CUSTOMERS SWAPPING BETWEEN PHASES FOR LOSS REDUCTION CONSIDERING DAILY LOAD PROFILE MODEL IN SMART GRID

Belal Mohamadi Kalesar
Ardabil Province Electricity Distribution Company (APED Co.), Islamic republic of Iran
belal.mohamadi@gmail.com

ABSTRACT

In general, power distribution systems have unbalanced feeders due to the unbalanced loading. The devices that dependent on balanced three phase supply are affected by the unbalanced feeders. This necessitates the balancing of feeders. The imbalanced feeder system can be balanced by implementing the phase swapping technique. The phase swapping constitutes a direct, effective and low cost alternative for load balancing We use Particle Swarm Optimization algorithm (PSO) as an optimization tool for customers swapping between phases. Load pattern variation of residential, industrial and commercial models can change optimum operating point of system from the view of operation at minimum power loss. In smart distribution networks, phase balancing can be achieved online or hour by hour. This paper investigates how load pattern variation of residential, industrial and commercial models influence optimal hourly phase balancing for loss minimization with minimum customers re-phasing.

INTRODUCTION

Distribution systems are unbalanced in nature due to unbalanced loading at the nodes. Unbalanced loading increases energy loss and risk of capacity constraint violation and also deteriorates power quality and rise in electricity cost. Load imbalance might lead to undesirable situations like, presence of current in the neutral conductor, increasing power loss, over-voltage problems in the least loaded phase [1,2]. Phase balancing not only concentrates on phase currents but also improves voltage, security and reliability. This result in a power service with higher quality and lower cost, and will improve the utility's competitive edge in the deregulated markets. Because the load pattern varies at different time, hourly phase balancing is needed in order to reduce system loss.

For the first time, phase swapping was implemented using mixed integer programming [3]. The references [4,5] have used fuzzy logic for this problem optimization in low voltage networks. The authors in [6] proposed an expert system is designed to derive the rephasing strategy of laterals and distribution transformers to enhance three-phase balancing of distribution systems. The immune algorithm (IA) is proposed to derive the rephasing strategy arrangement of laterals and distribution transformers to enhance three-phase balancing of distribution systems [7]. A heuristic rule-based algorithm with backtracking search [8] had been proposed to solve the phase balancing problem. The connection types of laterals in each service zone were identified and a three-phase load flow program with rigorous feeder model was executed to calculate phase current loading of each branch. In [9] a Self adaptive hybrid differential evolution technique has been employed to solve the phase balancing problem. The authors in [10] have proposed fuzzy and greedy search to power loss reduction using phase balancing optimization. In [11] a mixed integer nonlinear programming formulation is proposed. Also the proposed solution technique consists on a specialized genetic algorithm.

In this paper phase balancing problem will be optimized hour by hour based on load models and using PSO algorithm and the results are compared with seasonal phase balancing based on peak load. The objective function is minimization of weighted summation consists of obtained power loss to initial power loss ratio index (PLI) plus customer swapping number to total customer ratio (CSN) to minimize the number of selected customers for swapping between phases [12].

LOAD FLOW ANALYSIS

Basically, power flow algorithms are iterative and are based on different procedures: Gauss-Seidel, Newton-Raphson, backward/forward sweep. For distribution systems which are operated in radial configurations, the most recommended approaches are backward/forward sweep based algorithms.

The proposed method is developed based on two derived matrices, which has been described in [13].

For distribution networks, the complex load is expressed by

$$S_i = (P_i + Q_i), \quad i = 1 \dots N \tag{1}$$

And the corresponding equivalent current injection at the k–th iteration of solution is

$$I_i^k = (\frac{P_i + Q_i}{V_i^k})^* \tag{2}$$

where P_i and Q_i are equivalent active and reactive power injection of i-th bus respectively, and V_i^k is the i-th bus voltage at the k-th iteration.

The relationship between the bus current injections and branch currents can be expressed as

$$[B]=[BIBC][I] \tag{3}$$

where BIBC is the bus-injection to branch-current (BIBC) matrix.

The relationship between branch currents and bus voltages can be expressed as

$$[\Delta V]=[BCBV][B] \tag{4}$$

where BCBV is the branch-current to bus-voltage (BCBV) matrix.

Combining (7b) and (10b), the relationship between bus current injections and bus voltages can be expressed as

$$[\Delta V]=[BCBV][BIBC][I]=[DLF][I] \tag{5}$$

Also, the ΔV is voltage drop of network buses related to slack bus, voltage of network buses can be calculated from,

$$\left[V^{i(k+1)}\right] = \left[V^{bus(1)}\right] - \Delta V^{i(k+1)} \qquad (6)$$

The stop criteria for load flow process is

$$\max\left(\left|\left|V^{i(k+1)}\right| - \left|V^{i(k)}\right|\right|\right) < \varepsilon \qquad (7)$$

And the solution for distribution load flow can be obtained by solving the following steps iteratively.
The total power loss of the network is determined by the summation of losses in all branches, which is given as

$$P_{loss,t} = \sum_{i=1}^{n-1}\sum_{k=1}^{3} Rp_{(i,i+1),k} \times Ip^2_{(i,i+1),k} + \sum_{i=1}^{n-1} Rn_{(i,i+1)} \times In^2_{(i,i+1)} \qquad (8)$$

Where, n is the number of system buses, k is number of system phases, $Rp_{(i,i+1),k}$ and $Ip_{(i,i+1),k}$ are phase wire resistance and current between ith and i+1 th buses respectively, and R_n and I_n are related to neutral wire.
The load flow analysis is summarized in the following steps:
Step 1: set iteration counter to unit (k=1).
Step 2: set slack and other network buses initial voltage to 1 p.u.
Step 3- calculate equivalent current injection at the k–th iteration from Eq. (2)
Step 4: calculate bus voltages at the k–th iteration from Eq. (6)
Step 5: check stop criteria using Eq. (7), if it hasn't been satisfied increase counter (k=k+1) and then go to step 3, else, end the loop.
These steps are developed for unbalanced four wire system based on [14].

NETWORK ARCHITECTURE

Automatic meter reading (AMR) systems are used by energy suppliers in many countries. An AMR system (using smart meters) records the customer's energy consumption and can transmit this information using power line carrier (PLC) communications to a data concentrator unit (DCU) that placed in substation. All customers connected to power line using unique addressable Load Switching Selector (LSS) that its status can be remotely changed. Using a DCU the status of all switches is gathered and is sent to main server via GPRS environment. Then phase balancing optimization algorithm (PSO as an optimization tool) is executed to determine which switch should change its status i.e. which customer should change its phase. In this step all information is sent back to DCU to implement on LSS to change their status. On demand phase balancing can be implemented based on predetermined scenarios that will be effect time period to gather information and implementation on network.

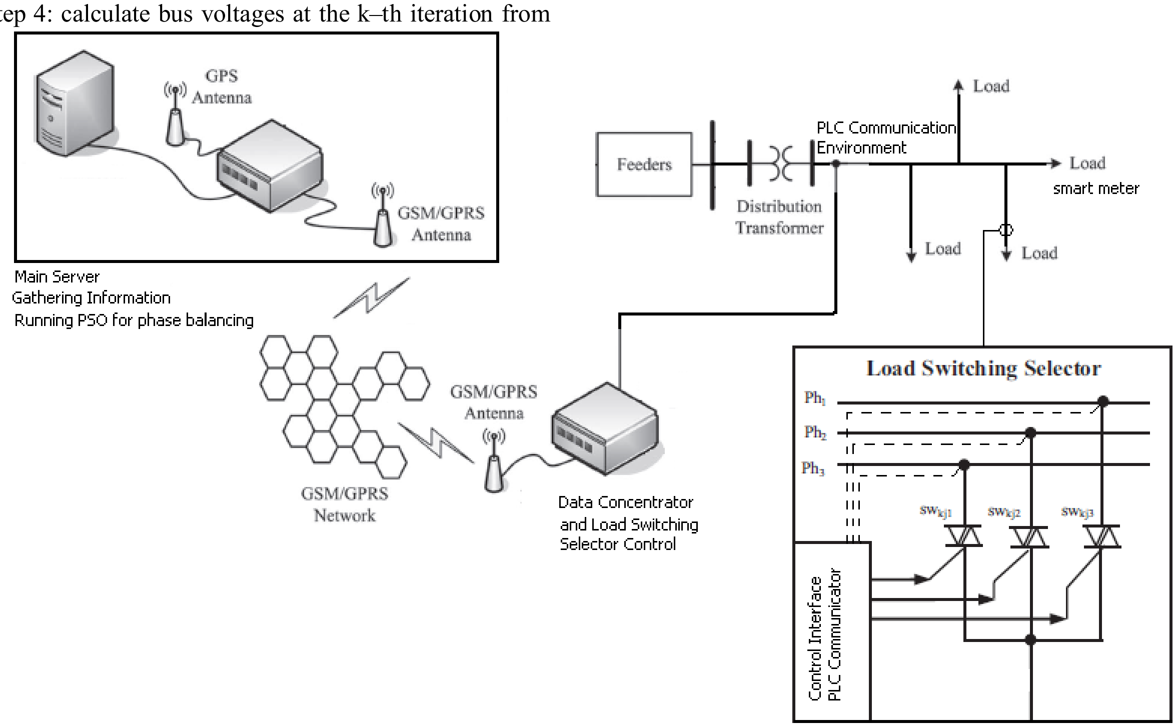

Fig.1. System architecture for the phase balancing of distribution feeders

PSO ALGORITHM

In PSO algorithm, the population has n particles that represent candidate solutions [15]. Each particle has m dimensional real valued vector where m is the number of optimized parameters.
Step 1: (initialization): set the time counter t=0, and

randomly generate n particles for position (X) and velocity (V) matrices.
Set these value as Pbest (j* and x*) as a local best solution.
Search for the best value of the objective function and Set the particle associated with Gbest (j** and x**) as the global best position with the best objective function.
Set the initial value of inertia factor w(0) = 0.98
Step 2: (time updating): update the time counter t = t + 1.
Step 3: (weight updating): update the inertia weight.
Step 4: (velocity updating): using the global best and the individual best to change the particle velocity in the following equation:

$$V_{j,k}(t) = \omega(t)V_{j,k}(t-1) + c_1 r_1 (X^{*}_{j,k}(t-1) - X_{j,k}(t-1) + c_2 r_2 (X^{**}_{best} - X_{j,k}(t-1))) \quad (9)$$

Step 5: (position updating): based on the updated velocity, each particle changes its position according to the following equation:

$$X_{j,k}(t) = X_{j,k}(t-1) + V_{j,k}(t) \quad (10)$$

If a particle violates is position limits in any dimension set its position at the proper limit.
Step 6: each particle is evaluated according to the updated position. if Jmin < j* then updates individual best as

$$X^{*}_{j}(t) = X_{j}(t)\ ,\ j_i = j^{*}_{j} \quad (11)$$

Step 7: now search for the minimum value, if Jmin < j** then updates global best as

$$j^{**} = j_{min} \ and\ x^{**} = x_{min}(t) \quad (12)$$

Step 8: if one of the stopping criteria is satisfied then stop, else go to step 2.

RESULTS

A 13 bus test system is considered in this paper (see Fig. 2). The maximum total loads (69 customers) on phase A, B and C are 51.55, 39.7 and 30.8 kw respectively. This problem will be discussed in two scenarios:

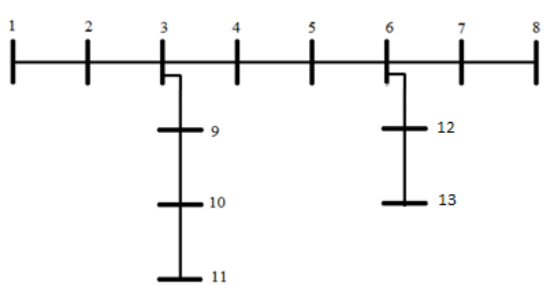

Fig.2. Single line diagram of 13 bus test system

Peak load situation

The results show that minimum voltage is occurred at 8th bus with value of [0.8854 0.9563 0.9862] p.u. and total power loss is 5.03 kw. After PSO algorithm run, between 69 loads only 3 loads should be swapped that are listed in table (1). The minimum value of voltage improved to [0.9307 0.9533 0.9443] p.u. and power loss reduced to 4.34 kw (about 14%).

Table 1- the loads should be swapped for peak load situation

Load value (w)	Bus No.	From phase	To phase
3000	3	A	C
2150	6	A	C
2950	7	A	C

Table 2- results of online phase balancing and

hour	total load	online						peak
		loss (kw)	load (w)	bus	from phase	to phase		loss (kw)
1	57.5	0.93	2250	10	B	C		1.00
2	53.3	0.80	-	-	-	-		0.86
3	49.0	0.67	-	-	-	-		0.72
4	46.7	0.61	-	-	-	-		0.66
5	47.2	0.61	1250	6	B	A		0.67
6	54.7	0.82	-	-	-	-		0.87
7	64.0	1.10	2350	3	A	C		1.14
8	80.5	1.77	2700	7	A	C		1.79
9	87.3	2.10	-	-	-	-		2.11
10	89.5	2.22	-	-	-	-		2.24
11	91.6	2.34	-	-	-	-		2.36
12	93.2	2.43	-	-	-	-		2.45
13	82.6	1.88	1550	7	C	A		1.95
14	71.4	1.42	-	-	-	-		1.49
15	71.4	1.43	-	-	-	-		1.49
16	91.1	2.41	2950	7	A	C		2.42
			2700	8	A	B		
17	96.5	2.71	2800	4	A	B		2.76
18	97.5	2.79	-	-	-	-		2.85
19	98.5	2.87	-	-	-	-		2.95
20	95.8	2.69	-	-	-	-		2.76
21	93.2	2.53	-	-	-	-		2.56
22	78.1	1.74	2800	4	B	A		1.82
			1700	8	C	A		
23	67.0	1.28	-	-	-	-		1.39
24	61.2	1.07	-	-	-	-		1.17
Total		**41.23**						**42.49**

The data on table (1) means that for example on 3rd bus, a customer with 3000w consumption is switched from phase A to C.

In this scenario we do phase balancing and determine which loads should be swapped and it will not be changed in the duration of day. In other word, this scenario is implemented based on peak load value. If we fix the position of swapped loads based on peak load value, then using load pattern in Fig. (3), calculate the power loss under load variation, total power loss during a day will be calculated about 42.5 kw. The results of power loss variation for this case are demonstrated on the last column of table (2).

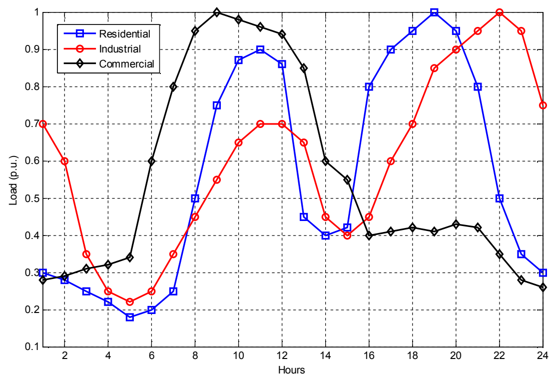

Fig.3. Residential, Industrial and Commercial loads profile

Online phase balancing

The results about how customers are switched using LSS between phases are demonstrated in table (2). The optimization process was took long less than 10 sec for each hours of day. It is clear from table (2) that during a day in 1^{st}, 5^{th}, 7^{th}, 8^{th}, 13^{th}, 16^{th}, 17^{th} and 22^{th} hours, only one or two customers between 69 customers are necessary to be swapped. Total power loss during a day will be calculated about 41.2 kw. At 16^{th} and 22^{th} hours two customers will be swapped.

CONCLUSION

With phase balancing voltage profile and power loss are improved. The hardware requirements are not complicated, and the software algorithm because of using PSO algorithm and direct approach load flow to power loss and voltage profile calculation is also fast.

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