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ON-LINE OPTIMUM LOAD SCHEDULING OF POWER SYSTEMS
USING MODIFIED FLETCHER-POWELL METHOD

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Abstract

The problem of optimum power dispatch has been the object of constant attention of power-system engineers in modern times and its importance is understandably enhanced in these times of energy shortage. This paper presents a new approach for obtaining on-line optimum load scheduling of power systems. The suggested algorithm could be used in conjunction with any standard load-flow routine, requiring little additional core storage. The output of the load-flow program is utilized to acquire a first hand knowledge of the total losses in an integrated power system, which in turn enables one to make an accurate estimate of the loss coefficients. The determination of power generation by different generating stations so as to minimize the given cost functional, subject to the constraints of maximum and minimum generations, and loss equation, is carried out by the constrained Fletcher-Powell method.

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Summary

An integrated power system consists of a number of generating stations, vast number of buses and various interconnections, spread over a large geographical region. Given the power demands and generations within an overall power system, load-flow study determines the voltages at different buses and power flow associated with different lines. Evidently, these generations are not necessarily optimal, in the sense that they are determined only to satisfy the nodal equations and not to minimize any particular functional. But, however, the load flow study provides an accurate estimate of the losses. Now the power system under investigation can be reduced to an equivalent system, consisting only of the generating nodes of the original system, such that the losses of the reduced system are the same as those in the original system. The minimum cost functional has been chosen here as the criterion for optimization and this paper employs the constrained Fletcher-Powell method, recently suggested by Haarhoff and Buys¹ for optimization of a nonlinear function subject to nonlinear constraints.

While Fletcher-Powell's method has been used earlier in solving the load flow problems, to the best of authors' knowledge, this is the first time that the Fletcher-Powell method in its present modified form is employed to solve the problem of optimal power dispatch. The salient feature of this method is that it can take care of any type of constraints.

The cost functional

$$J(P_1, P_2, \dots, P_n) = \int_{t_0}^{t_1} \left(\sum_{i=1}^n \alpha_i P_i + \beta_i P_i^2 \right) dt \quad (1)$$

where P_i ($i=1, 2, \dots, n$) are the power generations of the reduced plant,

α_i and β_i are known constants,

is to be minimized subject to the constraints given below by (2) and (3):

$$L(P_1, P_2, \dots, P_n) = \sum_{i=1}^n P_i - \sum_{i=1}^n \sum_{j=1}^n P_i Q_{ij} P_j \quad (2)$$

where Q_{ij} are the loss coefficients to be determined by the method suggested by Hill and Stevenson³.

$$\text{and } P_i^{\min} \leq P_i \leq P_i^{\max}, \quad i = 1, 2, \dots, n \quad (3)$$

where P_i^{\min} and P_i^{\max} are the minimum and maximum generations at the bus i .

The method of solution incorporates the constraints into a modified unconstrained objective functional which is then optimized by the unconstrained minimization technique of Fletcher-Powell. The inequality constraint given by (3) is treated by use of slack variables and transformation. The algorithm proceeds as follows:

Step I:

(a) The constraint (3) is reformulated as (where x_i are slack variables)

$$P_i + x_i^2 = P_i^{\max}, \quad i = 1, 2, \dots, n \quad (4)$$

For example if $P_i = 50$ to start with and $P_i^{\max} = 100$, $x_i = \sqrt{50} = 7.07$

The slack variables are updated as the algorithm progresses.

(b) The lower constraints are handled by means of a penalty function U added to the cost functional,

$$F = J - U.10^P \quad (5)$$

where U is set to be the minimum value of P_i ($i=1, 2, \dots, n$), or zero; and P is a large number. If P_i are per unit values, P can be of the order of 10. If P_i are in mega-watts, P is of the order of 30.

Step II:

Next considering the reformulated problem,

$$J(P_1, P_2, \dots, P_n) - U.10^P \quad \text{is to be minimized subject to} \quad (6)$$

$$G_1(P_1, \dots, P_n) = L - \sum_{i=1}^n P_i + \sum_{i=1}^n \sum_{j=1}^n P_i Q_{ij} P_j = 0 \quad (7)$$

$$G_{i+1}(P_1, \dots, P_n) = P_i + x_i^2 - P_i^{\max} = 0, \quad i = 1, 2, \dots, n. \quad (8)$$

Step III:

The new unconstrained objective function for the reformulated problem is

$$\Phi = J - U \cdot 10^p - \sum_{k=1}^{n+1} \lambda_k G_k + B \sum_{k=1}^{n+1} G_k^2 \quad (9)$$

where λ_k and B are constants.

Step IV:

A starting point, which can be obtained from load-flow study, is selected and J as well as G_k are determined. The λ_k are determined from

$$\sum_{i=1}^n \sum_{j=1}^{n+1} \left(\lambda_j \frac{\partial G_i}{\partial x_j} \frac{\partial G_k}{\partial x_i} \right) = \sum_{i=1}^n \left(\frac{\partial G_k}{\partial x_i} \frac{\partial F}{\partial x_i} \right), \quad k = 1, 2, \dots, n+1. \quad (10)$$

B is set at some positive number, 30 being the usual value.

Step V:

A series of search directions and one dimensional search steps are determined as per Fletcher-Powell general unconstrained method and are constantly updated at every step. When convergence is achieved $G_k=0$ and $F=\Phi$.

The presented method of solution is being applied to an experimental 20-bus system, to start with. First attempts indicate rapid convergence. Eventually it will be applied to a real-world system of 203 buses. The results of the detailed study on this and related topics will be reported in due time.

The proposed new approach and algorithm for optimum load scheduling together with any existing efficient load-flow routine seem to have a vast potential for being employed in on-line computation for any modern power system.

References:

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