A Novel Approach for Phase Balancing of Secondary Distribution Power System

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Abstract

Objectives: The main objective of the power distribution system is to reduce the loss in order to improve the system efficiency, alleviate the cost and increase the consumer satisfaction. Methods/Analysis: Power loss mainly depends on type of the load and its pattern. Load unbalance on distribution feeder leads to current raise in the heavily loaded phase, over voltage in the lightly loaded phase and neutral current and mal functioning of protection equipment. Findings: In power distribution energy management, phase balancing is one among the techniques available to reduce the loss incurred by load unbalance. Phase balancing is a concept of re-phasing service laterals such that load on three phases is balanced. Application/Improvement: The study mainly deals with phase balancing of secondary distribution feeder by rearranging the connections of consumer load/service laterals. The algorithm is designed to handle time varying loads with an objective of loss reduction and minimum number of phase moves.

Keywords: Candidate Node, Distribution Feeder, Loss Reduction, Phase Balancing

1. Introduction

Energy efficiency in the electricity supply system has always being a concern. Among three functional areas of electrical utility namely, Generation, Transmission and Distribution, the distribution sector needs more attention as it is complex and contributes high technical and commercial losses. With the increase in power consumption, load variety, sensitivity of new loads and increase in electrical knowledge of consumers, have lead distribution companies to pay special attention to the power quality indices and network reliability.

Unbalanced operation of distribution system deteriorates the power quality and increases the system operation and investment cost. Relative to cost, unbalanced operation affects equipment utilization, loss, and voltage profile and system protection. Unbalanced loading is perhaps the most predominant cause of unbalanced operations during normal operating conditions. Feeder reconfiguration and phase swapping are the two main approaches for load balancing by considering existing network. Even reactive power compensation is used for balancing the system by installing external equipment.

Power losses in distribution system significantly vary depending on the load imbalance. The challenge is to decrease the system technical loss and enhance the performance. The loss in the heavily load phase increases rapidly with unbalance due to quadratic nature of IR loss and it further increases with additional current in the neutral.

Practically, engineers use phase re-phasing to balance the phase load based on empirical methods. The process is laborious, time consuming and involves lots of power interruptions. The phase balancing algorithm will give the solution for optimal service lateral arrangement considering constraints like minimum power loss, number of phase moves, power interruptions and cost incurred.

The critical branch phase balancing for single phase loads with the objective of minimizing the maximum unbalanced flow of branch current is computed in 12.

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The average unbalance per phase is calculated and compared with the threshold value and fuzzy logic technique is applied for load balancing in\textsuperscript{14}. The phase balancing is carried out to minimize power loss and phase current deviation is presented in\textsuperscript{12}. The Phase Unbalance Index (PUI) is mentioned in\textsuperscript{8,9} and multi objective function including the neutral current of the supporting feeder, the rephrasing cost, the voltage drop, the line losses is reported in\textsuperscript{10-13}. A dynamic intelligent load balancing in power distribution networks for balancing is proposed\textsuperscript{14}.

In this paper, the phase balancing at each candidate node of secondary distribution feeder is carried out using an average of load per phase and load per service, as there is no reports are available till date.

Figure 1. Proposed algorithm flow diagram 1.

### 1.1 Proposed Phase Balancing Algorithm

The number of service laterals tapped at each candidate node will not exceed more than 20. Since 50 meters distance is maintained between any two nodes, thereby number of consumers near each node will be less. So instead of going for iterative optimization techniques, which are existing in literature for network reconfiguration and phase balancing at secondary distribution transformer terminal, we can go for simple mathematical expressions to obtain optimal phase balancing solution at each candidate node.

The flowchart of proposed phase balancing algorithm, does load balancing at each candidate node by simple expression of average current/power of service laterals on each phase as shown in Figure 1.

For single phase service laterals rephrasing, first average load per phase and average load per service is computed. Based on both average values, the appropriate number of services to move in/out is computed. Similarly amount of load to be moved from/into the service is obtained by calculating the difference of existing amount of load on phase and average load per service. Based on number of services to be moved from the phase, all possible combinations of services are computed. Depending on the amount of load particular combination is selected. The flow diagram for case A1, A2 and A3 is shown in Figure 2 and remaining cases are derived using the same logic.

Figure 2. Proposed algorithm flow diagram 2.
2. Results and Discussion

The proposed phase balancing algorithm is studied for IEEE 13 node test feeder shown in Figure 3. The IEEE 13 node test feeder will provide a good test for the most common features of distribution analysis. It is too small and relatively heavily loaded for a 4.16kV feeder with unbalanced spot and distributed loads.

Data in Table 1 and 2 represents spot load data and distributed load respectively. The load data considered for the study of the phase balancing in Table 3 is generated randomly by considering only single phase services for load data shown in Table 1 and 2.

The load data shown in Table 3 is employed for demonstrating the effectiveness of the proposed algorithm. Two cases are considered, one with an objective to obtain load balance at Node 1 (substation) alone where as the second case objective is to obtain balance at each and every node from the tail end. Loss in the system is computed using load flows. The loss and the numbers of service lateral moves by considering only single phase services are tabulated in Table 4. Column one values correspond to the phase balancing with respect to Node 1. Column two values correspond to the phase balancing at each Node.

From Table 4, it is clear that distribution system efficiency can be improved by undergoing phase balancing at each candidate node. By doing phase balancing at each candidate node, loss incurred in branches is reduced by reducing neutral current at each node and balancing all the 3 phases as shown in Table 4. Thereby we can avoid a case of heavy load phase incurring more $I^2R$ loss and loss due to neutral current.

3. Conclusion

A phase balancing algorithm is developed for balancing of IEEE 13 node unbalanced distribution tester feeder. It
Table 3. Load data assuming only single phase service laterals

| Ser No | Seq | $P_a^*$ (Mag) | $P_b^*$ (Mag) | $P_c^*$ (Mag) | $P_a^*$ (ang) | $P_b^*$ (ang) | $P_c^*$ (ang) | Bus No |
|--------|-----|---------------|---------------|---------------|---------------|---------------|---------------|--------|
| 1      | 0   | 0.864         | 0.000         | 0.000         | 0.532         | 0.000         | 0.000         | 2      |
| 2      | 0   | 1.108         | 0.000         | 0.000         | 0.532         | 0.000         | 0.000         | 2      |
| 3      | 1   | 0.000         | 3.337         | 0.000         | 0.000         | 0.522         | 0.000         | 2      |
| 4      | 1   | 0.000         | 4.279         | 0.000         | 0.000         | 0.522         | 0.000         | 2      |
| 5      | 2   | 0.000         | 0.000         | 5.930         | 0.000         | 0.000         | 0.527         | 2      |
| 6      | 2   | 0.000         | 0.000         | 7.603         | 0.000         | 0.000         | 0.527         | 2      |
| 7      | 0   | 2.356         | 0.000         | 0.000         | 0.000         | 0.602         | 0.000         | 4      |
| 8      | 0   | 7.692         | 0.000         | 0.000         | 0.000         | 0.602         | 0.000         | 4      |
| 9      | 0   | 28.786        | 0.000         | 0.000         | 0.000         | 0.602         | 0.000         | 4      |
| 10     | 1   | 0.000         | 1.820         | 0.000         | 0.000         | 0.644         | 0.000         | 4      |
| 11     | 1   | 0.000         | 5.942         | 0.000         | 0.000         | 0.644         | 0.000         | 4      |
| 12     | 1   | 0.000         | 22.238        | 0.000         | 0.000         | 0.644         | 0.000         | 4      |
| 13     | 2   | 0.000         | 0.000         | 1.820         | 0.000         | 0.000         | 0.644         | 4      |
| 14     | 2   | 0.000         | 0.000         | 5.942         | 0.000         | 0.000         | 0.644         | 4      |
| 15     | 2   | 0.000         | 0.000         | 22.238        | 0.000         | 0.000         | 0.644         | 4      |
| 16     | 1   | 0.000         | 5.977         | 0.000         | 0.000         | 0.634         | 0.000         | 5      |
| 17     | 1   | 0.000         | 16.233        | 0.000         | 0.000         | 0.634         | 0.000         | 5      |
| 18     | 1   | 0.000         | 2.135         | 0.000         | 0.000         | 0.634         | 0.000         | 5      |
| 19     | 1   | 0.000         | 17.858        | 0.000         | 0.000         | 0.634         | 0.000         | 5      |
| 20     | 1   | 0.000         | 9.712         | 0.000         | 0.000         | 0.521         | 0.000         | 6      |
| 21     | 1   | 0.000         | 12.715        | 0.000         | 0.000         | 0.521         | 0.000         | 6      |
| 22     | 1   | 0.000         | 17.977        | 0.000         | 0.000         | 0.521         | 0.000         | 6      |
| 23     | 1   | 0.000         | 5.177         | 0.000         | 0.000         | 0.521         | 0.000         | 6      |
| 24     | 1   | 0.000         | 7.456         | 0.000         | 0.000         | 0.521         | 0.000         | 6      |
| 25     | 0   | 15.695        | 0.000         | 0.000         | 0.519         | 0.000         | 0.000         | 7      |
| 26     | 0   | 25.795        | 0.000         | 0.000         | 0.519         | 0.000         | 0.000         | 7      |
| 27     | 0   | 27.626        | 0.000         | 0.000         | 0.519         | 0.000         | 0.000         | 7      |
| 28     | 0   | 3.384         | 0.000         | 0.000         | 0.519         | 0.000         | 0.000         | 7      |
| 29     | 0   | 6.014         | 0.000         | 0.000         | 0.519         | 0.000         | 0.000         | 7      |
| 30     | 0   | 12.143        | 0.000         | 0.000         | 0.519         | 0.000         | 0.000         | 7      |
| 31     | 1   | 0.000         | 16.672        | 0.000         | 0.000         | 0.519         | 0.000         | 7      |
| 32     | 1   | 0.000         | 27.400        | 0.000         | 0.000         | 0.519         | 0.000         | 7      |
| 33     | 1   | 0.000         | 29.346        | 0.000         | 0.000         | 0.519         | 0.000         | 7      |
| 34     | 1   | 0.000         | 3.595         | 0.000         | 0.000         | 0.519         | 0.000         | 7      |
| 35     | 1   | 0.000         | 6.388         | 0.000         | 0.000         | 0.519         | 0.000         | 7      |
| 36     | 1   | 0.000         | 12.899        | 0.000         | 0.000         | 0.519         | 0.000         | 7      |
| 37     | 2   | 0.000         | 0.000         | 17.697        | 0.000         | 0.000         | 0.520         | 7      |
| 38     | 2   | 0.000         | 0.000         | 29.084        | 0.000         | 0.000         | 0.520         | 7      |
Table 4. Loss and number of rephrasing

|       | Balancing From Node1 (Case 1) | Balancing at each Node (Case 2) |
|-------|------------------------------|---------------------------------|
| Loss  | 0.0825                       | 0.0774                          |
| No of Moves | 12                          | 13                             |

*Actual values are scaled up by 1000, Seq 0,1,2 corresponds to Phase A, B, and C respectively

*Before Load Balancing , Total Loss = 0.0875
is observed that Phase balancing at each candidate node from tail end of the feeder is superior to partial phase balancing. With the proposed algorithm for case 1, a loss reduction of 5.71% is observed and for Case 2, a loss reduction of 11.54% is observed. In nut shell, by doing phase balancing at each candidate node from tail end of the feeder can reduce the neutral current at each node and I2R losses in each branch.

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