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The Presentation of a New Model to Study Influence of Effective Parameters on Operation of Power Distribution Networks Using Experimental Design Method

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Abstract: In this study, after power flow execution in several stages, values of input and output variables are obtained and the effect of the input parameters of system on output parameters is investigated. Each output is expressed as a linear function of input parameters and are calculated with using of linear regression based model for the IEEE 33 buses. The proposed model converges more quickly rather than power flow. Results of presented model are confirmed by the statistics analysis and power flow results (with 2% error-tolerance).

Key words: Radial distribution systems, loss, effective parameters, normal distribution, linear regression, experimental design

INTRODUCTION

In distribution systems which are a connection between consumer and transmission systems, high losses are caused by low voltage and high current. There are different ways to reduce losses in distribution systems. Power distribution reconfiguration is used to reduce losses (Chiang and Jean-Jumeau, 1990; Baran and Wu, 1989). In order to minimize losses in reconfiguration method, the path of passing power from feeder to loads are changed by remaining the radial property of system. Another way to reduce losses is using capacitors in the systems. Power distribution networks losses are reduced by installing parallel capacitors (Chiang *et al*., 1990a, b). The size of capacitors depends on system's parameters and it can be reduced by optimizing the system.

To have a simple method in order to investigate the performance of each system, some output and input quantities can be determined by user. Some of these quantities are less important than the others. The experimental design technique has been applied to different subjects in different science such as Chemistry, Physics, Mathematics, control and electrical engineering to study the influence of the different factors effecting on the studying system (Abdel Aziz *et al*., 2008).

The optimization of the influencing parameters using one variable-at-a-time optimization method required many experiments. Furthermore there are maybe interactions between the investigated parameters. The total number of requires experiments can be reduced using experimental design technique. It is essential that an experimental design methodology will be very economical for extracting the maximum amount of complex information, saving significant experimental time as well as material used for analyses and personal costs. Such designs have been applied to the optimization of different process (Farhadi *et al*., 2008).

An approach based on experimental design has been proposed to build diverse types of sensitivity indices, which are the basis for evaluating efficiency of control actions and, therefore, for constructing rules included in knowledge base (Ekel *et al*., 1999, 2001). Their proposed approach has a universal character. Its validity and efficiency are illustrated by a practical application. The questions of rational implementing procedures of fuzzy inference, excluding manipulations with multidimensional implication relation matrices, have been considered. The results of Ekel *et al*. (1999, 2001) study are part of a project its realization is to improve the efficiency of control in the result of achieving traditional goals (observance of restrictions on voltage levels at buses and power-handling capacity of system elements and reduction of power and energy losses).

The performance of distribution system had been assessed, by means of DOE (Design of Experiment) method and t-student distribution (Nazarko, 2000).

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In order to design the optimum distribution systems, it is necessary to identify the parameters witch have more effects on the cost although after exploitation, by controlling over some parameters we can economize on cost.

At first, this study presents the properties of radial distribution systems. Then effective outputs and inputs parameters are introduced. At last each output is expressed by a linear function of inputs in the system. Coefficients related to each input in the function, which indicate effectiveness of inputs on outputs, are calculated by using of multi-variable regression model (Weisberg, 2005) in a 33 bus system. Obtained quantity from regression model are the estimations of real quantities with good accuracy. Accomplish statistical analysis in this article confirms the attained model for the system. This function can be used to predict output values with different input values.

PROPERTIES OF RADIAL DISTRIBUTION SYSTEMS

Unlike transmission systems, distribution systems have a high ratio of R/X. Therefore, one of the problems in distribution systems is line losses.

In a distribution system with n branch, losses which consist of active and reactive losses can be calculated by the following expression:

$$P_{L,total} = \sum_{i=1}^{n} R_i I_i^2 \tag{1}$$

Where:

I_i = Effective current in ith branch
R_i = Resistance in ith branch

Current in a branch can be divided into two parts: I_a (active) and I_r (reactive). Active and reactive losses are given by:

$$P_{L,active} = \sum_{i=1}^{n} R_i I_{ai}^2 \tag{2}$$

$$P_{L,reactive} = \sum_{i=1}^{n} R_i I_{ri}^2 \tag{3}$$

Finally, active and reactive power in supplying feeder of the system, active and reactive losses and voltage profile are accounted as important parameters in distribution systems. Study the effect of basic parameters on them with simple and efficient model, can improve the performance of the system.

DEFINITION OF INPUT PARAMETERS

There is no limit in defining input parameters. Input parameters could be determined with due to importance and alteration range. Five basic input parameters have been chosen for investigation.

X_1 : Sum load of active power
X_2 : Sum load of reactive power
X_3 : Voltage of system
X_4 : Sum resistance of lines
X_5 : Sum reactance of lines

Some other parameters such as:

- Reactance of supplying transformer
- Resistance of supplying transformer
- Sum of the resistance of receiving transformers
- Sum of the reactance of receiving transformer

Could be chosen as inputs but the changes are considered insignificant in this case.

DEFINITION OF OUTPUT PARAMETERS

Output parameters are also chosen due to their importance. Concerning importance of losses and voltage, output parameters are chosen as:

Z_1: Total active power at supplying bus.
Z_2: Total reactive power at supplying bus.
Z_3: Losses of active current.
Z_4: Losses of reactive current.
Z_5: Distortion of voltage profile.
Z_6: Total input current in distribution system.

Assessing the voltage profile take place with Z_5 variable which is a square deviation of feeder voltage from its nominal voltage (1 P.U). Increasing of this variable is not desirable and defines as below:

$$Z_5 = \sum_{k=1}^{n} (1 - V_k)^2 \tag{4}$$

where, n is number of feeders.

RELATIONSHIP BETWEEN INPUT AND OUTPUT PARAMETERS

According to the Fig. 1 the relationship between set of inputs and outputs can be shown as follow:

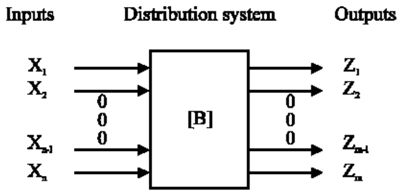

Fig. 1: Model of distribution system to study the effectiveness of parameters

$$F(X_1, X_2, ..., X_n, Z_1, Z_2, .., Z_m) = 0 \tag{5}$$

where, n is the number of inputs and m is the number of outputs. Outputs can be written as a combination of inputs:

$$\begin{aligned} &F_1(X_1, X_2, ..., X_n, Z_1) = 0 \\ &\vdots \\ &F_2(X_1, X_2, ..., X_n, Z_2) = 0 \\ &F_m(X_1, X_2, ..., X_n, Z_m) = 0 \end{aligned} \tag{6}$$

Regression is used to obtain the $F_1 \ldots F_m$ functions. A regression model is a linear function which relates inputs with output.

$$Z = B_0 + B_1X_1 + B_2X_2 + ... + B_nX_n + \varepsilon. \tag{7}$$

Where:
X_i = Inputs
Z = Output
B_i = Regression coefficients
ε_0 = Error

Suppose that output quantities for m set of different inputs are available. The equations are written as:

$$\begin{aligned} &Z_1 = B_{10} + B_{11}X_1 + B_{12}X_2 + ... + B_{1n}X_n + \varepsilon_1, \\ &Z_2 = B_{20} + B_{21}X_1 + B_{22}X_2 + ... + B_{2n}X_n + \varepsilon_2, \\ &\vdots \\ &Z_m = B_{m0} + B_{m1}X_1 + B_{m2}X_2 + ... + B_{mn}X_n + \varepsilon_m. \end{aligned} \tag{8}$$

Unknown coefficients should be calculated in a manner which

$$\sum_{i=1}^{m} \varepsilon_i^2$$

are minimized so

$$\sum_{i=1}^{m} \varepsilon_i^2$$

is written as a function of B_i:

$$L = \sum_{i=1}^{m} \varepsilon_i^2 = \sum_{i=1}^{m} (Z_i - B_0 - \sum_{j=1}^{n} B_jX_{ij})^2 \tag{9}$$

Function L should be minimized. Therefore partial differentiations of L should be equal by zero.

$$\begin{aligned} &\frac{\partial L}{\partial B_0} = -2\sum_{i=1}^{m}(Z_i - B_0 - \sum_{j=1}^{n} B_jX_{ij}) = 0 \\ &\vdots \\ &\frac{\partial L}{\partial B_j} = -2\sum_{i=1}^{m}(Z_i - B_0 - \sum_{j=1}^{n} B_jX_{ij})X_{ij} = 0 \quad j = 1, ..., n \end{aligned} \tag{10}$$

Simplifying Above equations leads to a system of linear Equations $\hat{Y} = XB$, which is solved to attain B_i coefficient.

CALCULATION OF RELATIVE COEFFICIENT BETWEEN INPUT AND OUTPUT

In order to calculate relative coefficient B, at first we run the load flow program for some different inputs and attain the output values. Then we attain a function using regression model to relate inputs to outputs. Finally we can relies which input have less or any effect on output. For calculating coefficients at least arrangements of input quantity is needed. More arrangements of input quantities will decrease error of each coefficient.

The scheme of input arrangement is constructed on the basis of Placket-Burman algorithm with combination of maximum and minimum variation. The Plackett and Burman (1946) statistical experimental design is very useful for screening the important variables. The total number of experiments to be carried out is K + 1, where K is the number of variables. Each variable is represented at two levels high and low denoted by (+) and (-), respectively (Imandi *et al*., 2008).

Assumed ranges of possible variation of input quantities are presented in Table 1.

Basis quantities are shown in the last arrangement in Table 2. X_0 is a hypothetical variable which always has increasing variation.

Five basic input and six output quantities have been chosen for investigation of mentioned system. Per unit inputs and outputs quantities are presented in Table 3.

Finally by usage of linear regression, unknown coefficients in (8) are obtained and results are shown in (11).

ANALYSIS OF OBTAINED COEFFICIENTS

Obtained coefficients in (11) differ in quantity and sign. Positive mark shows the same changes in output and input while negative mark shows different changes. In other words, an increase in input variables causes decreasing in output variables and vice versa.

Table 1: Range of variation of parameters in distribution system

Inputs	Range of variations (%)
X_1	±20
X_2	±15
X_3	±5
X_4	±12
X_5	±3

Table 2: Set of input arrangements in distribution system

Arrangement of inputs	Inputs					
	X_0	X_1	X_2	X_3	X_4	X_5
1	+	-	-	+	+	-
2	+	-	+	-	-	-
3	+	+	+	-	-	+
4	+	+	+	-	+	-
5	+	+	+	+	-	-
6	+	+	-	+	-	-
7	+	0	0	0	0	0

Table 3: Perunit quantities variable

X_{base}		Z_{base}	
$X_{1,base}$	3.7150 (kW)	$Z_{1,Base}$	5.5672 (MW)
$X_{2,base}$	1.9400 (kVar)	$Z_{2,base}$	2.1940 (MVar)
$X_{3,Base}$	10.0000 (kV)	$Z_{3,Base}$	1.8522(MW)
$X_{4,base}$	21.5785 (Ω)	$Z_{4,Base}$	0.2542 (MW)
$X_{5,Base}$	18.7883 (Ω)	$Z_{5,Base}$	0.4342
		$Z_{6,Base}$	456.97 (A)

$$
\begin{aligned}
Z_1 &= -0.6734+1.1620\ X_1+0.2589\ X_2-0.0881\ X_3+0.3842\ X_4-0.0283\ X_5\\
Z_2 &= -0.3085+0.1911\ X_1+0.9741\ X_2-0.0086\ X_3+0.0263\ X_4+0.1320\ X_5\\
Z_3 &= -2.0240+1.4869\ X_1+0.7781\ X_2-0.2648\ X_3+1.1548\ X_4-0.0849\ X_5\\
Z_4 &= -2.6633+1.6493\ X_1+0.7765\ X_2-0.0741\ X_3+0.2266\ X_4+1.1392\ X_5\\
Z_5 &= -2.8224+1.7165\ X_1+0.8909\ X_2-0.7596\ X_3+1.6994\ X_4+0.3491\ X_5\\
Z_6 &= -0.2454+0.8345\ X_1+0.2670\ X_2+0.0421\ X_3+0.0630\ X_4+0.0459\ X_5
\end{aligned} \tag{11}
$$

Variables in (11) are considered in per unit form and it can explain importance of parameters and effectiveness. For example sum of load active power (X_1) and sum of reactance of lines have maximum and minimum effects on losses of active currency part (Z_3).

X_3 Coefficient (voltage of system) is negative in Function Z_3. Table 4 shows that increasing in voltage of system will causes decreasing in losses of active currency part.

According to Fig. 2, remains accumulation is more between 0.01 to -0.01. So residuals have normal distribution and attained model is suitable. In addition variances of residuals for outputs are near to zero (Table 5), as a result the regression is so accurate.

CONFIRMATION OF ATTAINED MODEL

Attained quantities are compared with result of load flow by using three arrangements of inputs and efficiency of proposed model will be considered.

±20% variations of load active power: In this case, only one parameter (load active power) is changed. Results in Table 6 confirm qualitative conclusion in Table 4.

Table 4: Relation between inputs and outputs

Output parameters	Input parameters				
	ΔP_{load}	ΔQ_{load}	ΔV	$\Delta(\Sigma R_{branch})$	$\Delta(\Sigma R_{branch})$
Total active power at supplying bus	+	+	-	+	-
Total reactive power at supplying bus	+	+	-	+	+
Losses of active currency part	+	+	-	+	-
Losses of reactive currency part	+	+	-	+	+
Demolition of voltage profile	+	+	-	+	+
Total currency in distribution system	+	+	+	+	+

Table 5: Variances of residuals

Z_1	Z_2	Z_3	Z_4	Z_5	Z_6
0.026	0.008	0.08	0.071	0.016	0.0071

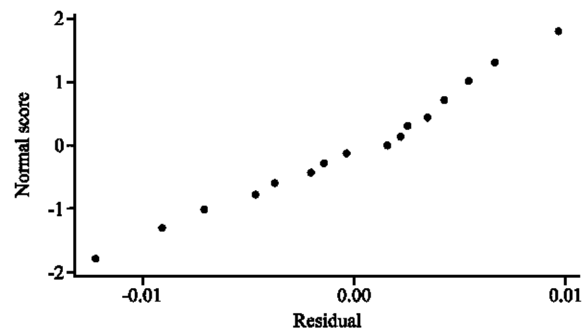

Fig. 2: Normal probability plot of residuals with MINITAB

According to the achieved model, it is anticipated that increasing load active power, leads to increasing all output variables. In Table 6, by increasing 10% of load active power, all outputs variables increased and it will confirm the qualitative results. In addition insignificant errors (1.5-4%) will confirm quantitative results of model. Decreasing in load active power will decrease outputs and it has been also shown in Table 6.

Variation of ±4% in voltage: In this case, the efficiency of the model will be assessed only with change of voltage parameter. According to Table 4, increasing in voltage quantity causes increasing in currency of the system but other outputs will decrease. The result of load flow model confirms the accuracy of proposed model. In other side, according to Table 6, the effectiveness of X_3 (voltage of the system) in Z_6 (total currency of system) is insignificant in both condition of increasing and decreasing voltage and it will confirm represented model. Quantity of increasing in total currency with ±4% variations of voltage is about 0.06% and it can be equaled by zero in proposed model so the model will be simplified. The other noticeable point is that: because of low losses,

Table 6: Results obtained from response of the system to variations of voltage and load active power from proposed model and comparison with load flow results

	Case studies							
	First case				Second case			
	Input condition				Input condition			
	Decreasing load active power by 10%		Increasing load active power by 10%		Decreasing voltage of the system by 4%		Increasing voltage of the system by 4%	
	Investigation method		Investigation method		Investigation method		Investigation method	
Output parameters	Load flow	Model	Load flow	Model	Load flow	Model	Load flow	Model
Z_1	1.1911	1.1315	0.8868	0.8991	0.9707	0.9849	1.0342	1.0491
Z_2	1.0201	1.0255	0.9824	0.9873	0.9886	0.9941	1.0136	1.0202
Z_3	1.1573	1.1648	0.8604	0.8974	0.9119	0.9248	1.0280	1.0477
Z_4	1.1732	1.1991	0.8484	0.8893	0.9017	0.9282	1.1173	1.1334
Z_5	1.1779	1.1955	0.8420	0.9022	0.8309	0.8490	1.2171	1.2485
Z_6	1.0854	1.0906	0.9174	0.9237	0.9930	1.0006	1.0082	0.9987

Table 7: Results obtained from response of the system to variations for all inputs and comparison with load flow results

		Investigation method	
Output parameters	Input variation	Load flow	Model
Z_1	X_1 (-10%)	0.8611	0.8696
Z_2	X_2 (10%)	1.0685	1.0718
Z_3	X_3 (2.5%)	0.7829	0.8087
Z_4	X_4 (-10%)	0.8277	0.8560
Z_5	X_5 (-2%)	0.6783	0.7052
Z_6		0.9348	0.9393

Table 8: Quantities of outputs variations to inputs variations

		Investigation method	
Output parameters	Input variation	Load flow	Model
Z_1	X_1 (10%)	1.1040	1.1167
Z_2	X_2 (-5%)	0.9543	0.9605
Z_3	X_3 (5%)	1.1121	1.1302
Z_4	X_4 (10%)	0.9875	1.0392
Z_5	X_5 (-3%)	1.0460	1.0572
Z_6		1.0703	1.0736

voltage profile is much better in high voltage distribution system and this point has been showed in proposed model.

Exerting different inputs with different variations: One of the capabilities of an efficient model is response to simultaneous variations in random inputs. In order to show this capability of proposed model, different inputs with different variations are exerted into the system (Table 7, 8). Results gained from both ways shows mentioned capability and the accuracy of the model. Errors are also insignificant in this case.

CONCLUSION

In this study the performance of distribution system with different inputs were studied. Output quantities were stated as a linear function of inputs. Different inputs in permissible range exerted into a system based on Placket-Burman algorithm. Unknown coefficients were calculated with multi-variable regression and the accuracy of the coefficients was confirmed with statistical analysis of residuals with normal distribution. Outputs Variation by changes of inputs was studied in points of qualitative and quantitative view and was compared with the results of load flow. Insignificant error about 1.5% show high efficiency in estimate of output. In step forward, outputs of model were compared with the result of load flow and with 2% error the comprehensiveness of model were confirmed. In this method, there is no limitation in defining outputs and inputs. For the usage of more output and inputs, only number of input arrangements will be increased.

Represented model in this study, can be used in forecasting outputs of the system for different inputs and the effects of each input on outputs will be analyses.

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