Extending MOLFOP Method for Balancing the LV Distribution Network Loads with Variable Power Factor

A. Raminfard, S. M. Shahrtash

***Abstract*—**In this paper, a new efficient method for load balancing in low voltage distribution systems is presented. The proposed method is an improved on MOLFOP method for load balancing.

The proposed objective function includes the both of real and imaginary parts of difference between three phase current phasors, as well as two other terms to provide the integer property of the variables; where the latter are the status of the connection of loads to different phases. Afterwards, improved algorithm is supplemented to undertake the integer values for the load connection status. Finally, the method is applied to different parts of Tabriz low voltage network, where the results have shown the good performance of the proposed method

***Keywords*—**Load balancing, Improved Leap-frog Method, Optimization algorithm, Low voltage distribution systems.

I. INTRODUCTION

DEVELOPING in distribution power systems, load variety and loads sensitivity have made distribution companies to pay special attention to power quality indices and networks reliability. One of the important topics in low voltage distribution systems is loss reduction, in order to reduce the costs.

The existing low voltage distribution systems have various single, two and three phase loads. Optimum distribution of single phase and double phase loads between three phases is one of the important factors in reduction of the difference in the amplitude of loads between the three phases and power losses, consequently.

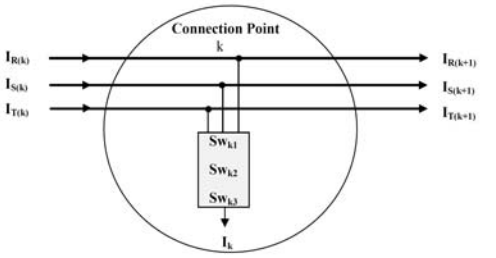
In this paper a practical algorithm for load balancing in LV distribution networks in presented which is based on applying Modified Leap Frog Method (MOLFOP) for optimization of loads' connections to different phases subject to the fact that each single phase can be connected to one of the phases and the variable parameter which indicates this connectivity should remain as an integer number through and in final stage of optimization process.

Due to the possibility of connection of different type of loads to a distribution substation, the load balancing should involve loads with variable power factors. Thus, in this paper such a condition is considered and the method in [9] is extended to include the loads with different power factors.

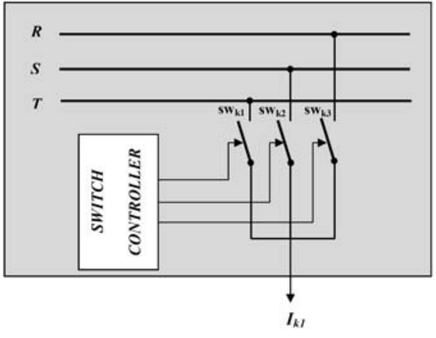
By applying this extended algorithm, the neutral current becomes very low and power losses due to unbalancing decrease significantly.

II. MODELING AND OBJECTIVE FUNCTION

Because of the various loads (commercial-domestic-industrial) with different power factors that may be connected to a distribution LV feeder, therefore as an improvement to the method in [9], load currents should be considered as the phasors.



(a)



(b)

Fig.1 (a) Distribution feeder around point k

(b) Load switching configuring for a load

Considering a distribution feeder, as shown in Fig (1.a); $\vec{I}_{k1}$ is a load connected to the network by means of virtual switches sw_{11} through sw_{33} at point k. Suppose that point k is a bus bar in an actual network; thus, several loads can connect to point k, whichever could be connected to one of the phases, depending on sw_{11} through sw_{33} situation (See Fig 1-b).

The objective function (J) used in [9] has an assumption that all of the loads have the same power factor which has been expressed as:

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$$J = (I_R - I_S)^2 + (I_R - I_T)^2 + (I_S - I_T)^2 \tag{1}$$

where I_R ,I_S and I_T represents the load currents at the feeding point of the system.

So in order to consider the power factor of the loads in the optimization procedure, the objective function can be stated as followed:

$$J = J_{re} + J_{im} \tag{2}$$

$$J_{re} = \left[\mathrm{Re}(\vec{I}_R) - \mathrm{Re}(\vec{I}_S)\right]^2 + \left[\mathrm{Re}(\vec{I}_R) - \mathrm{Re}(\vec{I}_T)\right]^2 + \left[\mathrm{Re}(\vec{I}_S) - \mathrm{Re}(\vec{I}_T)\right]^2 \tag{3}$$

$$J_{im} = \left[\mathrm{Im}(\vec{I}_R) - \mathrm{Im}(\vec{I}_S)\right]^2 + \left[\mathrm{Im}(\vec{I}_R) - \mathrm{Im}(\vec{I}_T)\right]^2 + \left[\mathrm{Im}(\vec{I}_S) - \mathrm{Im}(\vec{I}_T)\right]^2 \tag{4}$$

where $\vec{I}_R, \vec{I}_S, \vec{I}_T$ represents the phasors of the phase currents at the feeding point. Basically, the current along the feeder can be defined as:

$$\vec{I}_{Rk} = sw_{k1}\vec{I}_k + \vec{I}_{R(k+1)} \tag{5}$$

$$\vec{I}_{Sk} = sw_{k2}\vec{I}_k + \vec{I}_{S(k+1)} \tag{6}$$

$$\vec{I}_{Tk} = sw_{k3}\vec{I}_k + \vec{I}_{T(k+1)} \tag{7}$$

Therefore, it is obvious that J in (2) is a function of switch status parameters (sw_{ik}).

Finally, the objective function for optimization of load balancing on a feeder is proposed as:

$$P(sw_{ki}, \alpha) = J(sw_{ki}) + \sum_{k=1}^{n} \alpha C_k + \sum_{k=1}^{n} \beta C_k^{new} \tag{8}$$

where

$$C_k = (\sum_{i=1}^{3} sw_{ki})^2 - 1 \tag{9}$$

$$C_k^{new} = (F_k - 100)^2 (F_k - 10)^2 (F_k - 1)^2 \tag{10}$$

$$F_k = 100 sw_{k1} + 10 sw_{k2} + sw_{k3} \tag{11}$$

And α and β are penalty factors.

Although the proposed objective function has a some how similar representation as the one, previously presented in [9] by the authors, due to phasor representation of the currents, not only J(0) has a new definition but also the gradients are stated as fallows:

$$\frac{\partial P}{\partial sw_{k1}} = \frac{\partial}{\partial sw_{k1}} (\sum_{i=1}^{h} \lambda_i J_i (sw_{k1}, sw_{k2}, sw_{k3}) + \frac{\partial}{\partial sw_{k1}} (\sum_{k=1}^{n} p_2 C_k) + \frac{\partial}{\partial sw_{k1}} (\sum_{k=1}^{n} p_3 C_k^{new}) \tag{12}$$

$$\begin{aligned} &\frac{\partial}{\partial sw_{k1}} (\sum_{i=1}^{h} \lambda_i J_i (sw_{k1}, sw_{k2}, sw_{k3})) = \\ &\frac{\partial}{\partial sw_{k1}} (\sum_{i=1}^{h} \lambda_i (J_{real} + J_{\mathrm{Im}}) = \\ &\sum_{i=1}^{h} 2\lambda_i [2[\mathrm{Re}(\vec{I}_{Ri}) + \mathrm{Im}(\vec{I}_{Ri})] \\ &- [\mathrm{Re}(\vec{I}_{Si}) + \mathrm{Im}(\vec{I}_{Si}] \\ &- [\mathrm{Re}(\vec{I}_{Ti}) + (\mathrm{Im}(\vec{I}_{Ti})]].[\mathrm{Re}(\vec{I}_{ki}) + \mathrm{Im}(\vec{I}_{ki})] \end{aligned} \tag{13}$$

$$\frac{\partial}{\partial sw_{k1}} (\sum_{k=1}^{n} p_2 C_k) = 2 p_2 sw_{k1} \tag{14}$$

$$\begin{aligned} \frac{\partial}{\partial sw_{k1}} (\sum_{k=1}^{n} p_3 C_k^{new}) &= p_3 (\frac{\partial}{\partial F_k} . \frac{\partial F_k}{\partial sw_k}) \\ &= 200 p_3 \begin{bmatrix} (F_k - 100)(F_k - 10)^2 (F_k - 1)^2 + \\ (F_k - 10)(F_k - 100)^2 (F_k - 1)^2 + \\ (F_k - 1)(F_k - 100)^2 (F_k - 10)^2 \end{bmatrix} \end{aligned} \tag{15}$$

The process of optimization employing MOLFOP (shown in Fig.2 and 3) begins with initial values for switch status parameters for each load. This process is continued with the parameters indicating switches' statuses have shown no significant changes between too steps.

It is worth nothing that it was the inability of applying leap-frog method (LFOP) to give optimum load connection configuration, that made the authors to give a new objective function (to ensure keeping the switch parameters as 0 or 1) and adding a compensation algorithm (as shown in Fig.3) to maintain optimality of the final solution [9].This combinational algorithm is referred to as Modified LFOP (MOLFOP).

III. COMPENSATOR SUBROUTINE

Again, as for balancing the loads with different power factors it is the phasor of the currents which is considered in the optimization process and objective function, therefore the compensator algorithm in [9] should be inspected and adjusted as well.

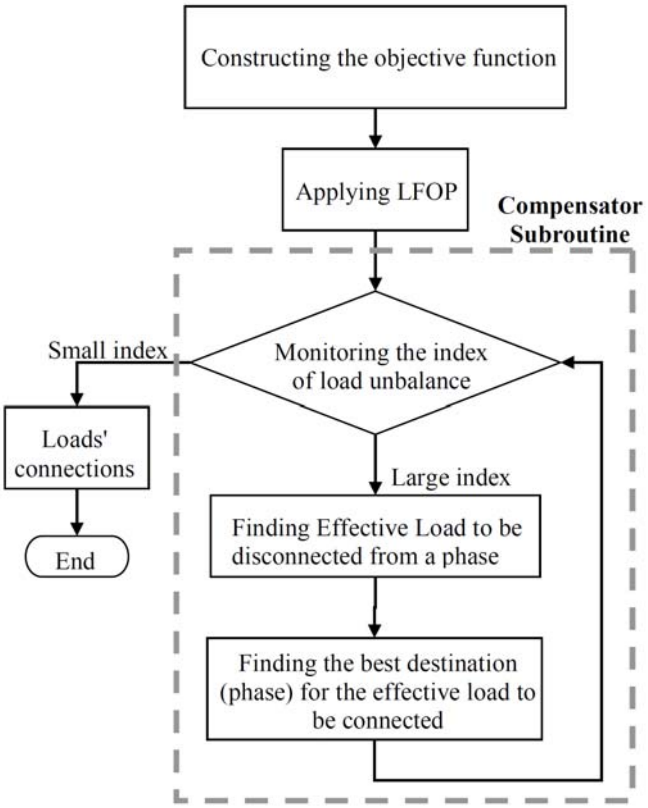

Fig.2 MOLFOP Algorithm for Load Balancing

The first step toward the definition of such supplementary algorithm is the definition of an index for network unbalance [l]where s real and imaginary parts, so the unbalance index could be defined as below:

$$\beta = \sqrt{\frac{|I|_M - |I|_m}{|I|_M + |I|_m}} \tag{16}$$

where, $|I|_M$ and $|I|_m$ are the currents with maximum and minimum norm in different phases of the feeder under consideration, respectively.

$$\Delta I_{ef} = \frac{|I|_M - |I|_m}{2} \tag{17}$$

A brief description of this algorithm could be presented as below:

a) The unbalance index of switching matrix obtained from MOLFOP algorithm (β) is compared with a predefined threshold value ($\beta_{\max}$). In the case of lower values, ($\beta < \beta_{\max}$), the algorithm is terminated and the switching matrix is used as the optimum configuration.

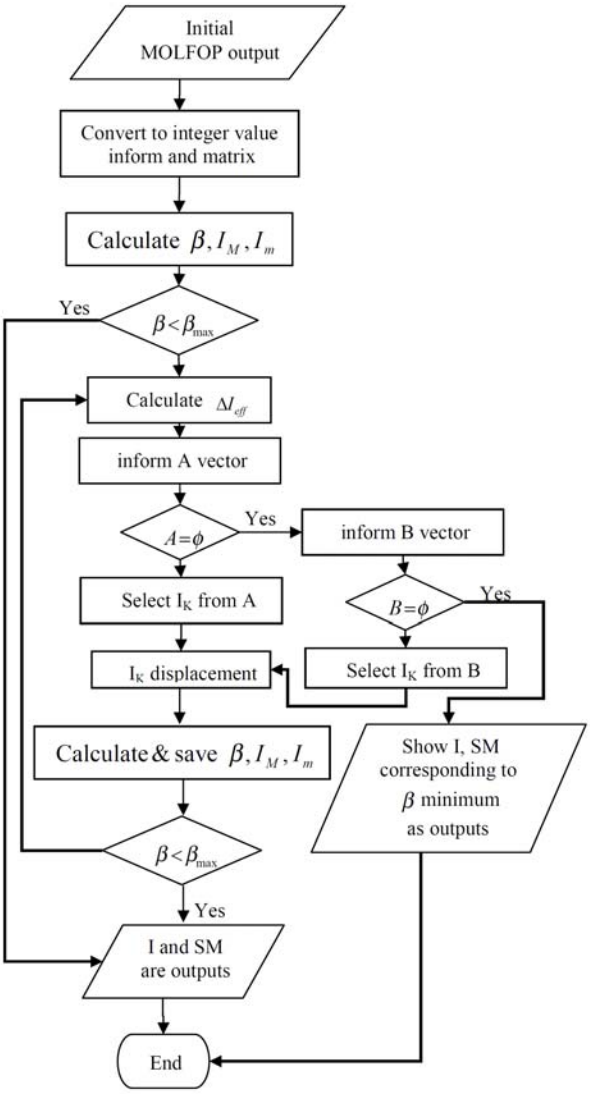

Fig.3 The compensator subroutine

b) Otherwise, in case of higher values for β, a current difference index parameter is defined, using the following relation:

Now the loads to be transferred between the phase with current $|I|_M$ and the phase with current $|I|_m$, named as effective load are determined as:

$$\{ I_k | \in |I|_M , \| I_k | - \Delta I_{ef} | < \Delta I_{ef} \} \tag{18}$$

Then, the effective load with the lowest value is moved from the phase indicated by ($|I|_M$) to the one named by ($|I|_m$).

Subsequently, the current differences index (ΔI_{ef}) is recalculated and the above steps are repeated until the set in (18) have not any other member.

c) In this step a new set of loads is constructed to achieve higher resolution in optimality of the final solution:

$$\left\{ |I_k| \in |I|_M , |I_j| \in |I|_m , \left| (|I_k| - |I_j|) - \Delta I_{ef} \right| < \Delta I_{ef} \right\} \quad (19)$$

here the procedure in the pervious step is also applied on this set.

However, if the procedure reaches the maximum number of iterations the procedure is terminated and the switching matrix with minimum value of β is used as the final optimum load configuration.

IV. RESULTS AND DISCUSSIONS FOR A REAL NETWORK

In order to verify the practicality of the proposed algorithm, it is applied to two low voltage feeders of Tabriz Electric Distribution Company, shown in Fig 4 and 5. Each of these networks, selected from Tabriz residential regions, have intense unbalancing because of abundant building constructions.

Feeder loads are given in Table 1 and 2 (the loads include some three and single phase loads with different power factors).

Single phase branches are modeled as single phase loads in branching point. To measure the greatest unbalancing, currents of loads are measured in daily peak load time. In addition, it is assumed that the loads have constant value in these case studies.

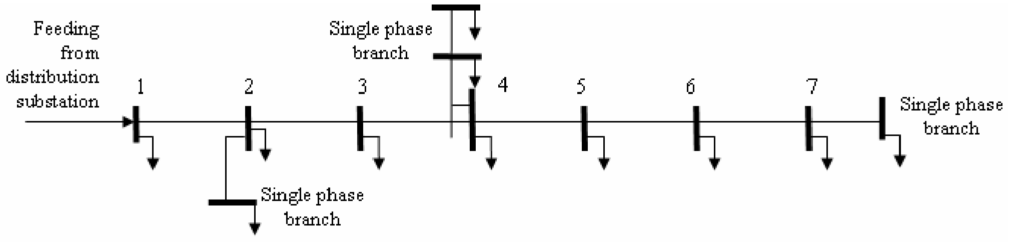

Fig.4 Javidkia alley configuration

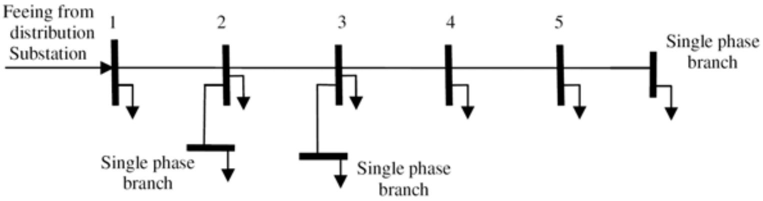

Fig.5 Zareiy alley configuration

TABLE I
JAVIDKIA ALLEY LOAD ARRANGEMENT

node	Single line (A), (cosφ)	Three phase Load1(A) (cosφ)			Three phase Load2(A) (cosφ)			Single phase loads(A) (cosφ)						
1	-	-	-	-	-	-	-	6.3 (.7)	-	-	-	-	-	-
2	10.5 (.8)	14.7 (.9)	13.2 (.85)	10 (.87)	8 (.95)	5.2 (.86)	3.6 (.8)	-	-	-	-	-	-	-
3	-	24.5 (.82)	13.5 (.78)	20 (.9)	-	-	-	3.3 (.85)	6 (.82)	3 (.9)	3.4 (.87)	7.4 (.78)	5.5 (.92)	5 (.6)
4	18.6 (.84)	21.3 (.69)	15 (.72)	7.9 (.79)	9 (.75)	4 (.69)	12.6 (.73)	8 (.8)	5.1 (.83)	2 (.75)	-	-	-	-
5	-	-	-	-	-	-	-	5.5 (.92)	7.6 (.9)	3 (.85)	-	-	-	-
6	-	16.2 (.8)	8.8 (.84)	9 (.89)	-	-	-	6.2 (.72)	4.3 (.6)	-	-	-	-	-
7	15 (.9)	-	-	-	-	-	-	4.8 (.84)	3.5 (.95)	7 (.93)	-	-	-	-

TABLE II
ZAREIY ALLEY LOADS ARRANGEMENT

node	Single line(1) (A), (cosφ)	Single line(2) (A), (cosφ)	Three phase load(A) (cosφ)			Single phase load(A) (cosφ)					
1	10.5 (.81)	12 (.8)	-	-	-	4.3 (.92)	8 (.8)	15.7 (.87)	-	-	-
2	-	-	-	-	-	8.1 (.8)	12 (.7)	4 (.94)	-	-	-
3	15 (.93)	10 (.9)	-	-	-	3.6 (.85)	7 (.92)	-	-	-	-
4	-	-	-	-	-		5 (.75)	5 (.82)	11.4 (.7)	8.5 (،9)	9.3 (.68)
5	51.8 (.89)	39 (.79)	-	-	-	-	-	6 (.9)	-	-	-

Table 3 has exhibited the three phases and neutral currents value at the feeding point. As it is shown, in both feeders the neutral current magnitudes are more than 35% of the magnitudes of the current with minimum norm ($|I|_m$). Table 4 has shown the load and neutral currents after applying the proposed method where clearly it can be seen that the load balancing is performed very well and present to the suitability of employing the proposed method for load balancing in LV networks.

TABLE III
NETWORK LOADS BEFORE BALANCING

Network number	Iph_1 (A)	Iph_2 (A)	Iph_3 (A)	β	In percentage of $\|I\|_m$
1	111.6 (.82)	143.1 (.76)	102.8 (.89)	.4	39
2	113.8 (.76)	162.4 (.85)	140 (.87)	.42	37.02

TABLE IV
NETWORK LOADS AFTER MOLFOP ALGORITHM APPLYIED

Network number	Iph_1 (A)	Iph_2 (A)	Iph_3 (A)	β	In percentage of $\|I\|_m$
1	118.2 (.85)	119.5 (.83)	119.8 (.93)	.081	1.7
2	141.8 (.8)	139.4 (.9)	135 (.88)	.156	4.42

V. CONCLUSION

Load balancing in low voltages distribution feeders, is a vital for loss reduction, for which an accurate and practical algorithm is presented in this paper.

The proposed optimization method take the advantage of a new defined cost function and constraints as well as an innovative post-algorithm in order to present the optimized load arrangement while keeping the integer property of the load connection parameters.

The results have shown better balancing between the currents in three phases rather than some of published methods.

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