satisfied all the secutity limits of the transmission lines.

## 8. CONCLUSIONS

For on-line implementation of the Optimal Load Flow problem, fast execution times and minimum computer storage are required. This paper has presented and evaluated an efficient methodology for solving the OLF problem. The proposed methodology decomposes the OLF problem into a real and a reactive subproblem, by exploiting the decoupling characteristic between network voltages and phase angles. The real and reactive subproblems are solved alternately until they converge.

Quadratic or linear programming is utilized to solve the two subproblems. If the cost curve of each generator is approximated as quadratic function then the cost function of the OLF problem is in quadratic form and quadratic programming is applied for the solution. If the effect of valve point loading is to be examined the cost function of the OLF problem becomes linear and linear programming is applied. Results obtained by the application of the Decoupled Optimal Load Flow algorithm to a 9 bus system and a 27 bus system have been presented. Application of the proposed algorithm resulted in reduction of fuel cost and system losses. Convergence was succeeded in two or three iterations for all test cases considered.

At each iteration of the methodology the non-linear constraints of the problem are transformed to linear constraints by utilizing Z-matrix techniques, sensitivity analysis and Generalized Generation Distribution Factors. The methodology for linearizing the non-linear constraints has been very effective. Generalized Generation Distribution Factors offer an accurate method for expressing the line flows as linear functions of the generator real outputs. Sensitivity analysis has been utilized success fully to linearize the reactive outputs of the generators and the voltage magnitudes of the load buses. Calculation of the system losses based on the equivalent bus impedance matrix if very accurate. It was proven that, using sparsity techniques, the work required to obtain the loss formula is minimal and it is well suited for large scale systems.

## REFERENCES

1. J.Carpentier,"Contribution a l'etude du dispaching economique", Bulletin de la Societe Francaise des Electriciens, Ser. 8, Vol. 3, August 1962.
2. H.W. Dommel, W.F. Tinney, "Optimal Power Flow Solution", IEEE Trans., Vol. PAS-87, 1968,pp.1866-1876.
3. A.M.Sasson, "Nonlinear Programming Solution for Load Flow Minimum Losses and Economic Dispatching Problems" IEEE Trans., Vol.PAS-88, 1969, pp. 399-409.
4. R.Podmore,"Economic Power Dispatch with Line Security Limits", IEEE Trans.,Vol.PAS-93,1974,pp.289-295.
5. R.R.Shoults,D.T.Sun,"Optimal Power Flow Based Upon P-Q Decomposition", IEEE Trans., Vol.PAS-101,1982, pp. 397-405.
6. R.C. Burchett, H.H.Happ, D.R.Vierath, K.A. Wirgau, "Developments in Optimal Power Flow", IEEE Trans., Vol. PAS-101, 1982, pp. 406-414.
7. E.Housos, G. Irissarri, "Real and Reactive Power-System Security Dispatch Using a Variable Weights Optimization Method", presented at IEEE PES 1982 Summer Meeting, held in San Francisco, July 1982.
8. G.C. Contaxis, B.C.Papadias, C. Delkis, "Decoupled Power System Security Dispatch", IEEE Trans., Vol. PAS-1983, pp. 3049-3056.
9. B. Stott, O. Alsac, "Fast Decoupled Load Flow",IEEE Trans., Vol. PAS-93, 1974, pp. 859-869.
10. W.Y. Ng, "Generalized Generation Distribution Factors for Power System Security Evaluations", IEEE Trans., Vol. PAS-100, 1981, pp. 1001-1005.
11. J.R. Neunswander, "Modern Power Systems", Internanional Textbook Company, 1971.

---

## Discussion

**J. Nanda, D. P. Kothari, K. S. Lingamurthy,** and **S. C. Srivastava** (Indian Institute of Technology, Delhi, New Delhi, India): We wish to commend the authors for their valuable contribution in providing new decoupled optimal load flow model for on-line implementation. However, we would like to seek the authors' clarification on the following points.

1) In the reactive power subproblem, the authors have used the fuel cost of slack generation as the objective function. How does this compare with regard to convergence properties, when the objective function is the slack power generation itself as used by several researchers e.g., (Ref. 2 of the Paper)?

2) We would like to know which of the QP methods has been used by the authors and would appreciate the authors' comments on the effectiveness of the method used from the viewpoint of memory, reliability and processing time.

3a) The control vector as defined in the paper consists of the real power outputs and voltage magnitudes of the generator buses. There appears to be a mistake in defining the state vector as it includes also generator bus voltage magnitudes. Please clarify this.

b) N and $N_G$ both have been used for the number of generator buses. But N has also been used on the first page for total number of buses.

4) In Fig. 3 circle 3 is not defined. Please clarify.

5) It would be appreciated if the authors could provide the values of the tolerances ($\epsilon$) used for the convergence of the subproblems and the comparison of computer time and memory requirements by LP and QP methods.

Once again we congratulate the authors for their very interesting paper.

Manuscript received August 8, 1985.

**G. C. Contaxis, C. Delkis** and **G. Korres**: We would like to thank the discussers for their interest in our paper and raising a number of important questions related to our paper. The issues raised by the discussers are briefly discussed below.

1) In the reactive power subproblem we have exactly the same results and convergence properties by using either the fuel cost of slack generation or the slack power generation itself as objective function, in the case of quadratic cost function. In the case of piecewise linear cost function we use the slack power generation itself as objective function.

2) We have used the QP and LP package of Land and Powell, based on Beales' method for quadratic programming and the Revised Simplex method for linear programming. The method uses sparsity techniques and it is very effective from the viewpoint of memory, computing time and accuracy.

3a) The state vector includes the phase angles of all the buses in the system and the voltage magnitudes of the load buses.

4) In Fig. 3 after the circle 3 we compare the difference $P_{G_1}(1)-P_{G_2}(2)$ with respect to a tolerance, to see if the constrained optimization converged. If not we proceed with the real subproblem.

5) We have used a tolerance of $\epsilon = 0.001$ pu for all the cases. In the case of piecewise linear cost function (LP method) the computer time and memory requirements are slightly increased, because more constraints and variables are introduced.

Manuscript received September 9, 1985.