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Optimization of Reactive Power in Large Electrical Networks: Algerian Network

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Abstract: This study describes the methodology adopted to deal with the reactive power dispatch and the network data storage problem in the Western Algerian system. A combined numerical techniques, has been chosen in view to study the problem of the load flow and the optimization of the reactive power in order to reduce the active losses in big and complex networks. A control strategy is proposed with new techniques for improving the performance of sparse-matrix vector by experimental analyses and optimization of the reactive power with the use of Reduced Gradient method, those techniques are applied in Algerian network. Finally, results are analyzed to show the validity of the proposed procedure.

Key words: Optimal reactive power flow, sparse-matrix, envelope method, reduced gradient method

INTRODUCTION

Electricity is a very convenient and useful energy form. It plays an ever increasing role in our modern industrialized society. Intimately connected to this development is the development of power transmission systems as a means to distribute electrical energy. These power systems today face several changes.

Generally, the nodes of the network all are not interconnected, from where; we will have a sparse structure of the data matrices. Moreover, so that the resolution of the linear systems is reliable, it is necessary that the resolution of the equation with Jacobian matrix digs is ensured by programs. The latter must preserve as much as possible this hollow structure during ordered triangular factorization.

In this study, we conceived a program which allows the resolution of a system of linear equations whose matrix is sparse and symmetrical. The non null elements of the matrix digs are stored

Load-flow analysis is used in planning and designing operation. Load flow also provides steady-state condition for other analysis such as stability studies, short-circuit and outage security assessment.

A simple control strategy is proposed. This strategy is then analyzed extensively. Mathematical methods and physical knowledge about the pertinent phenomena are combined and it is shown that this control strategy can be used for a fairly general class of devices. Computer simulations of the controlled system provide insight into the system behaviour in a system of reasonable size. The robustness and stability of the control system a re discussed as are its limits.

Further, the behaviour of the control strategy in a system where the modelling allows for dynamic phenomena is investigated with computer simulations.

The almost everywhere continuously increasing demand for electrical power makes it desirable to operate power systems closer to their thermal ratings than they currently are. Due to environmental concerns and right-of-way issues, the construction of new power lines is increasing difficult. The prime responsibility of power system operators is to supply electric power safely and economically to customers.

Optimal Power Flow (OPF) problem is one of the major issues in operation of power systems. This problem can be divided into two sub problems, MVar dispatch or Optimal Reactive Power Flow (ORPF) and MW dispatch. The main objective of ORPF addresses important aspect, minimizing the total transmission energy loss.

CONTROL ARCHITECTURE

Many attempts to propose standard architectures for control systems have been made (Fig. 1).

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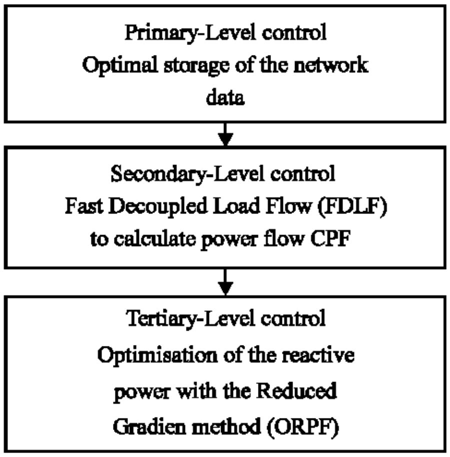


Fig. 1: Control levels in electrical power system in our strategy

IMPLEMENTATION OF ENVELOPE METHOD IN SPARSE SYMMETRIC MATRIX

Our problem lead to solving a large system of linear equations Ax = b, where A is a sparse symmetric matrix of coefficients, is frequently required in most power engineering problems. Such large sparse symmetric matrix is computed by the envelope method (Meurant, 1999).

We describe the matrix structures which are exploited to reduce the storage, and we discuss good orderings of the model problems used with envelope (or profile) algorithm.

The traditional sparse symmetric elimination algorithm is perhaps the best-known iterative technique for solving sparse linear systems that are symmetric and positive definite. For systems that are ill conditioned, it is often necessary to use a preconditioning technique. In this paper, we investigate the effects of various ordering and partitioning strategies using different architectures. Results show that for this class of applications, ordering significantly improves overall performance on both distributed and distributed shared-memory systems.

The envelope method stores the nonzero elements of [*A*] inside the envelope, which represents the main portion of the memory consumption of an envelope solver.

The definition of the matrix A and his profile on the matrix is represented respectively by the Fig. 2a and b.

Figure 2b the profile of the matrix [A], which effects only the elements located between the first no zero element of a line and the diagonal.

To store the matrices, we holds account only interior elements with the profile, what makes it possible to gain much place in memory.

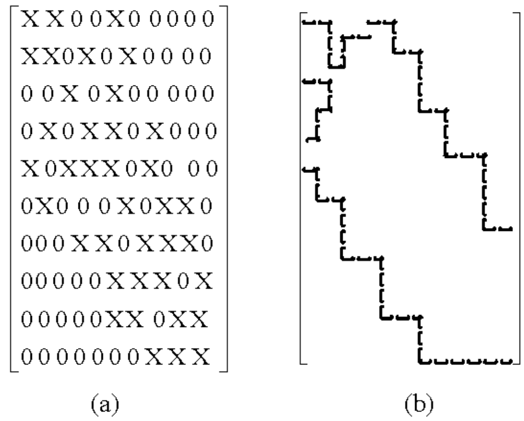
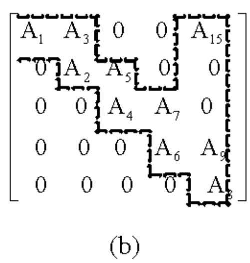


Fig. 2: All the elements of the matrix [A]

$$[A]=\begin{bmatrix} A_{11} & A_{12} & 0 & 0 & A_{15} \\ A_{12} & A_{22} & A_{23} & 0 & 0 \\ 0 & A_{32} & A_{33} & A_{34} & 0 \\ 0 & A_{42} & A_{43} & A_{44} & A_{45} \\ A_{51} & 0 & 0 & A_{54} & A_{55} \end{bmatrix}$$

(a)



(b)

$$\begin{bmatrix} A_1 \\ A_2 \\ A_4 \\ A_6 \\ A_8 \\ A_{13} \end{bmatrix}$$

(c)

Fig. 3: Arrangement of a symmetrical matrix by envelope method (a) Tables complete with two indices (b) Table [A] with one index (c): Table aux of the addresses of the diagonal terms [Max A]

Symmetric envelope method: This method consists in arranging in a table, with only one index, the coefficients located above the diagonal by not taking account of the null terms, located above the last term not null of a column (what is defined by a envelope) and which is shown by Fig. 3.

The coefficients will be arranged in the table [A] and the addresses of the diagonal terms in a table [Max A]. To define this table of addresses, we carry out the first sweeping of the elements allowing determining the heights of columns. By office plurality heights of columns, we obtain the addresses of the diagonal terms.

It may be better to use envelope elimination than sparse elimination.

In the electrical network [A] is symmetric, positive, definite and irreducible.

In comparing the traditional and envelope methods, we note that $Env(A) \subseteq |A|$, so that we would expect the envelope method to be more efficient, since it stores and operates on fewer matrix entries. As we will see in the next paragraphs, this intuitive comparison is substantiated in practice.

The role of the classification of the nodes: During phase 2 of the solution, the variables of each sub-matrix are reordered so that profile is minimized. To find an optimal reordering is an hard problem.

Although the number of nonzero terms of constant remainder, the height of column can vary considerably with the command of reordering of the nodes. It is imperative to minimize the difference of the numbers of the nodes belonging to the same element. We illustrate this in our network example.

This ordering could be implemented and would result in increased solution speed; however, it does require row pivoting to be done by the sparse matrix solution routines.

CONTROL OF ACTIVE POWER FLOW-MOTIVATION

During the last several years, interest in the possibilities to control the active power flows in transmission systems has increased significantly.

In many countries the operation of power systems has changed due to higher utilization of the transmission network and a deregulation of the power market (Herbig *et al*., 2001).

At the heart of the solution of the LF using Newton's method is the solution of the linear system of equations. During the Newton's method solution process, this system of equations is solved repeatedly. Because of this and because one of the primary objectives of an LF is to find its solution in a short amount of time, the speed of the solution of this linear system of equations is essential to a successful LF solution. Fortunately, as is the case with many power system matrices, The Jacobian matrix is extremely sparse. By implementing sparse matrix routines, the equations can be quickly solved.

This problem is solved by Fast decoupled Newton method.

The sparse matrix routines could also take advantage of simply skipping over the processing of the second-and third-row partitions because the only operations required by Gauss's method would be division by 1.

In the Newton Raphson NR technique (Khalid *et al*., 2004), we used matrix partitioning to achieve reusability, whereas in Fast Decoupled we modified the matrix equations while preserving sparsity structure.

As usual, the two matrices in FDPF to be solver iteratively are

$$[\Delta P/v] = [B'][\Delta\theta] \quad (1)$$

$$[\Delta Q] = [B''][\Delta v] \quad (2)$$

ΔP, ΔQ: Active and reactive power mismatch vectors;
Δv, $\Delta\theta$: Voltage magnitude and angle correction vectors;

Formulation for power loss minimization: We will deal first with the CPF problem, as simpler and moreover providing to the OPF with its feasible initial solution. The minimum steps of the algorithm are presented and commented.

Then the same guidelines are applied to the OPF. To illustrate the concepts and the performance of the method, The Western Algerian network case study is presented and its results are commented. Finally one shows the suitability of the method to deal with a most important problem for the planning engineer.

Optimal Power Flow (OPF) problem is one of the major issues in the operation of power system.

A coupled model Optimal Power Flow (OPF) formulation has been used to simplify the application of the proposed method (Sun *et al*., 1984).

In this model the active power generation of all the generators except at the slack bus is constant. The objective function is total power loss.

PROBLEM STATEMENT

A general minimization problem can be written in the flowing form (Martinez and Exposito, 1995):
Minimize f(x) Subject to:

$$h_i(x) = 0,\ i = 1,2,\ldots,m$$

$$g_j(x) \le 0,\ j = 1,2,\ldots,n$$

there are m equality constraints and n inequality constraints and the number of variables is equal to the dimension of the vector x.

The solution of this problem by the Generalized Reduced Gradient GRG method requires the creation of the Lagrangian as shown below:

$$L(x,u) = F(x,u) + \lambda^t G(x,u) + \mu^t H(x,u) \quad (3)$$

To resolve the Eq. 3, we can neglect the inequality constraints and we obtain:

$$L(x,u) = F(x,u) + \lambda^t G(x,u) \quad (4)$$

A gradient of the Lagrangian may then be defined:
Gradient = $\nabla L(Z) = [\partial L(Z)/\partial Z_i]$ = a vector of the first partial derivates of the Lagrangian.

From this we obtain the conditions of the optimality:

$$\nabla_x(Z^*) = \nabla f(x) + J^T_x \lambda = 0 \quad (5)$$

$$\nabla_u(Z^*) = \nabla f(u) + J^T_u \lambda = 0 \quad (6)$$

$$\nabla_\lambda(Z^*) = H(x, u) = 0 \quad (7)$$

$Z^* = [x^*, u^*, \lambda^*]$ is the optimal solution.

Thus solving the Eq. $\nabla_z(Z^*) = 0$ will yield the optimal problem solution.

Then power flow equations and "security" constraints are as follows:

$$\text{Min } Pl(vi,\theta i) \qquad \text{(objective function)} \quad (8)$$

$$P_L = \sum_{i}^{n}\sum_{j}^{m} -G_{ij}(V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}) = 0 \quad (9)$$

$$P_{gi} - P_{li} - V_i\sum_{k1}^{n} V_k(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) = 0 \quad (10)$$

$$Q_{gi} - Q_{li} - V_i\sum_{k=1}^{n} V_k(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik}) = 0 \quad (11)$$

$$j = 2,..........,N$$

$$Q_i^{g\min} \le Q_i^g \le Q_i^{\max} \qquad i = 2, ..., Ng \quad (12)$$

$$V_i^{\max} \le V_i \le V_i^{\max} \qquad i = 1, 2, ..., N \quad (13)$$

$$T\min \le T \le T\max \quad (14)$$

Where:
P_L: Total power loss of transmission lines
N: Number of buses
Ng: Number of generators

The adjustment of the reactive power balance at the network nodes may be more complex because the network itself may be a source of reactive power. Therefore, in order to facilitate this adjustment, at those nodes where a difficulty might occur, we shall put in generating variable instead of the voltage variable. This allows to find easily an initial acceptable voltage profile.

The Lagrangian function obtained is:

$$L = P_L + \left[\lambda_1 , ..., \lambda_{2(n-1)}\right]\begin{bmatrix}\Delta P_2\\ \Delta Q_2\\ \\ \Delta P_n\\ \Delta Q_n\end{bmatrix} \quad (15)$$

And the conditions of optimization are:

$$\begin{cases}\dfrac{\partial L}{\partial\theta_i} = \dfrac{\partial P_L}{\partial\theta_i} + \sum_{k=2}^{n}(\lambda_k\left[\dfrac{\partial P_k}{\partial\theta_i}\right] + \left[\dfrac{\partial Q_k}{\partial\theta_i}\right]) = 0\\ \dfrac{\partial L}{\partial v_i} = \dfrac{\partial P_L}{\partial v_i} + \sum_{k=2}^{n}(\lambda_k\left[\dfrac{\partial P_k}{\partial v_i}\right] + \lambda_k\left[\dfrac{\partial Q_k}{\partial v_i}\right]) = 0\end{cases} \quad (16)$$

$$\left[\frac{\partial L}{\partial Q_i}\right] = 0 + \left[\frac{\partial \Delta Q_i}{\partial Q_i^g}\right][\lambda_i] \quad (17)$$

And:

$$\frac{\partial L}{\partial \lambda_i} = 0 \rightarrow \Delta P_i = 0 \text{ and } \Delta Q_i = 0 \quad (18)$$

From the Eq. (15), (16) and (17) we can obtain the values of the vector $[\lambda_i]$ which will be used to calculate the values of the vector $\left[\frac{\partial L}{\partial Q_i^g}\right]$.

After that we calculate the new values of the reactive power generate:

$$Q_i^{g(k+1)} = Q_i^{g(k)} - \frac{\partial L}{\partial Q_i^g} \quad (19)$$

This new values Q_i^g calculated by the GRG method will be injected in the FDLF algorithm to find the new values of power losses in our network.

ILLUSTRATION

The Fig. 4 shows the one-line diagram of Algerian 220/60 kv transmission/sub-transmission system and its main data and operational limits are shown in Table 1 and 2.

From the structure of the Western Algerian network, we can note considerably his symmetry and his sparse

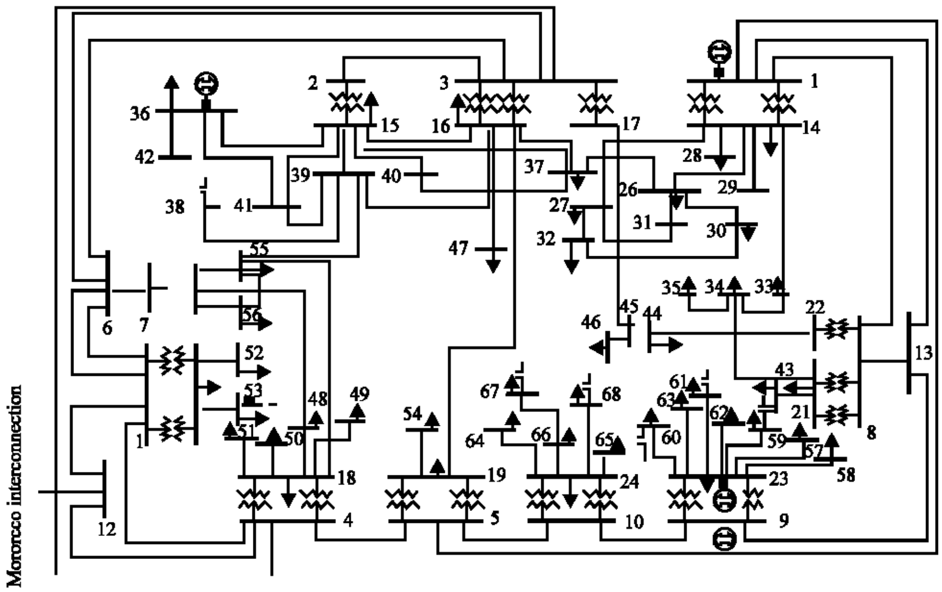


Fig. 4: Agerian 220/60 kv transmission/sub-transmission system

Table 1: Main data of the Western Algerian system

Load buses	64
Generator buses	4
Lines	78
Transformers	12
Shunt capacitors	8

Table 2: Limits of control variables and bus voltages

Magnitude	Lower	Upper
220 kv voltage	0.99	1.11
60 kv voltage	0.95	1.10
Taps (20 steps)	0.9	1.1
Q_{Shunt} (2 steps)	0	10 MVAR
Q_1^g	-250 MVAR	500 MVAR
Q_9^g	-90 MVAR	180 MVAR
Q_{23}^g	-15 MVAR	35 MVAR
Q_{36}^g	-20 MVAR	36 MVAR

Table 3: Dimensions of the network

Matrix	Dimension	Elements	Nonzero elements	Zero elements
Western Algerian network	68×68	4624	180	4444

Real data of Algerian network 220/60 kv transmission/subtransmission system as shown in Fig. 4

Table 4: Two classifications used to illustrate our method

1	**43**	**26**	**25**	**24**	**35**	**18**	**67**	**37**	**36**	**40**	**47**
1	2	3	4	5	6	7	8	9	10	11	12
41	**22**	**33**	**57**	**38**	**29**	**58**	**34**	**32**	**52**	**11**	**28**
13	14	15	16	17	18	19	20	21	22	23	24
60	**61**	**42**	**62**	**63**	**20**	**65**	**64**	**9**	**21**	**66**	**39**
25	26	27	28	29	30	31	32	33	34	35	36
23	**10**	**31**	**17**	**46**	**5**	**44**	**27**	**6**	**45**	**2**	**30**
37	38	39	40	41	42	43	44	45	46	47	48
14	**15**	**16**	**4**	**56**	**3**	**55**	**19**	**68**	**54**	**12**	**52**
49	50	51	52	53	54	55	56	57	58	59	60
53	**51**	**8**	**13**	**50**	**49**	**7**	**48**				
61	62	63	64	65	66	67	68				

Bold values: The first classification given in fig. 5, Normal values: The second classification as given in fig. 4 and 6

Table 5: The results of both used classifications

Storage methods	No. of zero elements stored	No. of non zero elements	Total No. of stored elements	Percentage
Classique method	2256	90	2346	100
Envelope Classification 1	780	90	870	37.08
Envelope Classification 2	504	90	594	25.31

Table 6: Evolution of power losses thought the process

	FDLF	OPF
Losses (MW)	28.07	24.2
Reduction MW		3.82
Reduction (%)		13.63

form (Table 3). By applying the envelope method defined earlier, we can store only the element in the profile as presented in Fig. 5.

The Table 4 show two approaches how to reorder the nodes of our network.

The nodes of the Fig. 5 are ordered randomly and the profile of the Fig. 6 is given by ordering of their internal neighbours.

It produces two different profiles, the first one is significant and the second is small.

The second reordering of the nodes increases the size of the envelope of the resulting matrix.

Following the methodology adopted, we can see use only 37.08% of the size of the initial matrix, sow we economize 62.92% of the main memory (Table 5).

And by choose the good reordering of the nodes, we increase the size the envelope of the resulting matrix, as shown in the second classification 74.69% of the matrix memory.

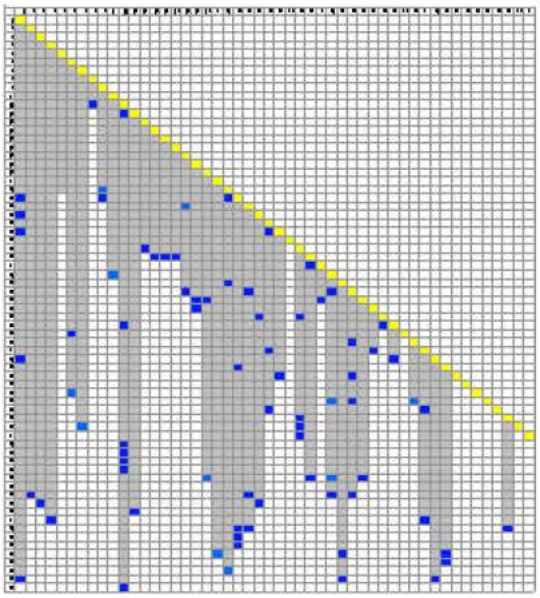


Fig. 5: First classification of the network buses

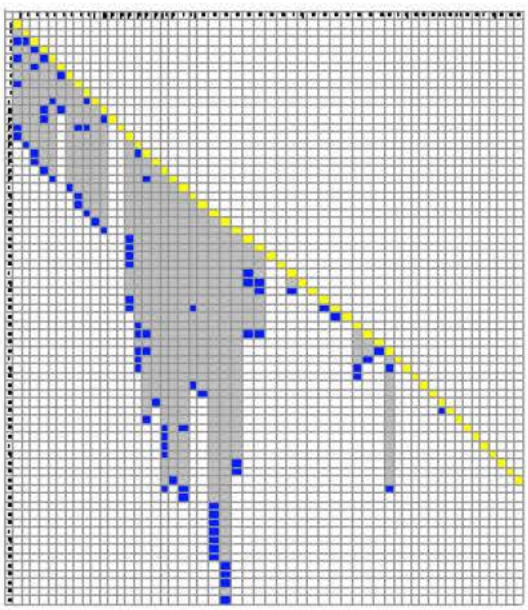


Fig. 6: Second classification of the network buses

- The diagonal element of the matrix
- The non-zero element of the matrix
- The zero element of the matrix

Then the result with a smaller profile is chosen.

The western Algerian network with 68 buses is used for minimization of energy loss. The losses found in the FDLF method are equal to 28.07 MW (Table 6) .

The energy loss is minimized by employing the GRG method (OPF). The total energy loss found in this method is equal to 24.2 MW.

By comparing the results, we observe that the energy loss in the GRG method for the above example is 13.63 less than that from the FDLF method.

CONCLUSIONS

A new strategy for on-line optimal reactive power dispatch is proposed and implemented. The method minimizes the total energy loss. By using the Reduced Gradient GRG method the problem has been solved.

By experiments, we have shown that the new algorithm for the reordering of matrices produces profiles smaller by approximately 15%. It corresponds to savings of 15% of main memory.

The algorithm, tested on a representation on the actual Western Algerian power grid, proved to be effective. The active loss has been reduced and satisfactory efficiency has been obtained.

In order to show the feasibility of the approach only three kinds of inequality constraints were considered.

REFERENCES

Herbig, A., G. Andersson, C.R. Fuerter-Esquivel, E. Acha and H. Ambriz-Perzez, 2001. A comprehensive Newton-Raphson UPFC model for the quadratic power flow solution of practical power networks. IEEE Trans. Power Sys., 16: 948-949.

Khalid, M.N., H. Mokhlis and T. Abdul Ghani, 2004. Reusability techniques in load-flow analysis computer program. IEEE Trans. Power Sys., 19: 1754-1762.

Martinez, R.J.L. and G. Exposito, 1995. A hybrid tool to assist the operator in reactive power/voltage control and optimization. IEEE Trans. Power Sys., 10: 760-768.

Meurant, G., 1999. Computer solution of large linear systems: Studies in mathematics and its applications. Elsevier Science B.V., Amsterdam, 28: 416-504.

Sun, D.I., B. Ashley, B. Brewer, A. Iluges and W.F. Tinney, 1984. Optimal power flow by Newton approach. IEEE Trans. Power Sys., 103: 2864-2880.