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Implementing Distributed Optimal Power Flow Using the Alternating Direction Method

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Abstract - The recent requirement for faster and more frequent solutions has encouraged the consideration of parallel implementations using decentralized processors. Distributed multi-processor environments can potentially greatly increase the available computational capacity and decrease the communication burden, allowing for faster Optimal Power Flow (OPF) solutions. This paper presents a mathematical approach to implementing distributed OPF using the alternating direction method (ADM) to parallelize the OPF. Several IEEE Reliability Test Systems were adopted to demonstrate the proposed algorithm.

Keywords: Alternating direction method, distributed optimal power flow, parallel implementation, regional decomposition

1. Introduction

In this paper, we present an approach to parallelizing optimal power flow (OPF) that is suitable for distributed implementation and is applicable to very large interconnected power systems. The approach could be used by utilities to optimize economy interchange without disclosing details of their operating costs to competitors.

We solve optimal power flows for each region and coordinate the multiple OPFs through an iterative update on constraint multipliers. In the interconnected system, for instance, each individual utility solves a modified OPF that includes its own service area and the borders it shares with other utilities. The iterative updates require global synchronization and the exchange of a very modest amount of data between adjacent regions.

2. Review of Distributed OPF

Initially, array computers were used in the applications of parallel computing to the problems experienced by power systems. These computers are equipped with specialized processors for performing vector computations efficiently [1]. Sundarraj et al. [2] demonstrated a distributed decomposition of constrained economic dispatch on a hypercube multiprocessor using the Dantzig-Wolfe decomposition method.

While there has been some other works and progress in parallelizing power system problems (see the discussion and references in [1]), major efforts have concentrated on parallelizing individual steps such as Jacobian factorization, and furthermore current implementations are centralized, making use of large mainframe computers.

In [3], Kim and Baldick proposed an approach to parallelizing optimal power flow (OPF) that is suitable for distributed implementation and is applicable to very large inter-connected power systems. In the approach, the OPF is solved in a decentralized framework, consisting of each region, in which a local processor would perform its own OPF for the region and its border. Regions interact by adjusting flows between regions depending on the prices quoted for inter-regional interchanges.

3. Distributed Optimal Power Flow

We propose a scenario where each individual utility solves a modified OPF that includes its own service area and the border it shares with other utilities. The modified OPF is similar to a standard OPF except that *dummy generator* (G_{DB}) and dummy load (L_D) are modeled at the border buses as in Figure 1. Naturally, the OPFs solved in each region can be implemented with the fastest available algorithms. However, it is also possible for each utility to have a different OPF implementation for its own area.

The overall algorithm involves alternating solutions of individual OPFs and updates of prices. It converges, in principle, to a solution of the overall multi-utility OPF, yielding appropriate generation levels in each utility to minimize overall production costs. The multipliers on the constraints could be used to set prices for the exchange of real and reactive power.

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3.1 Regional Decomposition

In our distributed scheme, regions buy and sell electricity from adjacent regions at prices that are coordinated by negotiations between adjacent regions. The price-setting itself can be performed without a centralized processor. The advantage of such decentralization is that only synchronization information needs to be exchanged globally, improving reliability in the event of communication failure.

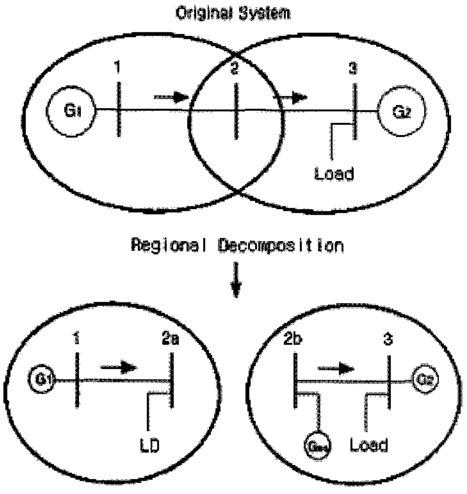

Fig. 1 Decomposition for algorithm-ADM

3.2 Algorithm-Alternating Direction Method (ADM)

Gabay and Mercier [4], Tseng [5], and Eckstein et al. [6, 7] proposed the *alternating direction method*. The basic idea underlying this approach is to sequentially perform the minimization with respect to x with z, λ fixed, then with respect to z, followed by an update of the multiplier λ. This approach removes the difficulty of the joint minimization in core variables, x and z, and thus preserves separability. This approach can be viewed as a variant of the sequential decomposition technique.

The iterative scheme can be given as:

- Step 1: Initialization.
- Step 2: Solve

$$x^{k+1} = \arg\ \min\left\{ f_a(x) + (\lambda^k)^+ Ax + \frac{\gamma}{2}\left\| Ax - z^k \right\|^2 \right\}.$$

- Step 3: Solve

$$z^{k+1} = \arg\min\left\{ f_b(z) - (\lambda^k)^+ z + \frac{\gamma}{2}\left\| Ax^{k+1} - z \right\|^2 \right\}$$

- Step 4: Compute $\lambda^k + \gamma(Ax^{k+1} - z^{k+1})$.
- Step 5: Repeat Steps 2-4,

Where, the parameter r is optimally determined depending on the characteristics and size of the problem, and the number of interconnected (decomposed) regions. In ADM, however, the minimization steps cannot be performed independently, and this restricts its potential advantage in parallel implementations.

4. Case Study

Several case studies are performed to demonstrate the distributed OPF using the ADM method. The objectives of the case studies are, first, to discover the viability of the proposed algorithm in practical implementation and, second, to test and compare the convergence property of the Algorithm-ADM.

Data from two IEEE Reliability Test Systems were used to demonstrate the performance of the algorithm. Table 1 summarizes the test systems. The first column denotes the system identification number, the second column indicates the total number of buses in each system, while the third and fourth columns show the number of regions and the number of core buses in each region. The fifth column presents the number of tie-lines that interconnect the regions, while the sixth column shows the total number of transmission lines in each complete system. The last column indicates the total per unit loads in the systems. The five smaller systems consist of two, three, or four copies of two IEEE Test Systems.

Performance comparisons are based on the cpu-times and number of iterations required for desired accuracy. For the case studies, an optimization package, GAMS 2.25 (MINOS5 and CONOPT) [8] was employed.

Table 2 presents the number of iterations for parallel OPF with Algorithm-ADM. It is seen that the proposed algorithm reaches the solution within 6 or 7 iterations, and the number of iterations depends rather on the system configuration than the size of the individual system or the number interconnected regions (systems).

Table 1 Case study systems

No.	Buses	Regions	Core Buses	Ties	Lines	Load
1	50	2	24,24	2	80	50
2	78	3	24,24,24	6	126	74
3	108	4	24,24,24,24	12	186	100
4	238	2	118,118	2	376	76
5	360	3	118,118,118	6	570	126

The cpu-time results from the undecomposed (centralized) and the parallel implementation of Algorithm-ADM are summarized in Table 3, where all the cpu-times include the overheads necessary for reading data and communicating among processors. As seen in Table 3, the parallelized (distributed) scheme has no advantage over the centralized scheme in cpu-time because of excessive overheads, but as the size of the individual system (region) increases, the parallelized scheme exercises considerable efficiency over the centralized scheme.

Table 2 Number iterations for parallel OPF with GAMS: Algorithm-ADM

System Number	No.1	No.2	No.3	No.4	No.5
Iterations	6	6	7	4	5

Table 3 Comparison of Cpu-time (sec)

System Number	No.1	No.2	No.3	No.4	No.5
Centralized OPF	1.9	2.4	4.2	7.2	11.7
Algorithm-ADM	2.1	2.9	4.8	5.5	8.3

5. Conclusion

We have presented an effective parallel algorithm, based on the alternating direction method (ADM) that can be applied to the distributed OPF. In a distributed environment there are overheads that may reduce the possible iteration number.

The case studies indicate that the proposed algorithm can be implemented for solving optimal power flow problems in a parallel manner.

Our future study is to improve the convergence property of the proposed algorithm.

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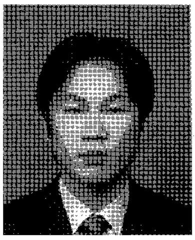

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