

Efficiency and Cost Evaluation of Distribution Systems based on Multiple Time Points

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Abstract—Phase balancing can offer planning engineers a low-cost means of reducing operating costs, improving efficiency in electric power systems. In general, utilities make phase balancing based on peak load by thinking that is the worst case scenario, but every time is not the case. In this paper, time varying phase balancing algorithm is proposed to investigate the effect of hourly phase balancing for all year (8760 hour for a year) and also evaluate system efficiency and cost saving for all hours. Additionally, it is important for the planning engineers to estimate losses accurately to make phase moves, and the peak load does not always provide the most efficient phase moves among the hours in year. In this paper, there different scenarios will be compared; base case, phase balancing based on peak load, and hourly time varying phase balancing. These scenarios will be compared based on loss reduction, and cost saving with Locational Marginal Price (LMP) to provide the planning engineers ideas about effective power system planning.

Keywords— Feeder Performance, Electric Power Distribution System, Locational Marginal Price (LMP), Time varying phase balancing, Power System Efficiency

I. INTRODUCTION

The goal of electric power system planning is to ensure that the system serves its load reliably within certain technical specifications at lowest long-term cost. What makes planning difficult is the fact that the future loading on the system is not precisely known when the system is first being built. If the utility underbuilds the system, it will face the very costly task of rebuilding the system when the load increases beyond the system's capacity. On the other hand, the utility cannot afford to overbuild the system up-front for every possible load increase for many years. An economic balance must be found between underbuilding and overbuilding for future load growth.

One of the keys to achieving this balance is accurate load forecasting. Before the engineer runs any kind of power flow analysis, he needs to know the load on the system. A brief discussion of load forecasting is therefore provided in section II.

Once the planning engineer has the system topology and forecasted load data incorporated into his model, he may begin analyzing the model to check for various criteria, including and especially overloads and low voltages. When he finds an overload and/or a low voltage on the system, he must find the means of resolving that problem that will minimize the long-term cost of building and operating the system.

While phase balancing may not always remedy the problems found in the system, it is the least-expensive operation available to the planning engineer, and should therefore be considered before considering more expensive projects such as adding capacitors or voltage regulators, reconductoring, or building new substations [1].

Phase balancing refers to the operation of moving a single-phase lateral from one phase to another at the point where the single-phase lateral is fed from a 2- or 3-phase branch. While a circuit may start off well balanced when initially constructed, variations in load growth can cause portions of the circuit to become very imbalanced, as the load grows faster than expected in an area served by one phase but grows slower than expected in an area served by another phase [2].

Utilities typically plan phase moves based on the peak load of the feeder [3, 4, 5, and 6]. Phase balancing is needed to be done several time points to be able to compare among alternatives [7].

Past research has focused on the use of phase balancing to reduce losses [8, 9, 10, 11] based on the peak load since they assume if the system has reached its peak, that it would be the worst case scenario for system, but it is not always case.

Thus, in this paper, time varying phase balancing is offered and special attention is given to the efficiency and its cost as a multi-time-point attribute—having a time varying load and price over the system.

This paper is organized as follows: Principal factors affecting phase balancing are discussed in section II. The multi time point phase balancing algorithm will be shown in section III. In Section IV, a case study is presented to show how phase moves should be evaluated, investigating tradeoffs between peak and off-peak. Finally, the conclusions are summarized in section V.

II. PRINCIPAL FACTORS FOR PHASE BALANCING

A. Load Forecasting and Growth

Load forecasting models take as inputs such data as historical load data, expected population growth, load density, alternative energy sources, industrial plans, city plans, geographic factors, and more [12]. The outputs are the forecasted loads—both magnitude and location—at various time points, typically 1, 2, 3, 5, 7, 10, 15, 20, and 25 years ahead

[13]. Large sections of books and even whole books can and have been written on the subject [13, 14, 15, 16]. Here, only a few important points will be considered.

The forecasted loads vary by region—even within a circuit—and the rates of growth vary over time in different regions. In other words, two nearby regions will not have the same growth rates, and even the same region will not have the same growth rate during every forecast year.

Planning engineers need to forecast load at the time they do phase balancing based on inputs of load forecasting models. Before phase balancing occurs, accurate load forecasting needs to be calculated, because utilities will decide phase moves based on the load at that time. The more accurate load forecasting, the more accurate phase balancing is implemented.

B. Distribution System Efficiency

Phase balancing swaps loading condition from one phase to another, and with this modification phase balancing tries to reduce overloading on a single phase laterals. That creates system with fewer losses, means that more efficient.

Main purpose of phase balancing algorithm is to achieve system with less loss, so if utilities see increase in the system losses, they can know some unbalanced occurs on the system. Unbalanced operations affect protection systems coordination, system voltage levels, losses and eventually it will cause to increase the cost of losses in the distribution system.

C. Electricity Dynamic Market Price

Hourly load data for the entire year is really necessary to accurately assess the cost of losses. Not only does the load change continually throughout the year, but the price of energy changes continually throughout the year. The actual price of energy is determined by the real-time bidding managed by the regional transmission organization (RTO) or independent system operator (ISO) and published as the real-time locational marginal price (LMP).

Phase balancing, in general, is implemented when the system load is at the peak. When demand is at the peak, LMP is at the peak too. The cost of energy is the product of power and price at that time, so LMP is directly one of big the effect on planning actions.

III. OPTIMAL MULTI TIME POINTS PHASE BALANCING ALGORITHM

Utilities sometimes get unbalanced loads due to uncertain changing of load growth in the systems. Some feeders contain single lines which can go to area with lightly load, whereas other single lines can go to area with heavy loads. That cause system become unbalanced and have lost of cause since losses are related to magnitude of currents, heavy loaded single line causes more losses than lightly loaded lines. Sometimes, utilities putting new lines on parallel to heavy loaded conductors to support voltage on that conductor instead of balancing their systems. Phase balancing simply moving phase lateral from one phase to another [17, 18]. To be able to run optimal phase balancing algorithm, we need to calculate system losses for each hour, and decide optimal phase move to obtain minimum losses our system. If next hour phase moves gives us better benefit based on losses, than we need to keep these phase moves until we find better phase moves. This continues for all time points in a year. 8760 points analyze is implemented here. Figure 1 shows time varying phase balancing flow chart.

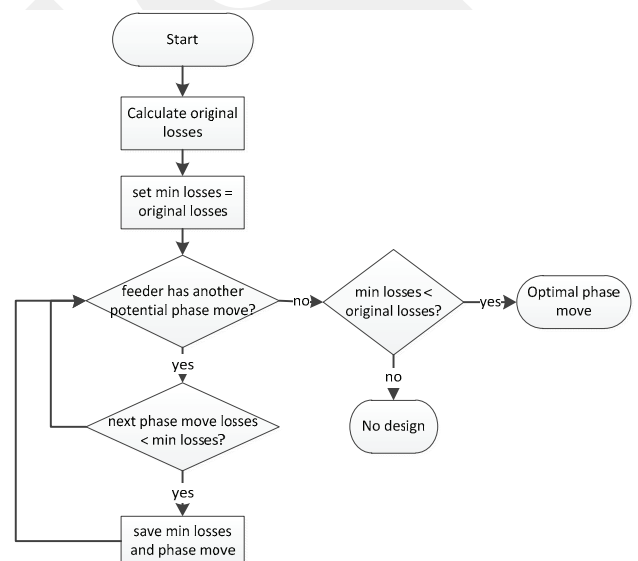


Fig. 1. Phase Balancing Flow Chart

Besides reducing the system losses, phase balancing effects system line loading condition and voltage drops problems on heavy loaded conductors. All phase balancing needs are crews and truck to go to area phase balancing need to be done.

In Figure 2, the losses and LMPs are given for one day, using LMP data from NYISO and a feeder in the ISO's region [19].

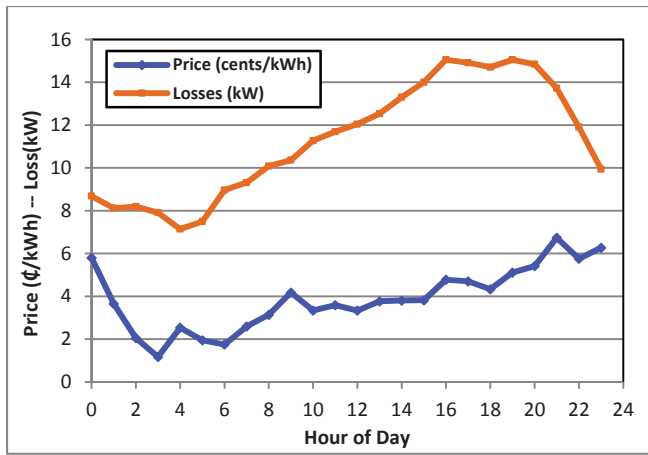


Fig. 2. LMP and Losses for one day

The total actual price of the losses for the day should be calculated by

$$\sum_{i=0}^{23} P_{loss_i} * LMP_i \quad (1)$$

where: P_{loss_i} is the real power losses for the i^{th} hour, and LMP_i is the LMP price at the i^{th} hour. Using the hourly cost and hourly losses, the total actual price of losses for the day is \$11.10. To compare with average price and average losses, average results are in a cost estimate of \$10.57, which is about 5% below the actual price [9]. In order for a utility to accurately calculate its losses, it needs to use the actual hourly loads and the actual price.

IV. SYSTEM EVALUATIONS AND PLANNING

This method also helps planning engineers target feeders for improvement based on two criteria: efficiency and cost of losses. Overall simulation results will be given in tables below and 39 feeders test circuits is shown in Figure 3.

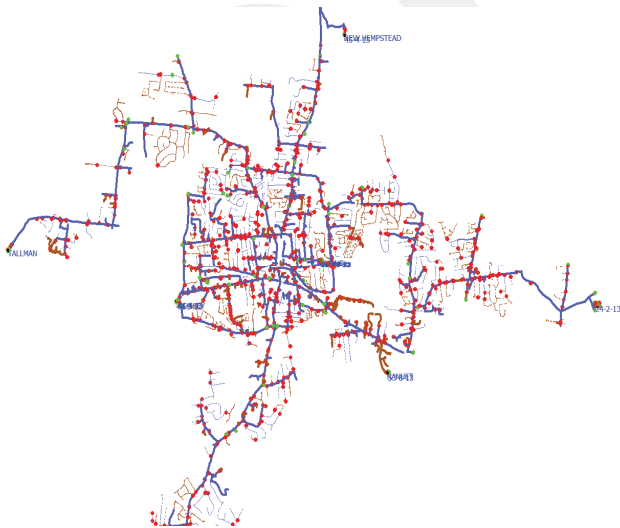


Fig. 3. Test Circuit used in the paper

Three cases will be shown in order of:

- Case 1: Cost of Losses (\$) and energy efficiency are calculated on base model (existing system).
- Case 2: Cost of Losses (\$) and energy efficiency on base model (existing system) will be compared with peak load based “Phase Balanced” model.
- Case 3: Cost of Losses (\$) and energy efficiency on base model (existing system) will be compared with time varying nature of load and price based “Phase Balanced” model.

Figure 4 shows cost of losses and efficiency for different feeders (the case study model has 39 feeders).

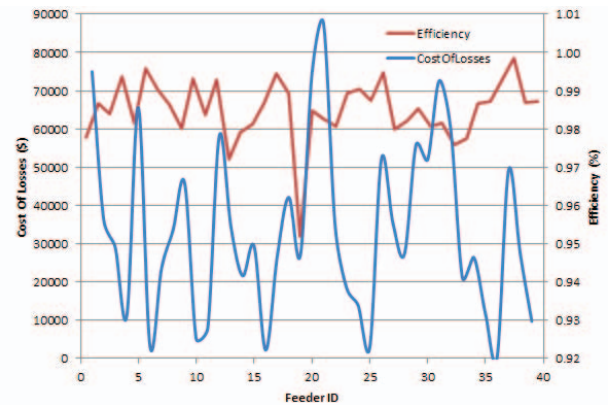


Fig. 4. System Annual Loss Cost and Efficiency Plot

Results of cost comparison between base case models (existing model) versus “phase balanced” models based on peak load and between “phase balanced” based on peak load and “phase balanced” based on time varying model are shown in Table I.

TABLE I CASE COMPARISONS FOR COST EVALUATION

Year	Case 1	Case 2		Case 3	
	Cost of Losses k\$	Cost of Losses k\$	Δ Annual Lost Cost (\$k)	Cost of Losses k\$	Δ Annual Lost Cost (\$k)
2015	583.78	571.38	12.40	569.40	14.38
2016	621.07	607.47	13.60	605.72	15.35
2017	650.12	635.14	14.98	634.12	16.00
2018	693.74	678.16	15.58	676.38	17.36
2019	747.18	730.32	16.86	728.51	18.67
2020	797.43	779.74	17.69	777.35	20.08

That gives planning engineers idea of how much they can save just implementing phase balancing and time-varying phase balancing for following 5 years. When case 2 and case 3 are compared based on cost, Table I shows that if we balance phases with respect the time varying nature of loads and price

than we would have more saving than just balanced phases based on peak load. This analysis is based on 5 years planning and load growth rate applied for future years. To calculation of energy cost for future year historical LMP data are used and escalated based upon the Department of Energy's forecast for gas energy prices.

Table II shows the results of efficiency comparison between base cases models (existing model) versus "phase balanced" models based on peak load and between "phase balanced" based on peak load and "phase balanced" based on time varying model.

TABLE II CASE COMPARISONS FOR EFFICIENCY EVALUATION

Year	Case 1	Case 2		Case 3	
	Loss MWh	Loss MWh	Δ Annual Loss (MWh)	Loss MWh	Δ Annual Loss (MWh)
2015	11254.73	11025.32	229.41	10979.25	275.49
2016	11491.29	11254.21	237.08	11210.12	281.16
2017	11700.70	11452.20	248.50	11415.84	284.85
2018	11904.03	11645.00	259.03	11608.50	295.54
2019	12090.20	11800.00	290.20	11790.54	299.66
2020	12297.18	12001.00	296.18	11990.54	306.63

Table II gives planning engineers idea of how much they can improve system efficiency just implementing phase balancing and time-varying phase balancing for following 5 years. For efficiency improvement, phase balancing based on peak load results itself are amazing and results are much better for phase balancing based on time varying load. It can be said that time-varying analysis also helps to increase capacity and that capacity can be used for other system operation such reconfiguration, capacitor installation etc.

V. CONCLUSIONS

This paper investigates the efficiency and cost savings with phase balancing application based on time varying nature of load and prices. Generally, phase balancing is based on the system peak since it is generally worst case scenario, but in this work it is shown that it is not the always case.

Three different scenarios are run to compare. First existing system efficiency is calculated to compare improvement with phase balancing. Second phase balancing application is run based on the peak load to compare efficiency and cost saving with the existing system. Finally time-varying phase balancing application is proposed and run to compare the efficiency and cost savings with phase balancing based on peak load.

Results show that time varying calculation offers planning engineer more efficient and economical solution than phase balancing based on peak load. Study will be extend to time varying capacitor design, reconfiguration and other power system applications.

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