VOLTAGE PROFILE QUALITY OF CONFORMANCE EVALUATION WITH PROCESS CAPABILITY ANALYSIS IN THE PRESENCE OF DISTRIBUTED GENERATION

Bahman Jamshidi	Abbas Saghaei	Akbar zare	Mohamadali Safari	Ali golmohamadi
West Tehran PPDC Sharif University of Technology Iran	Islamic Azad University, ,Science and research branch –Iran	West Tehran PPDC Iran	West Tehran PPDC Iran	West Tehran PPDC Iran
BahmanJamshidi@gmail.com	a.saghaei@srbiau.ac.ir	ak.zare@gmail.com	safari@wtppdc.ir	golmohammadi@wtppdc.ir

ABSTRACT

Quality is defined as meeting the requirements of the customers, so it is vital for distribution companies to provide electric power with specified voltage in all time for all customers in the competitive energy market. In the absence of distributed generation (DG) it is possible to control voltage profile with proper network design and optimized setting of high voltage transformer online tap changers, but in the presence of DG, especially renewable resource like photovoltaic panels and wind turbines, the voltage profile is affected by stochastic behaviour wind velocity, sun light and DG owners decisions. In this study process capability analysis and statistical control chart have been used together to evaluate of distribution system capability to maintain voltage in design level and to detect abnormalities in voltage profile in the presence of distributed generation.

INTRODUCTION

Competitive energy market, government regulatory and increasing knowledge of customers about power quality have stimulated the utilities strategy to focus on quality as a pivotal concept. Although customers' complaint, regulatory penalties and decrease in business confidence can threat profitability of distribution companies, quality plan can help companies to control these threats as well as to increase their productivity. It is clearly reasonable to spend on quality improvements for larger savings for either the distribution company or the customers. This requires a trade-off between the costs of operation and the losses acceptable to the customers arising from voltage variation.

Growth of distributed generation (DG) can reduce transmission and distribution losses as well as the number of transmission and distribution lines that need to be upgraded or built [2]. The location and size of DG units are the most important factors that influence on voltage profile. It is proved that proper DG placement method can improve voltage stability significantly and reduce power losses [3] [4] but improper location or capacity of DG may increase power losses and lead to poor voltage profile [5]. The optimal placement and sizing of DG units on the distribution network has been studied for minimization of the energy losses of the feeder, total network supply costs or best utilization of the available generation capacity [6]. Static voltage stability index (VSI) was used by Chen in 2006 can help engineers to estimate the health of the network. The value of this index is between zero (No-Load) and 1 (Voltage Collapse). The branch with the highest Voltage Stability Index (VSI) is weakest branch and the most vulnerable branch to voltage collapse [4]. Network Performance Enhancement Index (NPEI) that has been introduced by Sharma and vital in 2010 was proposed to quantify the total effect of using distributed generator on power loss reduction, voltage stability improvement, Voltage profile improvement and maximum reduction of power losses per unit size of DG [5].

The quality of any products or services like electricity has two distinct but interrelated aspects: Quality of design measuring how well the service is designed to achieve its stated purpose and quality of conformance that represents how closely the service matches the design goals indicated in the service design specification [1]. In other words, quality of design is the power quality, which the distribution company is intending to offer to its customers that meeting or exceeding customer requirement. Quality of Conformance is the level of power quality actually perceived by customers. Although customers sensitive to quality of conformance, the majority of the distribution companies focus on quality of design and sometimes ignore the conformance quality of their services. Customers acceptable if the engineer who created the design specifications did not correctly interpret what the customers wanted may still not perceive supplying product and services with high quality of conformance.

This article has focused on voltage level, which is one of the most important aspects of power quality. West Tehran province power distribution company (WTPPDC) has started a study for evaluation of its ability to maintain voltage profile quality of conformance in the presence of distribution generation. In this project process capability analysis and control charts have been used for detecting level of non-conformity and meaningful changes in voltage profile that consequence of DG behaviour change. If the Process capability indices are high enough the quality of conformance of voltage level is acceptable but if these indexes are less than defined range the voltage control strategy is not capable and some customers will inevitably suffer low power quality.

POWER QUALITY OF DESIGH AND QUALITY OF CONFORMANCE

Distribution companies are obliged to supply electric power to their customers. Electricity like other products or services has specified requirements that describe of what the customer needs. In an ideal condition all customers are supplied with a sinusoidal voltage having an amplitude and frequency given by national standards, but in a real world it is not possible to supply all customers with nominal voltage specified in standards. The quality of electrical power may be described as a set of parameters like continuity of service, voltage and current transient, variation in voltage magnitude and harmonic content in the waveforms. Two main quality concepts that have been studied in this project are undervoltage and overvoltage. Undervoltage occurs when the voltage drops below and overvoltage occurs when the voltage rises above acceptable range for more than one minute.

In competitive energy marketing distribution companies and government regulatory should be aware of reality; Every deviation of electrical parameters causes a cost, which is often cost of customer dissatisfaction, therefore distribution companies should balance utility cost against customers dissatisfaction cost.

Power quality requirement should meet customers need. If a requirement expresses what is genuinely needed, then any parameter that does not meet requirements will not satisfy the need, but if parameters that do not meet requirements satisfy the need, then the requirement should be changed to reflect reality.

CAPABILITY ANALYSIS OF VOLTAGE PROFILE

Process capability refers to inherent ability of any process like energy supply to produce similar products or services for a period of time under given set of condition and process capability analysis is a systematic procedure for estimate the capability of process. The capability of distribution companies to maintain voltage level for their customers is very important criterion for power quality. As mentioned earlier, in the absence of distribution generation, it is possible to maintain voltage level in acceptable band with proper transformer tap position and network design, but in the presence of DG, voltage profile is not deterministic because of its probabilistic behaviour. For estimating the capability of network to maintain voltage level WTPPDC has used combination of simulation and process capability analysis. In this project independent scenarios of distributed generation placement have been studied.

Process capability analysis of any service or product could be estimated by following steps: [7]

1- Determination of acceptable band of any related parameters: In this study voltage level has been defined in national standard.

2- Data collection: DG position and nominal power have been selected by random functions. The instantaneous energy demand of each load and produced power of each DG have been determined by their statistical behaviour. Note that all random variable is dependent to each other, but the correlation between different variables is not equal. For example, there is not considerable correlation between outputs of two separated gas turbine generators, in contrast power output of some renewable energy resource like wind turbines or photovoltaic panels are highly correlated. After simulation, voltages of all busbars have been used for statistical analysis.

3- Data analysis: The process capability indices calculation needs basic statistics like average and standard deviation of related data.

4- Distribution Identification and transformation: Process capability calculation relay on normal statistical distribution therefore it is necessary to perform a hypothesis tests to examine whether or not the observations follow a normal distribution. In this test, null hypothesis means data follow a normal distribution. P-value determines the appropriateness of rejecting the null hypothesis in a hypothesis test. The smaller P-value means smaller probability that rejecting the null hypothesis is a mistake. A commonly used value is 0.05. If the p-value of a test statistic is less than 0.05 null hypothesis will be rejected. If voltage profile distribution does not follow normal distribution function, it is necessary to use non-normal distribution capability test or to use transformation. In this project normalization has been performed by Johnson transformation.

5- Process capability indices Calculation

Consider that:

USL = Maximum acceptable voltage

LSL = Minimum acceptable voltage

S = Standard deviation

Mean = Average

$$CP = \frac{USL - LSL}{6S}$$

$$CPU = \frac{USL - Mean}{3S}$$

$$CPL = \frac{Mean - LSL}{3S}$$

$$CPK = Min(CPL, CPU)$$

$$ZScore = 3CP$$

If CPK value is less than one, model is not capable and customers will suffer low power quality but if CPK is more than two the network is capable to maintain voltage in predefined band.

6- Converting process capability indices to non-conformance percentage

CONTOL CHART OF VOLTAGE PROFILE

Voltage level is not constant, many things like customer demand change, transformer tap position, and transmission line voltage level can change medium and low voltage profile. There are random and unavoidable voltage variation related to minor customers demand change as well as meaningful voltage changes and control charts are powerful tools that can help engineers to distinguish them.

Control chart is a power tool, which can help to detect abnormal behaviour of voltage profile especially in the presence of DG. In this project Shewhart control chart has been used for monitoring voltage level of interested point. Calculation needed for drawing control chart can be found in reference 1.

CASE STUDY

WTPPDC has studied voltage profiles of many industrial zone feeders by process capability analysis. Case study, which has been chosen for this paper, is about one of the Nazarabad region medium voltage feeders. Feeder main branch length is approximately 19 km. network had been constructed with 73 mm^2 ACSR wire but about 6 km of main branch has been upgraded to 126 mm^2 ACSR wire. More than 60 medium voltage transformers have been installed in this feeder and after transformers clustering, voltage profile of 22 related bus-bars have been studied. This feeder has one active DG but in this case study voltage profile behaviour of feeder in the presence of up to seven DG is studied in 200 scenarios. In this study voltage profile of bus-bar 1 and 19 have been selected for detailed report. Bus-bar 1 was near high voltage substation and its distance from that substation is about 1 km. Bus- bar 19 was place almost at the end of feeder.

RESULT AND DISCUSSION

Result of capability analysis of network to maintain voltage profile of some bus-bars has been inserted in table 1 (in the absence of DG) and table 2 (in the presence of DG).

Table1: capability of maintaining voltage level in the absence of DG

Bus-bar	Mean	CPK	Undervoltage risk	Overvoltage risk
Bus-bar 1	0.993	12.78	negligible	negligible
Bus-bar 2	0.976	1.16	negligible	negligible
Bus-bar 3	0.976	1.53	negligible	negligible
Bus-bar 4	0.972	1.13	%0.03	negligible
Bus-bar 5	0.972	1.11	%0.04	negligible
Bus-bar 6	0.966	0.61	%3.3	negligible
Bus-bar 9	0.961	0.41	%11.16	negligible
Bus-bar 12	0.958	0.26	%21.92	negligible
Bus-bar 15	0.960	0.34	%15.21	negligible
Bus-bar 19	0.958	0.27	%21.13	negligible
Bus-bar 21	0.958	0.26	%22.19	negligible

Table2: capability of maintaining voltage level in the presence of DG

Bus-bar	Mean	CPK	Undervoltage risk	Overvoltage risk
Bus-bar 1	0.998	2.43	negligible	negligible
Bus-bar 2	0.991	0.54	%5.37	%1.25
Bus-bar 3	0.991	0.53	% 5.49	% 1.34
Bus-bar 4	0.990	0.45	% 8.66	% 2.19
Bus-bar 5	0.990	0.45	% 9.02	% 2.46
Bus-bar 6	0.987	0.34	% 15.23	% 4.09
Bus-bar 9	0.985	0.29	% 19.0	% 5.82
Bus-bar 12	0.984	0.26	% 21.78	% 6.61
Bus-bar 15	0.986	0.28	% 20.43	% 7.16
Bus-bar 19	0.986	0.26	% 22.20	% 9.17
Bus-bar 21	0.986	0.25	% 22.43	% 9.09

In the absence of DG, risk of overvoltage is negligible and WTPPDC has solved Undervoltage problem with proper medium voltage transformer tap position, but the presence of DG, risk of overvoltage and undervoltage in some bus-bar is very high. This problem cannot be solved by transformer tap position because high standard deviation of voltage level, therefore some network modification should be considered. One of the expensive but effective solutions is to replace high resistance wires (In this network 73 mm^2) by low resistance wires (In this network 126 mm^2). Table 3 has show the effect of network upgrade on voltage profile.

Table3: capability of maintaining voltage level in the presence of DG (after network upgrade)

Bus-bar	Mean	CPK	Undervoltage risk	Overvoltage risk
Bus-bar 1	0.998	2.39	negligible	negligible
Bus-bar 2	0.998	1.50	negligible	negligible
Bus-bar 3	0.998	1.49	negligible	negligible
Bus-bar 4	0.998	1.41	negligible	negligible
Bus-bar 5	0.998	1.39	negligible	negligible
Bus-bar 6	0.997	1.26	%0.01	negligible
Bus-bar 9	0.997	1.17	%0.02	%0.01
Bus-bar 12	0.998	1.13	%0.04	%0.01
Bus-bar 15	0.998	1.12	%0.04	%0.02
Bus-bar 19	0.998	1.05	%0.08	%0.04
Bus-bar 21	0.998	1.05	%0.08	%0.04

Table4: capability of maintaining voltage level after network upgrade

	Bus-bar 1 without DG	Bus-bar 1 with DG	Bus-bar 19 without DG	Bus-bar 19 with DG
Sample Mean	0.9938	0.9986	0.9873	0.998
Standard Deviation	0.001146	0.00677	0.00265	0.01538
CP	14.55	2.46	6.29	1.08
CPL	16.36	2.39	4.70	1.05
CPU	12.75	2.53	7.88	1.12
CPK	12.75	2.39	4.70	1.05
Under Voltage risk	negligible	negligible	negligible	%0.08
Over Voltage risk	negligible	negligible	negligible	%0.04

Figures 1 and 2 and tables 4 have represented the voltage level distribution and detailed process capability analysis result of bus-bar 1 and 19 after network upgrade. Distribution of voltage level in the absence of DG has small standard deviation but the mean of it is far from unity, in contrast, in the presence of DG although the mean value of voltage level is almost unity but standard deviation is very large and in this case DG installation have increased the risk of overvoltage in spite of its ability to enhance the mean of voltage level.

In figure 3 control chart of bus-bar 19 voltage level after network upgrade has been illustrated. In all scenarios voltage level is in ‘acceptable band’ therefore voltage profile of the related bus-bar is stable.

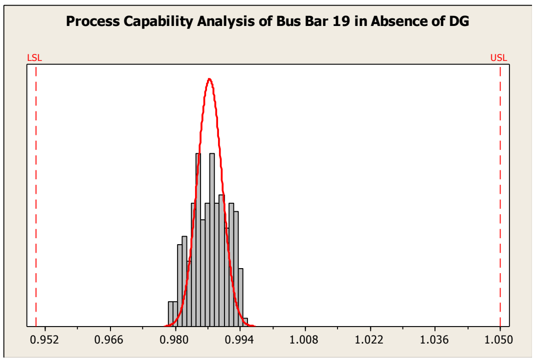

Figure 1: voltage level and fitted normal probability distribution of Bus-bar 19 in the absence of DG

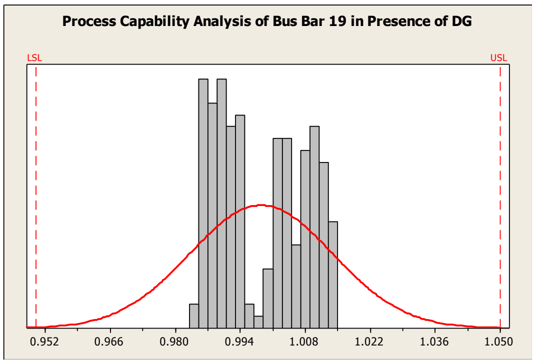

Figure 2: voltage level and fitted normal probability distribution of Bus-bar 19 in the presence of DG

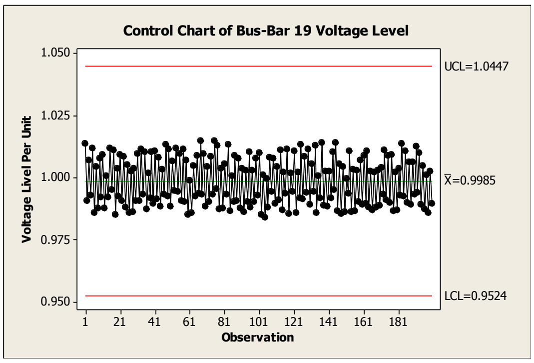

Figure 3: control chart of bus-bar 19 voltage level in the presence of DG

CONCLUSION

Voltage profile is vulnerable to stochastic behaviour of distribution generation especially renewable resource like wind turbines and photovoltaic panels. DG can improve the mean value of voltage level but it can increase its standard deviation. Capability of network to maintain voltage level in specified range is related to both mean value and standard deviation therefore distribution companies should evaluate the risk of overvoltage and undervoltage by statistical tools like control charts and process capability analysis. If process capability indices are small, the risk of overvoltage or undervoltage is very high and it is necessary to modify network design. Simulation and capability analysis help engineers to select appropriate network modification which can improve voltage profile economically.

REFERENCE

[1] John S. Oakland, 2008, *Statistical Process Control*, Elsevier publication, 4:1 pp257-272

[2] Zhou and Zhu, 2011, "Voltage Assessment in Distributed Network with Photovoltaic Plant ", *International Scholarly Research Network.* Volume 2011, Article ID 520278.

[3] Kumar Injeti and Navuri P Kumar, 2011, "Optimal Planning of Distributed Generation for Improved Voltage Stability and Loss Reduction", *International Journal of Computer Applications.* Volume 15– No.1, February 2011.40-46

[4] Chen H., Chen J., Shi D. and Duan X., 2006, "Power Flow Study and Voltage Stability Analysis for Distribution Systems with Distributed Generation ", *Power Engineering Society General Meeting.* Montreal, CANADA.

[5] K. Manjunatha Sharma and K. P. Vittal, 2010, "A Heuristic Approach to Distributed Generation Source Allocation for Electrical Power Distribution Systems", *Iranian Journal of Electrical & Electronic Engineering.* Vol. 6, No. 4, Dec. 2010, 224-231.

[6] M. Sedighizadeh, and A. Rezazadeh, 2008, "Using Genetic Algorithm for Distributed Generation Allocation to Reduce Losses and Improve Voltage Profile", *World Academy of Science, Engineering and Technology.* vol. 37.251-256

[7] M. Suozzi, 1999, "Process capability study", *Hughes Aircraft Company*, Internal document.