INFLUENCE OF MODELING IN LOAD FLOW ANALYSIS OF THREE PHASE DISTRIBUTION SYSTEMS

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ABSTRACT

It is of significant importance to use specialized algorithms to study operating steady state conditions in distribution systems. These algorithms should consider their particular characteristics, as otherwise, results may not reflect the real performance of these systems.

This paper presents a comparison of three phase load flow algorithms for distribution power systems. Reference is made to traditional single-phase load flow methods used in transmission systems and the main three-phase load flow methods used in distribution. Studies of two chilean distribution networks are made with an algorithm based on the power summation method, and a comparison of errors and the influence of modeling are reported.

1. INTRODUCTION

The most frequent study of an electrical power system, whether a transmition or a distribution one, corresponds to the analysis of the operating steady state conditions. Efficient computer load flow algorithms have been developed for this, based on the indirect Gauss-Seidel method (busbar admittance matrix), direct Gauss-Seidel (busbar impedance matrix), Newton-Raphson and its decoupled versions. Nevertheless, these algorithms have often been designed thinking on transmition systems, so that their application to the distribution systems usually does not provide good results and many times convergence is hardly achieved. The distribution networks present particular characteristics which diference them from the transmition ones. Amongst these, it is possible to distinguish their radial topologies, multiple conexions (single phase, two phase, etc.), loads of different nature, lines with resistance values similar to the reactance ones, and untransposed lines. In general, the direct application of the single phase load flow algorithms developed for transmition systems to distribution ones, shows bad convergence characteristics [3,4,5]. The Newton-Raphson method, in its decoupled versions, is the less suitable one for distribution, given the large variation of the X/R relation. On the other hand, the bus impedance matrix techniques (direct Gauss-Seidel) seem to work faster, although with an excesive use of computer memory. These unsatisfactory results are a direct consequence of the already mentioned distribution system characteristics, specially the radial topologies and the wide X/R change. For this reason the distribution companies frequently appeal to simplified analysis methods which partially satisfy their short term needs [6,7].

The distribution companies growing need for more complete studies and the increase in system automation have motivated the development of specialized algorithms for distribution systems, that consider all their particular characteristics. This paper shows the benefits of using such specialized algorithms.

2. RADIAL LOAD FLOW METHOD

As indicated previously, studies made with Gauss-Seidel traditional methods and the Newton-Raphson one, do not give good results when used for distribution networks [1,9]. Specialized radial load flow methods for distribution systems have been developed, the most used being the ladder method, the current summation method and the power summation method. They only correspond to derivations of the iterative Gauss-Seidel method. In fact, the ladder method solves the network up stream (towards the substation), previously assuming a voltage profile and applying directly the current and voltage Kirchoff laws to get to the source bus. Therefore, it is possible to evaluate the source bus voltage. The error (difference between this value and the specified one) is added to the previously assumed voltage, so as to obtain a new profile to start the next iteration. Convergence is achieved when the resulting voltage in the source bus coincides with the specified one. The other two methods perform two calculation processes: up stream and down stream. In the up stream process, with a previously assumed voltage profile, currents or bus loads are calculated (current summation method or power summation method). In the down stream process, new values are obtained for the voltages, starting from the previous calculation. These voltage values are the ones that are used in the next iteration. Convergence is verified observing voltage values.

These methods, when applied to distribution systems, show better convergence characteristics (speed and reliability) than the traditional ones [3, 4, 5, 8]. When the system load level is increased, the power summation method presents better convergence.

The ladder method has as its main disadvantage the limitation in the depth of the system subfeeders, because each one of them needs subiterations. Its convergence characteristic is not good for loaded systems [5]. For a system with nominal load, the current summation method and the power summation method converge in the same number of iterations [8]. Nevertheless, when load is increased, only the power summation method converges.

3. POWER SUMMATION METHOD

The power summation method is an iterative technique for radial load flow calculations which works with two processes: nodal power calculation and nodal voltage

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calculations. These two processes, up stream first and down stream second, are incorporated in a same iteration. Loads and losses are evaluated and added in the up stream process, obtaining as a result an equivalent power (nodal power) in each bus. Then, the voltages are calculated in the down stream process through a fourth grade equation for the module, and an explicit equation for the angle [2]. Figure 1 provides a single phase bus scheme, showing the set of branches that reach it from the down stream buses, and the branch that comes from an up stream bus. Line self admittances and coupling between phases are included, modeling these last ones by current controlled voltage sources.

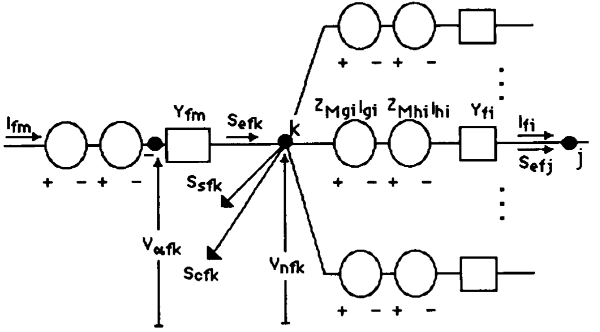

Fig. 1 Typical busbar scheme

Terms for Figure 1:

f, g, h : subscripts indicating the three phases
i, m : subscripts indicating branches i and m
k, j : subscripts indicating busbars k and j
S_{efk}, S_{efj}: equivalent power in phase f seen from k and j
S_{cfk} : load in bus k of phase f
S_{sfk} : shunt reactive power injected to bus k in phase f
S_{pfi} : power losses in phase f of line i
Z_{Mgi} : mutual impedance of phase f with phase g in line i
Z_{Mhi} : mutual impedance of phase f with phase h in line i
Y_{fi}, Y_{fm}: admittances of lines i and m
$V_{\alpha fk}$: voltage of phase f at the intermediate bus between m and k
V_{nfk} : voltage of phase f at bus k
I_{fi}, I_{fm} : currents in phase f on lines i and m
I_{gi}, I_{hi} : currents in phases g and h on line i

A computer program, based on the power summation method, was developed in Pascal and run in a VAX 8600 computer and in a PC AT microcomputer. The program includes modeling of loads as voltage functions, lines including mutual effects, transformers considering iron losses and shunt condensers.

4. APPLICATION TO REAL SYSTEMS

The studied example systems correspond to networks of the General Company of Industrial Electricity (CGEI) and the Austral Society of Electricity (SAESA) [2].

The CGEI system corresponds to a typical urban-rural distribution network. The studied substation has four feeders. CGEI buys energy in the 66 kV level; a 10 MVA power transformer lowers the voltage to 15 kV for primary distribution. The transformer automatically regulates the voltage in the 15 kV bars of the substation to 1 to 1.05 per unit level. The studies consider a feeder with a maximum demand of 1819 kVA. The percentages of unbalance in the loads are fixed in 37%, 33% and 30% for phases one, two and three respectively. For the two phase loads, factors of 50% for both phases were assumed.

Three phase load flow studies were performed. Figure 2 shows the voltage profile obtained for the three phases from the substation (bus 1) to the most far away bus (bus75). The effect of the minor unbalanced conditions can be seen, with the smallest voltages in phase one, corresponding to the most loaded phase.

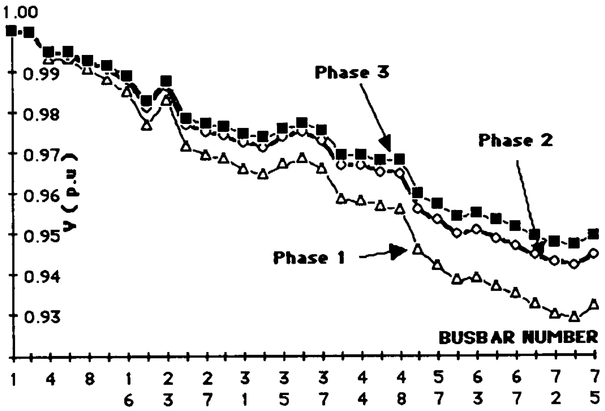

Fig. 2 Voltage profile

The appropiate location of shunt condenser banks is another problem of interest for distribution companies. For the CGEI system, different possibilities of bank locations were studied. The case without shunt compensation was considered (case 1) and three cases with condenser banks in different buses (cases 2, 3 and 4). Figure 3 shows the total active power losses of the system for different load levels in the four compensation cases. On the other hand, Figure 4 shows the voltage profile of phase one obtained for the four study cases. The voltage profile improves for the three compensation schemes with respect to the case without compensation. The best voltage profile is obtained in case four.

5. COMPARATIVE ANALYSIS

A comparison was made of the effect of modeling in the load flow studies for the CGEI rural urban system, already described, and the SAESA rural system. The results of the following studies were compared:

-Single-phase load flow: it does not contemplate unbalanced loads nor phase couplings
-Three phase load flow without coupling: assumes the coupling between phases are negligible.
-Complete three phase load flow: contemplates unbalanced loads and coupling between phases.

The comparison concentrated into two aspects:
i. Model incidence in power losses and maximum voltage drop.
ii. Incidence of unbalances in the power losses.

Figures 5 and 6, show the percentage errors for the different models with respect to the complete model (complete three phase load flow). These errors are refered to the active losses (kW), reactive losses (kVAR) and maximun voltage drop (V). The aproximate models correspond to a single-phase load flow and a three phase load flow without

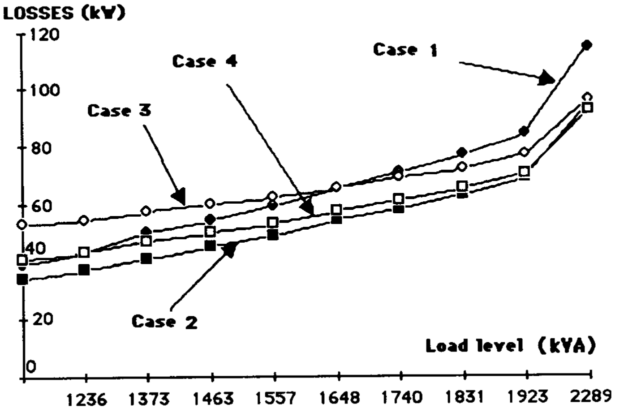

Fig. 3 Active losses vs load level

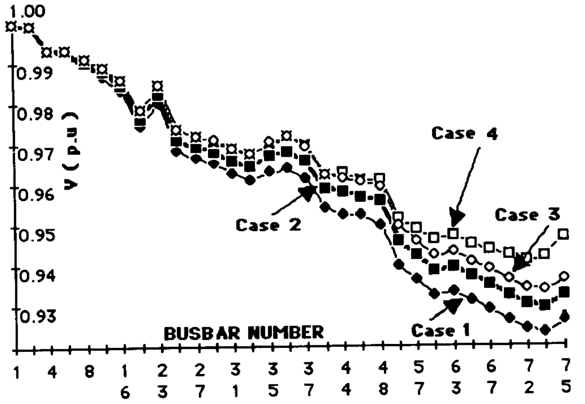

Fig. 4 Voltage profile

coupling. In general, it can be said that errors are insignificant for the CGEI rural-urban system (Figure 5). The highest error is obtained for the reactive losses, with 1,7% error with a single-phase load flow. Nevertheless, it can be appreciated that errors decrease in a great proportion with a three phase load flow without coupling.

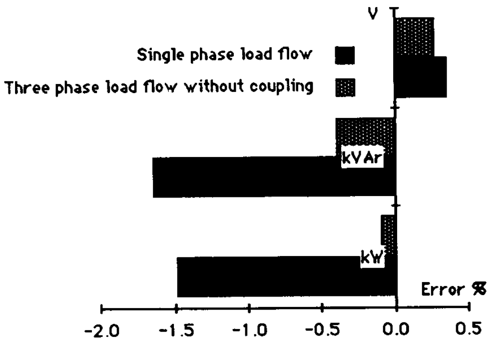

Fig. 5 CGEI system.

On the other hand, for the SAESA rural system, errors increase considerably (Figure 6). As in the previous case, errors are larger in the single-phase load flow. An error of 3% is obtained for the voltage drop, 3% for the active power losses and 8% for the reactive power losses.

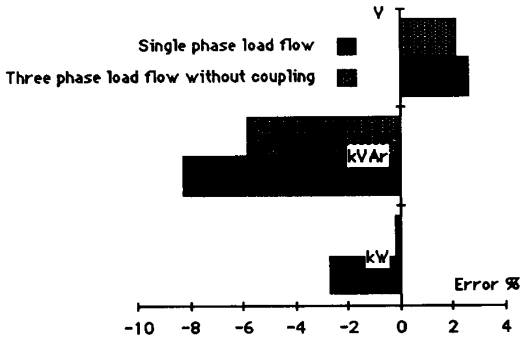

Fig. 6 SAESA system

The relation between losses and the level of unbalance between phases was studied for the CGEI rural urban system. These studies are refered to the same load level, but the way loads are distributed among the phases is varied. Figure 7 shows the loss increases (kW and kVAr) from the balanced case (factors of 0.33, 0.33 and 0.33 for loads in phases 1,2 and 3). It is observed that the active and reactive loss levels increase when the phases are more unbalanced, obtaining up to 60% increment with two-phase loads (factors of 0.5, 0.5 and 0.0 for loads in phases 1,2 and 3 respectively). This is very important, as a single-phase load flow study could severely underestimate losses in a system with many two-phase loads.

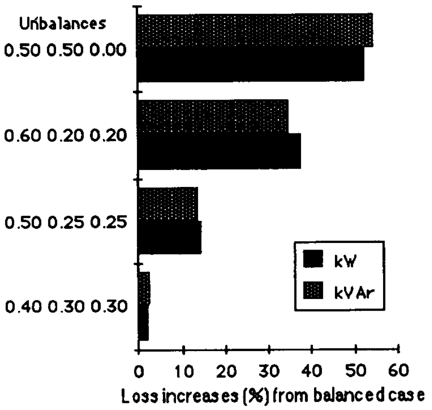

Fig. 7 Losses vs unbalances - CGEI system

6. CONCLUSIONS

It is of significant importance to use specialized algorithms to study operating steady state conditions in distribution systems. These algorithms should consider their particular characteristics, as otherwise, results may not reflect the real performance of these systems.

The comparative studies presented in relation to the effect of modeling in the results indicate that this effect depends strongly on the system nature (rural-urban). In the rural-urban system the results with approximate load flow studies did not differ significantly from the three phase load flow with coupling. Nevertheless, in the rural system errors grow, reaching 8% for reactive losses. This is because in rural systems the lines are longer (lines over 10 km long) and therefore, mutual effects are not negligible. Significant errors in the evaluation of losses, up to 60%, can be encountered if two phase loads are represented as balanced three phase ones.

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