performance index of the process is increased by 50%;
19	Performance index of the process considering centering	P_{pk}	1,12	1,55	1,39	performance index of the process considering centering is increased by 39%;
20	Capability ratio	CR	0,61	0,53	0,87	
21	Performance ratio	PR	0,78	0,53	0,69	
22	Standard deviation unit	Z_{min}	4,25	4,69	1,10	standard deviation unit with removed special causes variations is increased by 10%;

6. CONCLUSION

Statement that process control based on χ^2-test is unacceptable is probably too rigorous, but result obtained could be for sure accepted as identification of possibility of process improvement, by eliminating at least some part of special causes variations.

Regarding confidence, process could be evaluated as quite acceptable, in spite of significant presence of special causes variations, because all measured values of 110 kV and 20 kV voltage are inside specified limits. The proof for that could be seen on histograms (Picture 3 and Picture 4), as well as on applied X/σ control chart quantified indicators.

Performing of adequate preventive and corrective actions, will improve process control and process confidence will be more enhanced.

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