International Journal on "Technical and Physical Problems of Engineering" (IJTPE)
Published by International Organization of IOTPE
ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com
June 2022 | Issue 51 | Volume 14 | Number 2 | Pages 293-301

ENERGY MANAGEMENT AND LOSS REDUCTION BY CAPACITOR: METHODS, DAMAGES AND SOLUTIONS

N. Taghizadegan Kalantari M. Ahangari Hassas

Department of Electrical Engineering, Faculty of Engineering, Azarbaijan Shahid Madani University, Tabriz, Iran
ntaghizadegan@yahoo.com, morteza.ahangar@yahoo.com

Abstract- The energy management strategy should ensure high system efficiency and high reliability with least cost. In the paper after a comprehensive examination of the issue, an optimal and innovative method is offered for locating and sizing of capacitor banks along a distribution feeder. The method is based on the identification of electric reactive power on a distribution feeder. In the planned method electric reactive power of the capacitor bank placed in a location is proportionate to the electric reactive power feeding in that location. Hence electric reactive power compensation is completely achieved and loss minimization is attained. On the other hand, it would be probable that the number of capacitor positioning location is lessened, so the electric reactive power of capacitor banks is enlarged, then, the cost of electric reactive power compensation is also lessened.

Keywords: Energy Management, Electric Distribution Feeder, Capacitor Bank, Loss Reduction, Locating.

1. INTRODUCTION

Formerly, electric distribution networks have not received as much attention as electric generation and transmission networks. Deregulation of the electric power system is causing extensive variations in the electric distribution network. The increasing needs of different customers and the state-of-the-art technologies being established to attain such necessities relative to regulatory supervision are the motivations that are bringing about an innovative modification in electric distribution networks.

Energy consuming at high power quality with a high level of reliability is greatly looked for now than ever before. Efficient automation design and functioning tools are essential to make the developing electric distributions networks robust, efficient and cost effective. It is an essential condition imposed by restructuring. A diversity of technological remedies must be established and fulfilled to cater to the miscellaneous demands. Electric distribution power firms must be flexible so as to contest efficiently with their contestants. So, electric distribution networks must be optimally planned and functioned [1-4].

Researchers have used a wide variety of methods in an attempt to solve the problem of loss minimization in distribution networks [5]. But none of them is economically considered the matter in the deregulated power system. In this paper, in view point of economical matter, a simple and practical procedure is presented for loss minimization through a distribution feeder by optimal sizing and positioning of electric capacitor banks on the electric distribution feeder. The method is based on the identification of electric reactive power on the electric distribution feeder. In the proposed method, the reactive power of the capacitor bank that is installed at one point is very close to the reactive power consumption at the same point [6, 7]. So, electric reactive power compensation is nearly completely accomplished and loss minimization is attained.

2. POSITIONING AND SIZING FOR MINIMUM LOSS

A typical electric distribution network is shown in Figure 1. Electric reactive current at start and finish of electric feeder is nominated as I_1 and KI_1, respectively. The electric reactive current is presumed to be unvaryingly distributed on the line and is assumed a lumped load at the end. The relation for electric reactive current as a function of x may be quantified as [8]:

$$i(x)=\frac{KI_1-I_1}{l}x+I_1 \tag{1}$$

The electric power loss at each phase because of the reactive com-ponent of line current is:

$$P_{Loss}=\int_0^l i^2(x)Rdx \tag{2}$$

After some calculations we can write:

$$P_{Loss}=\frac{l}{3}I_1^2(K^2+K+1)R \tag{3}$$

By using equation $Q=\sqrt{3}V_L I_L$ we have:

$$P_{Loss}=\frac{l}{9V_L^2}Q_1^2(K^2+K+1)R \tag{4}$$

where, R is the resistance of one meter of the feeder.

When only one capacitor is attached to the feeder, reactive current profile is changed to that of Figure 2. Reactive current of the feeder maybe written as follows [9]:

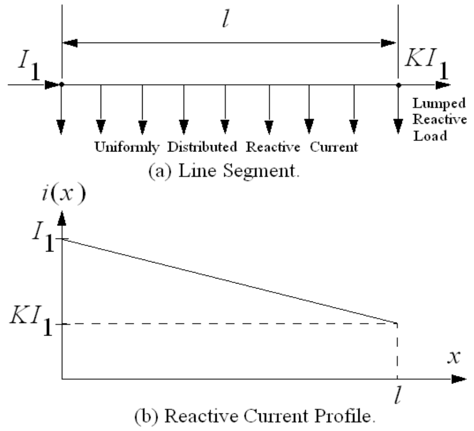

Figure 1. Reactive load current distribution

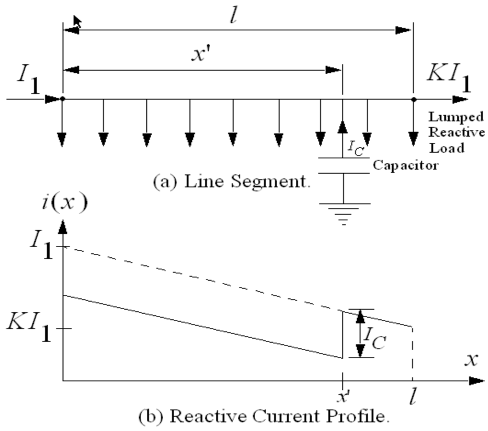

Figure 2. Reactive load current distribution with capacitor added

$$i(x) = \frac{KI_1 - I_1}{l}x + I_1 - I_c \qquad 0 \le x \le x' \tag{5}$$

and

$$i(x) = \frac{KI_1 - I_1}{l}x + I_1 \qquad x_1 \le x \le l \tag{6}$$

The power loss per phase with installation of the capacitor bank can be obtained by (2) as:

$$P_{Loss} = \{\frac{x'^2}{l}\left(I_1 I_c (1-K)\right) + x'(I_c^2 - 2I_1 I_c) + \frac{l}{3}\left[I_1^2\left(K^2 + K + 1\right)\right]\}R \tag{7}$$

by means of relation, $Q = \sqrt{3}V_L I_L$, the outcome is [10]:

$$P_{Loss} = \frac{1}{3V_L^2}\{\frac{x'^2}{l}\left(Q_1 Q_c (1-K)\right) + x'(Q_c^2 - 2Q_1 Q_c) + \frac{l}{3}\left[Q_1^2 (K^2 + K + 1\right]\}R \tag{8}$$

In order to obtain the optimal value and location for capacitor placement with the aim of minimizing losses, derivatives of (7) or (8) are calculated in regard to I_c and x', then equating them to zero the result are as follows [11]:

$$\frac{\partial P_{Loss}}{\partial x'} = 0 \tag{9}$$

$$\frac{\partial P_{Loss}}{\partial I_c} = 0 \tag{10}$$

The results are as follows:

$$x' = \frac{2/3}{1-K}l \tag{11}$$

$$I_c = \frac{2}{3}I_1 \tag{12}$$

where, $K \ge \frac{1}{3}$ the results will be as follows:

$$x' = l \tag{13}$$

$$I_c = \frac{K+1}{2}I_1 \tag{14}$$

3. IDENTIFICATION Of REACTIVE POWER

Reactive powers are measured at a number of locations on the electric feeder. Hence, the profile of reactive power is as shown in Figure 3. Assuming that at point x_i, the reactive power measurement is Q_i, its model maybe written as follows [12]:

$$Q_i(x_i) = ax_i^2 + bx_i + c + e_i \tag{15}$$

where, constant parameters of a, b and c must be determined. Also, e_i is the error function. Now it is assumed that:

$$\theta = [a \;\; b \;\; c]^t \tag{16}$$

$$Y = [Q_0 \;\; Q_1 \; ...Q_i ...Q_N]^t \tag{17}$$

$$U = \begin{bmatrix} 0 & x_1^2 & ... & x_i^2 & ... & \ell^2 \\ 0 & x_1 & ... & x_1 & ... & \ell \\ 1 & 1 & ... & 1 & ... & 1 \end{bmatrix}^t \tag{18}$$

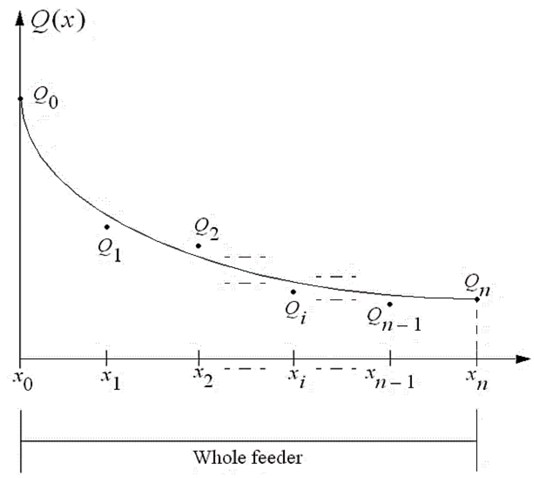

Figure 3. Profile of reactive power along the feeder

We can write all the data in matrix form as [12]:

$$Y = U\theta + e \tag{19}$$

Cost function of the error is defined as:

$$S = e^t e \tag{20}$$

Derivative of Equation (20) is calculated in regard to the θ, and is equated with zero as follows:

$$\frac{\partial S}{\partial \theta}=0 \tag{21}$$

The result is as follows:

$$\theta=\left(U^t U\right)^{-1} U^t Y \tag{22}$$

Now constants of the *a*, *b* and *c* maybe calculated and the reactive power equation can be written as follows:

$$Q=ax^2+bx+c \tag{23}$$

3.1. Approximating a Parabola with Adjoining Lines

With the aim of approximating a parabola with the adjoining lines, assuming that ends of the lines are positioned on the parabola as shown in Figure 4, then zone function can be defined in this manner [13]:

$$\begin{aligned} S(x_1,x_2,...,x_{i-1},x_i,...x_{n-1}) &= \frac{x_1}{2}(ax_1^2+bx_1+2c)+ \\ &+\frac{x_2-x_1}{2}[a(x_1^2+x_2^2)+b(x_1+x_2)+2c]+ \\ &+...+\frac{x_i-x_{i-1}}{2}[a(x_i^2+x_{i-1}^2)+b(x_i+x_{i-1})+2c]+...+ \\ &+\frac{l-x_{n-1}}{2}[a(x_{n-1}^2+l^2)+b(x_{n-1}+l)+2c] \end{aligned} \tag{24}$$

where, *S* is equal to the geometric area between the all lines and abscissa.

The following derivatives are taken [13]:

$$\frac{\partial S}{\partial x_1}=0,\ ...\ ,\ \frac{\partial S}{\partial x_i}=0\ ...\ ,\ \frac{\partial S}{\partial x_{n-1}}=0 \tag{25}$$

Following set of equations can be obtained:

$$x_1=\frac{1}{n}l,\ ...\ ,\ x_i=\frac{i}{n}l,\ ...\ ,\ x_{n-1}=\frac{n-1}{n}l \tag{26}$$

Briefly, if the length of *l* is likewise separated, approximating of a parabola with the adjoining lines is attained.

4. OBJECTIVE FUNCTION

Objective function maybe written in this way:

$$J(n)=C_{Loss}(n)+C_{cap}(n) \tag{27}$$

$$J(0)=C_{Loss,0} \tag{28}$$

where, *n* is the number of subsections or capacitor banks; $C_{Loss,0}$ is the charge of electric feeder losses before installation of any capacitor banks; $C_{Loss(n)}$ is the charge of electric feeder losses next to connection of *n* capacitor banks through their period of operation and $C_{cap(n)}$ is the charge of buying, connection, maintenance, and repair of capacitor banks through their period of operation.

4.1. Minimization of the Objective Function

The differentials of objective functions are measured till the differential turn out to be negative. At that time, the past *n* becomes the number of optimal subsections which minimize the objective function. The method is exemplified as in Figure 5.

$$\Delta J(n)=J(n)-J(n+1)\ \ ,\ \ n=0,1,2,... \tag{29}$$

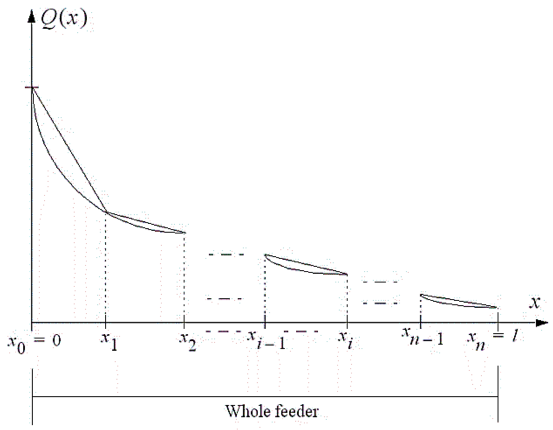

Figure 4. Approximating a parabola with adjoining lines

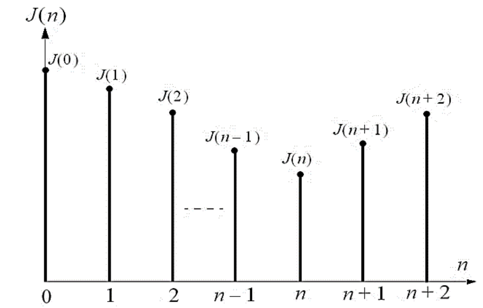

Figure 5. Illustration of minimization of objective function

5. A CASE STUDY IN TABRIZ DISTRIBUTION FEEDER

In a three-phase distribution network in the city of Tabriz, the measurements of lengths and reactive powers at some locations are made known in Table 1. The reactive power model is obtained as given by (23) like this [18]:

$$Q(x)=-0.0227x^2-115.7044x+7.9751\times 10^4\ \text{VAr} \tag{30}$$

Firstly, based on the result of section 3.1, the overall line length of the feeder is equally divided into *n* line subsections. The correct procedure is to begin for locating and sizing the capacitors at the line subsection farthest away from the source, i.e., subsection *n*. Next, the reactive profile of all the line subsections closer to the source, i.e., subsections *n*–1, …, 1 will be modified. The same procedure is repeated till the line subsection 1 is reached.

This procedure will result in the minimizing of losses for all line subsections of the feeder. Therefore, line subsection *n* will be analyzed first, followed by line subsection *n*–1 and so on.

For the reason that the capacitor banks must be installed on the poles, the actual position for the installation of the capacitor banks are usually other than calculated ones. The actual position for installation of capacitor banks is given by:

$$x_{act}=[\frac{x_{cal}}{d}+\frac{1}{2}]\times d \tag{31}$$

where, [] is the operator of Greatest Integer Function for its operand;

where, x_{act} is the actual position for installation of the capacitor banks, x_{cal} is the calculated position for installation of the capacitor banks and d is the distance between two nearby poles.

The procedure for minimization of cost function presented in section 4.1 is applied on the distribution system and the results are mentioned in Table 2. Aimed at n=4 the optimum outcome is gained. Loss reduction of electric feeder and reactive power compensation are shown in Table 3, in percent.

Table 1. The measurements of lengths and reactive powers at some locations

x [m]	$Q(x)$ [kVAr]	x [m]	$Q(x)$ [kVAr]	x [m]	$Q(x)$ [kVAr]
0	79.5	240	50.5	510	17.0
30	76.0	300	44.0	540	7.5
90	69.5	360	37.5	610	2
150	63.0	390	28	-	-
180	57.0	450	23	-	-

Table 2. Number of subsections and the specifications of installed capacitor banks in the typical feeder

Number of subsections	Location and size of capacitor banks	First capacitor bank	Second capacitor bank	Third capacitor bank	Fourth capacitor bank	Fifth capacitor bank	Sixth capacitor bank
n=1	l_C [m]	410	-	-	-	-	-
	Q_C [kVAr]	4×12.5	-	-	-	-	-
n=2	l_C [m]	512	298	-	-	-	-
	Q_C [kVAr]	2×12.5	3×12.5	-	-	-	-
n=3	l_C [m]	347	395	169	-	-	-
	Q_C [kVAr]	2×12.5	2×12.5	2×12.5	-	-	-
n=4	l_C [m]	563	455	280	152	-	-
	Q_C [kVAr]	12.5	2×12.5	12.5	2×12.5	-	-
n=5	l_C [m]	573	473	366	244	122	-
	Q_C [kVAr]	12.5	12.5	12.5	2×12.5	2×12.5	-
n=6	l_C [m]	580	488	393	297	199	98
	Q_C [kVAr]	12.5	12.5	12.5	12.5	12.5	12.5

where, l_C is the distance of capacitor installation point from the beginning of the feeder and Q_C is the reactive power of installed capacitor bank.

Table 3. Reduction of loss and compensation of reactive power in a typical feeder for several subsections

Number of subsections	Reduction of loss (%)	Compensation of reactive power (%)
n=1	88.6	62.9
n=2	91.1	78.6
n=3	94.5	94.3
n=4	96.1	95.3
n=5	97.5	96.1
n=6	98.4	97.3

6. PRINCIPAL THEORY OF THE VOLTAGE MAGNIFICATION

As you see in Figure 6, we consider a distribution network to explore the voltage magnification.

The switching of capacitor C_2, on the load side creates the over voltages in the range of 1.3-1.4 [pu] in the load. The switching of capacitor C_1, on the substation side creates the over voltages in the range of 3-4 [pu] in the load. The equivalent circuit of this network during transient states has been shown in Figure 7.

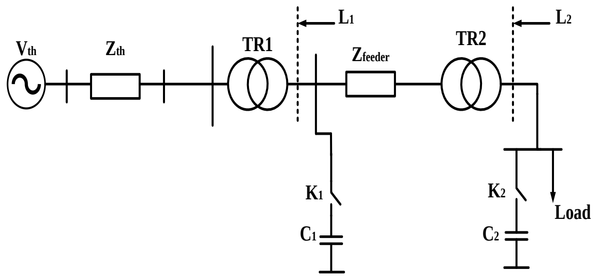

Figure 6. A sample distribution network

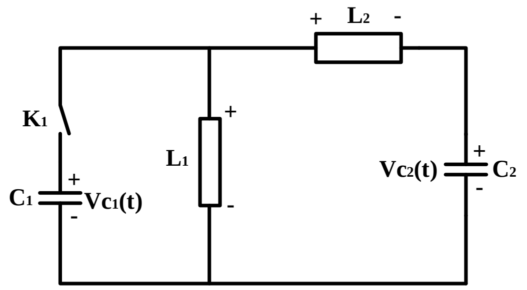

Figure 7. The equivalent circuit of the distribution network during the transient state

When capacitor switching happens, the initial voltages and currents are given in capacitors and inductors, respectively as follows:

$$v_{C1}(0) \triangleq 0 \tag{32}$$

$$v_{C2}(0) \triangleq V_2 \tag{33}$$

$$i_{L1}(0) \triangleq I_1 \tag{34}$$

$$i_{L2}(0) \triangleq I_2 \tag{35}$$

To obtain bus voltages after capacitor switching, C_1, equations of the network node are given as a matrix as follows:

$$Y_n e = i_s \tag{36}$$

where, Y_n is the admittance matrix of nodes, e is the voltage supply matrix of nodes, and i_s is the current supply matrix of nodes [8].

Network nodal equation can be written in the time domain or Laplace domain. To obtain the equations in the Laplace domain, considering initial conditions of the distribution network, the network is shown again in Figure 8.

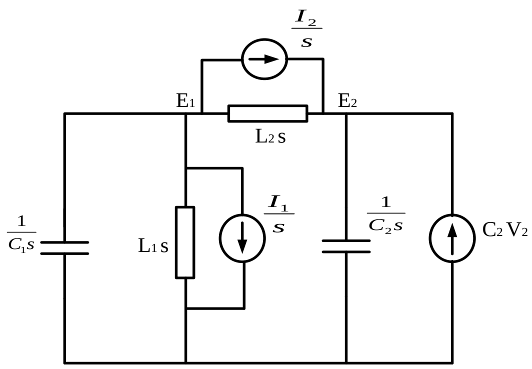

Figure 8. The schematic diagram of the distribution network in the Laplace domain during the transient state

According to the Figure 8, we have:

$$Y_n(s)=\begin{bmatrix} C_1 s+\frac{1}{L_1 s}+\frac{1}{L_2 s} & -\frac{1}{L_2 s} \\ -\frac{1}{L_2 s} & C_2 s+\frac{1}{L_2 s} \end{bmatrix} \quad (37)$$

$$E(s)=\left[E_1(s) \quad E_2(s)\right]^t \quad (38)$$

$$I_s(s)=\left[-\left(\frac{I_1}{s}+\frac{I_2}{s}\right) \qquad \frac{I_2}{s}+C_2 V_2\right]^t \quad (39)$$

According to Equations from (36) to (39), the voltage, $E_2(s)$, can be written as follows:

$$E_2(s)=\frac{V_2 s^3+\frac{I_2}{C_2}s^2+\frac{V_2}{C_1}\left(\frac{1}{L_1}+\frac{1}{L_2}\right)s+\frac{1}{C_1 C_2}\left(\frac{I_2}{L_1}-\frac{I_1}{L_2}\right)}{s^4+\left(\omega_1^2+\omega_2^2+\frac{1}{C_1 L_2}\right)s^2+\omega_1^2\omega_2^2} \quad (40)$$

where, we have:

$$\omega_1 \triangleq \frac{1}{\sqrt{L_1 C_1}} \quad (41)$$

$$\omega_2 \triangleq \frac{1}{\sqrt{L_2 C_2}} \quad (42)$$

If s_1 and s_2 are roots of the characteristic equation of $E_2(s)$, then we have:

$$s_1^2+s_2^2=-\left(\omega_1^2+\omega_2^2+\frac{1}{C_1 L_2}\right) \quad (43)$$

$$s_1^2 s_2^2=\left(-\omega_1^2\right)\left(-\omega_2^2\right) \quad (44)$$

If we consider an assumption as follows:

$$\omega_1^2+\omega_2^2 \gg \frac{1}{C_1 L_2} \quad (45)$$

so, we have:

$$s_1^2=s_2^2=-\omega_1^2=-\omega_2^2 \triangleq -\omega_0^2 \quad (46)$$

Hence, the voltage function changes as follows:

$$E_2(s)=\frac{N(s)}{\left(s^2+\omega_0^2\right)^2} \quad (47)$$

where, $N(s)$ is the numerator of the voltage function. The Equation (47), shows that the load voltage can be high when $\omega_1=\omega_2=\omega_0$, because the circuit resonates at the frequency ω_0. Briefly, we have:

$f_1=f_2 \Leftrightarrow$ Voltage Magnification

Our goal is not to solve Equation (47). This Equation is used only for comparison and measurement. In this Equation, resistors of the distribution network have been ignored. It is noted that the resistance creates damping in the amplitude of fluctuations. In the following, the response of the Equation (47) is reviewed by simulation during different states with the help of EMTP software.

7. SIMULATION OF TRANSIENT OVER-VOLTAGES AND DISCUSSION OF POWER QUALITY

According to these simulations, the distribution system of the Figure 6, is studied under different states.

In this study, all parameters of the distribution system are constant. Only C_1 and C_2 change due to switching effect. Information about the various components of the distribution system have been given in Table 4. Simulations are performed in two states, i.e., $f_1 \neq f_2$ and $f_1 = f_2$.

7.1. The First State: $f_1 \neq f_2$

In this state, the capacitance of C_1 and that of C_2 are given as follows:

C_1=100 [μF]

C_2=1400 [μF]

Simulation results of consumer voltages and those of the distribution substation have been shown in Figures 9 and 10, respectively.

Table 4. Numerical values of components in the distribution network

	TR_1	TR_2	Z_{feeder}	Z_{th}	V_{th}
V_1 [KV]	63	20	-	-	63
V_2 [KV]	20	380	-	-	-
X	0.16 [pu]	0.06[pu]	0.0314[Ω]	0.0314 [Ω]	-
R	0.12 [pu]	0.04 [pu]	0.1 [Ω]	0.5 [Ω]	-
S [MVA]	25	1	-	-	-
f [Hz]	50	50	50	50	50
R_c [pu]	500	500	-	-	-
X_m [pu]	500	500	-	-	-

7.1.1. The Consumer Voltage

As you can see in Figure 9, first, the key of K_2 is closed on the consumer side at t = 0.25T, where, T is the fluctuation period of the power voltage. On the load side, the maximum transient voltage or transient recovery voltage are less than 2 [pu]. The tear and wear of transient states due to the switching occurs within almost 0.5T. In t = 1.25T, the key of K_1 is closed on the distribution substation side.

The amplitude of transient states of the consumer voltage are higher than before i.e., 2 [pu]. Duration time of fluctuations and depreciation is relatively longer. In this state, the consumer voltage has three various frequencies with different harmonics [9]. The power quality (voltage quality) is strongly influenced by the switching and is not satisfactory.

7.1.2. The Voltage of The Distribution Substation

Figure 10 shows the voltage of the distribution substation. In t = 0.25T, the transient state created by the voltage is not very high. In t = 1.25T, the distribution bus voltage decreases strongly. This damping takes a long time. The power quality (voltage quality) is influenced by switching and is low.

7.2. The Second State

In this state, the capacitance of C_1 and that of C_2 are given as follows:

C_1=10 [μF]

C_2=1400 [μF]

Simulation results of consumer voltages and those of distribution substation have been shown in Figures 11 and 12, respectively.

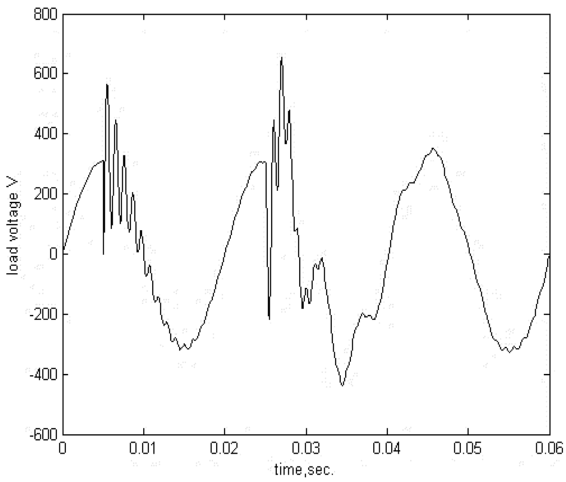

Figure 9. Transient states of the bus voltage due to closing keys of K_1 and K_2 in the first state ($f_1 \neq f_2$)

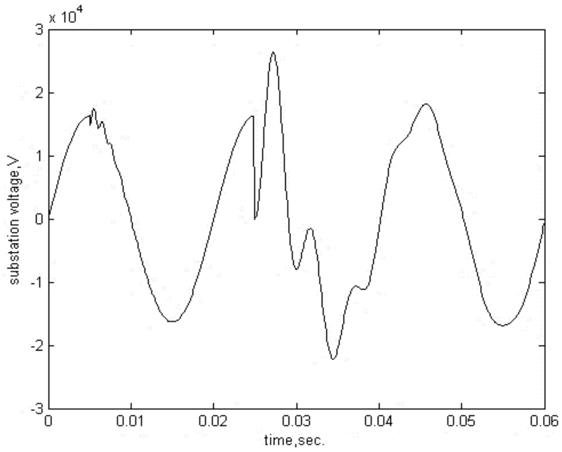

Figure 10. The transient state of the distribution bus voltage due to closing keys of K_1 and K_2 in the first state ($f_1 \neq f_2$)

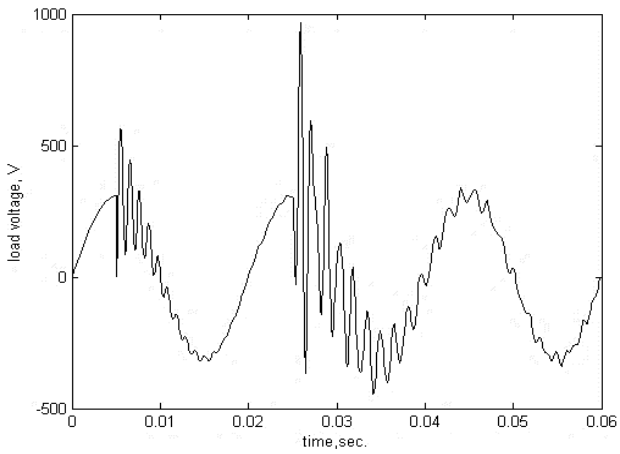

Figure 11. The transient state of the consumer bus voltage due to closing keys of K_1 and K_2 in the second state ($f_1 = f_2$)

7.2.1. The Consumer Voltage

The first switching does not have any difference with the first state. In the second switching, the excess amplitude of transient voltages is very high and more than 3 [pu], i.e., the voltage magnification. Duration time of fluctuations and depreciation is relatively longer.

In addition to fluctuation of the power frequency, only one fluctuation is shown during the voltage transient state ($f_1 = f_2$). The power quality (voltage quality) is very low.

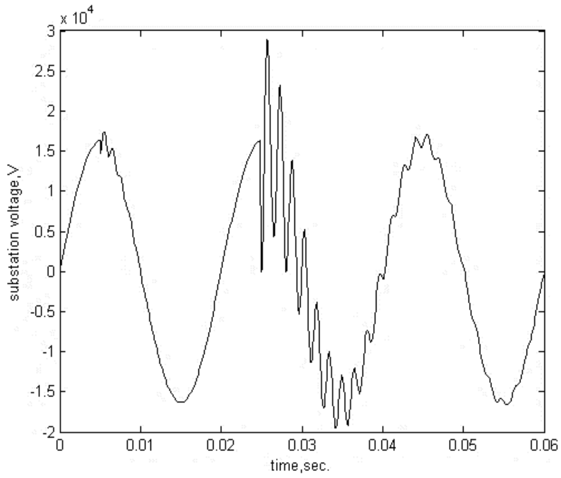

Figure 12. Transient states of the distribution substation voltage due to closing keys of K_1 and K_2 in the second state ($f_1=f_2$)

7.2.2. The Distribution Substation Voltage

The first switching does not have so much difference with the first state. In the second switching, the voltage has many depressions and distortions. Damping time of fluctuations is very long. The excess amplitude of the voltage is between 1 and 2 [pu]. The power quality (voltage quality) is very poor.

8. SOLUTIONS

Because of wide range for power correction capacitors and distribution transformer, the change of their size is not a practical solution for preventing of the voltage magnification [10-13]. Seven different methods are proposed to control the transient over-voltages that happen by closing capacitor in distribution substation as follows:

- The use of keys with an initial resistance;
- The use of synchronous closing keys;
- The use of a small reactor in series with a capacitor;
- The use of surge arrester on the consumer side;
- The use of harmonic filters instead of power factor correction banks;
- Closing the capacitor in the distribution substation at a convenient time before increase of the load demand;
- Closing the capacitor in the appropriate distribution substation.

8.1. Resimulation with Applying Two Solutions

In this section, only the effects of initial series resistors along with synchronous key closing are simulated [14, 15].

8.2. Initial Series Resistor

Such keys have an initial resistor in series with themselves. At time $t = 0.25T$, this resistor run out of the circuit. But during this time, the resistor shows its impact on amplitude reduction of the over-voltages. Here, at the worst case that $f_1 = f_2$ and the highest amplitude of transient over-voltages occurs, the simulations are performed. Figures 13 and 14 show voltages of the load and those of the distribution substation with the least value of the resistor used for closing the key. The least value of closing resistor is selected with trial and error or experimentally in order to not allow the second over-voltages exceeds the initial over-voltages. It is observed that due to using the closing resistor, transient states are reduced and the power quality (voltage quality) is improved than before.

Figures 15 and 16 show voltages of the load and those of the substation at the worst case ($f_1 = f_2$). Here, the resistor for closing the key is bigger than the least necessary value, albeit this value is not used in practice [16]. Obviously, using bigger closing resistors improve much better the power quality (voltage quality).

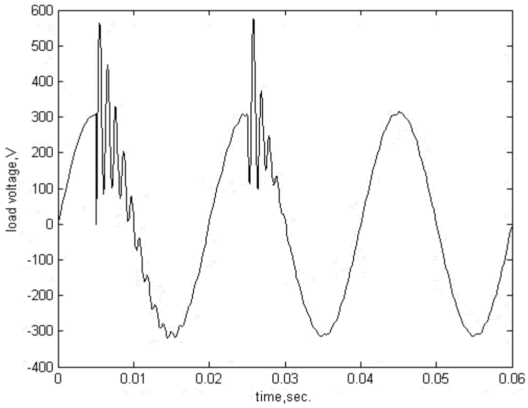

Figure 13. Transient over-voltages of the load in the worst case with the least closing resistor of R_{min}=23 Ω

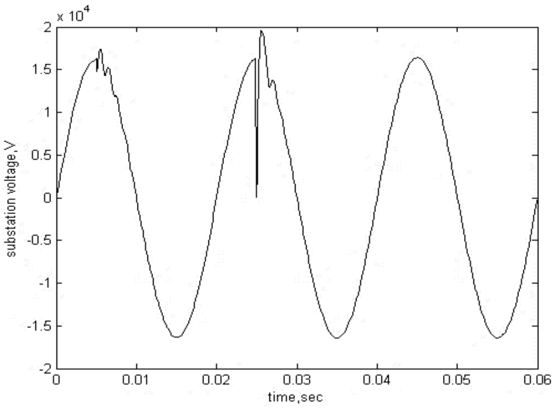

Figure 14. Transient over-voltages of the substation in the worst case ($f_1 = f_2$) with the least closing resistor of R_{min}=23 Ω

8.3. Synchronous Key Closing

In such keys, when the system voltage is equal to the capacitor voltage, two contacts of the switch are connected to each other. Therefore, there is not any sudden change in the voltage of the capacitor and the transient states are disappeared. The initial voltage of the capacitor, C_1, is zero due to presence of discharge resistors across it. So, synchronous closing time of key is at time when the voltage is 0 [V]. At the worst case, i.e., when $f_1 = f_2$, the highest amplitude of over-voltages occurs.

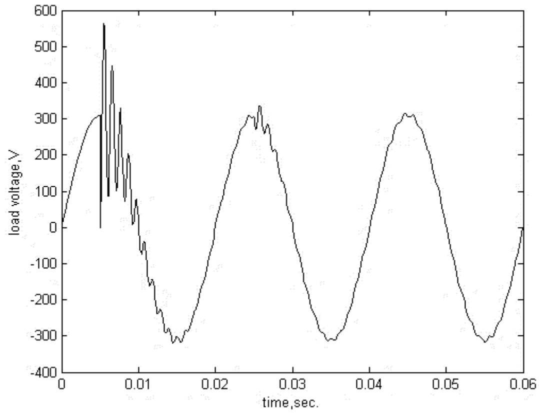

Figure 15. Transient over-voltages of the load in the worst case ($f_1 = f_2$) with big closing resistor of R=200 Ω

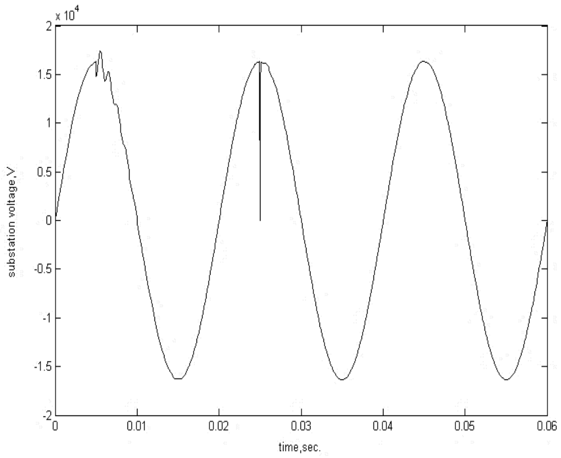

Figure 16. Transient over-voltages of the distribution substation in the worst case ($f_1 = f_2$) with large closing resistor of R=200 Ω

Figures 17 and 18 show the synchronous closing effect of keys during transient states on load and distribution substation voltages. Obviously, with synchronously closing keys, the power quality (voltage quality) is improved [17].

At the end of this section, it is renowned that using closing resistors and synchronous closing keys, likewise in $f_1 \neq f_2$, the power quality and the transient state of the voltage is improved [18], but the simulations of it is not included in the text.

9. CONCLUSIONS

This paper presents a new and efficient method to reduce losses in electricity distribution networks. This method is in fact a kind of electrical energy management that has many practical applications. The above method is based on mathematical and complete modeling of the distribution network and reactive power. Therefore, it has led to favorable results.

It should be noted, however, that capacitors can lead to unintended and dangerous consequences in distribution networks that need to be carefully considered. One of these cases is the multiplication of voltage or voltage magnification. The other is some decrease in the power or voltage quality. This case was also carefully studied and analyzed here and several methods were presented to deal with it.

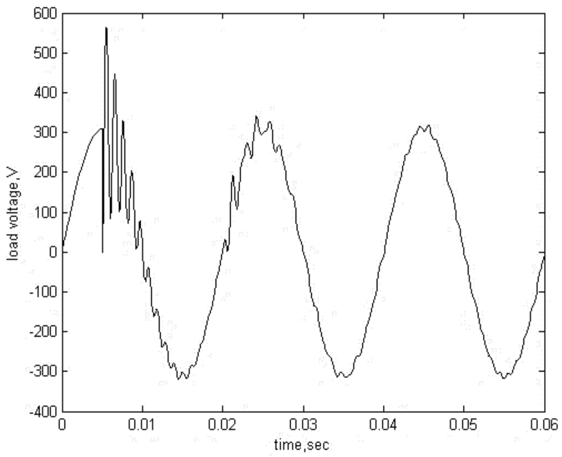

Figure 17. The transient voltage of the load at the worst case ($f_1 = f_2$) when keys are synchronously closed

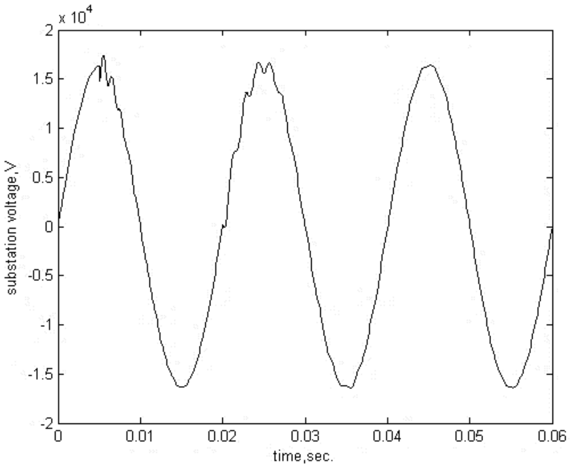

Figure 18. The transient voltage of the distribution substation at the worst case ($f_1 = f_2$) when keys are synchronously closed

REFERENCES

[1] V.S.C. Lim, J.D.F. McDonald, T.K. Saha, "Comparative Distribution of System Losses to Market Participants Using Different Loss Allocation Methods", Transmission and Distribution Conference and Exhibition: Asia and Pacific, pp. 1-7, August 2005.

[2] S. Fazlhashemi, M. Sedighizadeh, M.E. Khodayar, "Day-Ahead Energy Management and Feeder Reconfiguration for Microgrids with CCHP and Energy Storage Systems", Journal of Energy Storage, Vol. 29, pp. 1-24, June 2020.

[3] M. Aryanezhad, "Management and Coordination of LTC, SVR, Shunt Capacitor and Energy Storage with High PV Penetration in Power Distribution System for Voltage Regulation and Power Loss Minimization", International Journal of Electrical Power and Energy Systems, Vol. 100, pp. 178-192, September 2018.

[4] P. Rajesh, F.H. Shajin, "Optimal Allocation of EV Charging Spots and Capacitors in Distribution Network Improving Voltage and Power Loss by Quan-tum-Behaved and Gaussian Mutational Dragonfly Algorithm (QGDA)", Electric Power Systems Research, Vol. 194, pp. 1-11, May 2021.

[5] N. Nazir, M. Almassalkhi, "Stochastic Multi-Period Optimal Dispatch of Energy Storage in Unbalanced Distribution Feeders", Electric Power Systems Research, Vol. 189, pp. 1-7, December 2020.

[6] D. Zhu, A. Jain, R. Broadwater, F. Bruna, "Feeder Voltage Profile Design for Energy Conservation and PV Hosting Capacity Enhancement", Electric Power Systems Research, Vol. 164, pp. 263-271, November 2018.

[7] M. Mejbaul, M.S. Ali, P. Wolfs, F. Blaabjerg, "A UPFC for Voltage Regulation in LV Distribution Feeders With a DC-Link Ripple Voltage Suppression Technique", IEEE Transactions on Industry Applications, Vol. 56, Issue 6, pp. 6857-6870, November-December 2020.

[8] A. Ahuja, A. Pahwa, "Using Ant Colony Optimization for Loss Minimization in Distribution Networks", The 37th Annual North American, pp. 470-474, October 2005.

[9] I.E. Davidson, N.M. Ijumba, "Optimization Model for Loss Minimization in a Deregulated Power Distribution Network", The 6th Africon Conference in Africa, Vol. 2, pp. 887-894, October 2002.

[10] D. Das, "Maximum Loading and Cost of Energy Loss of Radial Distribution Feeders", International Journal of Electrical Power and Energy Systems, Vol. 26, Issue 4, pp. 307-314, May 2004.

[11] A.R. Abul Wafa, "Optimal Capacitor Allocation in Radial Distribution Systems for Loss Reduction: A Two Stage Method", Electric Power Systems Research, Vol. 95, pp. 168-174, February 2013.

[12] J.C. Carlisle, A.A. El-Keib, D. Boyd, K. Nolan, "A Review of Capacitor Placement Techniques on Distribution Feeders", The 29th Symposium on System Theory, pp. 359-365, March 1997.

[13] R.T. Bosela, "Introduction to Electrical Power System Technology", Prentice Hall, pp. 1-510, December 1997.

[14] M. Zile, "Optimization of Energy Management in Solar/Wind Power Stations Using Developed Artificial Bee/Ant Hybrid Heuristic Algorithm", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 47, Vol. 13, No. 2, pp. 124-129, June 2021.

[15] A.M. Hashimov, A.R. Babayeva, H.B. Guliyev, "Shunt Reactors Control Algorithm Using Fuzzy Sets Theory", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 38, Vol. 11, No. 1, pp. 10-15, March 2019.

[16] D. Mak, D. Choi, "Optimization Framework for Coordinated Operation of Home Energy Management System and Volt-VAR Optimization in Unbalanced Active Distribution Networks Considering Uncertainties", Applied Energy, Vol. 276, pp. 1-16, October 2020.

[17] R. Amilcar, J. Leite, J. Mantovani, "Automatic Restoration of Large-Scale Distribution Networks with Distributed Generators, Voltage Control Devices and Heating Loads", Electric Power Systems Research, Vol. 176, pp. 1-11, November 2019.

[18] S.H. Hosseini, N. Taghizadegan, "A Novel and Optimal Method for Locating and Sizing of Capacitors in Distribution Systems Based on Reactive Power Identification", The 10th IEEE International Conference on Electronics, Circuits and Systems, Vol. 1, pp. 364-367, December 2003.

BIOGRAPHIES

Navid Taghizadegan Kalantari was born in Tabriz, Iran, 1965. He received the B.Sc. degree from University of Tabriz, Iran, and the M.Sc. degree from University of Tehran, Iran, and the Ph.D. degree from University of Tabriz, Iran, all in Electrical Engineering, in 1989, 1995 and 2007, respectively. He is currently lecturing in Azarbaijan Shahid Madani University, Tabriz, Iran as an Associate Professor. He is an author of numerous international papers and had published several technical books and book chapters in the field of electrical engineering at national and international publishers. He was also directed several research projects in the Ministry of Energy of Iran. His research interests are in the area of power system dynamics and control, electrical machines and distribution systems.

Morteza Ahangari Hassas was born in Tabriz, Iran, 1990. He received the B.Sc. degree from Islamic Azad University, Tabriz, Iran, and the M.Sc. degree from Science and Research Branch, Islamic Azad University, Tehran, Iran, all in Electrical Engineering, in 2012 and 2016, respectively. He is now a Ph.D. candidate in Azerbaijan Shahid Madani University, Tabriz, Iran. He is currently secretary of board of directors at Iran Energy Association. His research interests are in the area of renewable energies, hybrid systems, water-energy-food nexus, energy management and storage systems.