A NEW METHOD FOR CALCULATING LOSS COEFFICIENTS

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ABSTRACT

A method is proposed which avoids many limitations associated with traditional B-coefficient loss coefficient calculation. The proposed method, unlike the traditional B-coefficient method, is very fast and can handle line outages. The method utilzes network sensitivity factors which are established from DC load flow solutions. Line outage distribution factors (ODF's) are formulated using changes in network power generations to simulate the outaged line from the network. The method avoids the use of complicated reference frame transformations based upon Kron's tensor analysis. The necessity of data normalization used in least squares and the evaluation of the slope of θ_j versus PG_n is not necessary with the proposed method. Using IEEE standard 14-bus and 30-bus systems, the method's results are compared against results obtained from an AC load flow program (LFED). The method's solution speed is compared to that of the LFED method, the base case database method and the conventional B-coefficient method based on A_{jn}-factor. The proposed method is easy to implement and, when compared to other methods, has exhibited good accuracy and rapid execution times. The method is well suited to on-line dispatch applications.

Keywords : economic dispatch, loss coefficients, sensitivity factors

LIST OF SYMBOLS

$ACLF$	=AC load flow
$A_{m,i}$	=GSDF for line m, due to generation shift of ith unit
B_{ij}	=loss coefficients
$d_{m,f}$	=ODF from power injection method
$d_{m,f(1)}$	=ODF from generation change method
$D_{m,i}$	=GGDF for line m, due to generation of ith unit
$GGDF$	=generalized generation shift distribution factor
$GSDF$	=generation shift distribution factor
$LFED$	=economic dispatch by using the ACLF method
NB	=total number of buses
NG	=total number of generation units
NL	=total number of transmission lines
ODF	=line outage distribution factor
$\mathbf{P}$	=power injection vector
P_f	=power flow on line to be removed
P_{ij}	=transmitted active power from i to j
P_m	=power flow on line m
P_m^0	=base flow on line m
PF_i	=penalty factor of ith unit
$PF_{i(new)}$	=penalty factor of ith unit before smoothing
$PF'_{i(new)}$	=penalty factor of ith unit after smoothing
$PF_{i(old)}$	=penalty factor of ith unit in previous iteration
PG_i	=generation of ith unit
ΔPG_i	=generation shift of ith unit
PL	=system power loss
PL_m	=power loss on line m
$PTDF$	=power transfer distribution factor
R_m	=resistance of line m
S_{ij}	=transmitted complex power from i to j
v_i	=voltage of bus i, $V_i\angle\theta_i$
X_{ki}, X_{ki}	=elements of $\mathbf{X}$
X_m	=reactance of line m
Z_m	=impedance of line m
θij	$=\theta i - \theta j$
Θ	=voltage angle vector
α	=smoothing factor
$\rho_{m,i}$	=PTDF of line m, due to power injection change in bus i

94 WM 204-8 PWRS A paper recommended and approved by the IEEE Power System Engineering Committee of the IEEE Power Engineering Society for presentation at the IEEE/PES 1994 Winter Meeting, New York, New York, January 30 - February 3, 1994. Manuscript submitted April 7, 1992; made available for printing November 29, 1993.

INTRODUCTION

The economic dispatch of an electric power system is to determine a generation schedule which will not violate unit operating limits while minimizing the total generation cost. Owing to rapidity computation,the conventional method to calculate the incremental losses from the B-coefficients is still widely used for real-time economic dispatch of power systems. However, the B-coefficients are not constant for all different operating points and this will sacrifice the solution accuracy. Their application to generation scheduling are based on the following assumptions[1]:

(i) All load currents maintain a constant ratio to total current.

(ii) The voltage magnitude at every source bus remains constant.

(iii) Power factor at each source remains constant.

(iv) The voltage angle at every source bus remains constant.

(v) The ratio R_m/X_m for all transmission lines is the same.

(vi) All load currents have the same phase angle.

The results will lose significant accuracy if these assumptions are violated. The last two assumptions can be eliminated by using the tensor method [2] which reduces the electric power system to an equivalent one with a single hypothetical load; nevertheless, the complicated approach of reference frame transformations is necessary. The assumptions stated above can be replaced with those described by Early et al.[3], as follows:

(i) The substation load varies between its peak load and minimum load values linearly with total system load.

(ii) The bus voltage varies linearly with total system load from its value at peak load to its value at minimum load.

(iii) The power factor of each load varies from its value at system peak load to its value at minimum load linearly with total system load.

(iv) The reactive generation varies linearly with real power generation.

The method as described in [3] evaluates loss coefficients from the normalization of data procedure by the method of least squares. Improvements upon these two methods were presented afterwards [4-6], while they were distressed about the inherent properties of poor accuracy and time consuming.

To challenge these shortcomings, Hill et al.[7] proposed the A_{jn}-factor method to improve the developed methods.It is assumed that the bus voltage magnitudes remain constant and the bus voltage angles vary linearly with the active generation of any one unit .The A_{jn} factor represents the variation of bus voltage angle θ_j with respect to generation output PG_n in place of the partial derivation $\partial\theta_j/\partial PG_n$ and can be expressed by the slope of plotting θ_j versus PG_n from a series of load flow studies. This method eliminates many assumptions and detours complicated calculations, yet it requires running load flow many times and the loss coefficients result in poor accuracy when they are applied to different load levels.

We present a new method for calculating B-coefficients to overcome the defects as stated above. The algorithm starts with an initial dispatch without considering power loss. A DC model is then used to calculate line flows and the system power loss.The B-coefficients can be expressed in terms of sensitivity factors which are evaluated by taking these line flows as a base condition.Finally, the generation schedules are completed by using an iterative technique. Since the DC approximations are included in GSDF's derivations, the base flow calculation by a DC model doesn't increase any assumption. The assumptions of the proposed method are :

(i) The ratio R_m/X_m for each transmission line is much smaller than unity.

(ii) The voltage magnitude at every bus is unity.

(iii) The angles across transmission lines are small.

The situation of line outage that conventional B-coefficient application can not handle is considered by modifying sensitivity factors and line flows. The unconforming loading variations are taken into account by evaluating the on-line B-coefficients in this paper. Consequently, the proposed method overcomes the deficiencies of conventional approaches.

SENSITIVITY FACTORS

The use of a sensitivity method to compute line flows in system security and contingency analysis remains very popular .The excellent properties of simplicity, linearity, accuracy and rapidity computation make it widely acceptable in real-time application.The generation shift distribution factor (GSDF) and the ODF[8] are two of the most important sensitvity factors in the conventional approaches. The former can reflect the generation shift to line flows, while the latter shares the flows of outaged line between the unfaulted lines. Here, we concern ourselves with the GSDF first.

On account of possessing the feature of reflecting the shift of bus generation to each transmission line,the GSDF can be used to calculate line flows after generation rescheduling. Using the definition of the reactance matrix and the dc approximation ,we can calculate the GSDF by:

$$\begin{aligned} A_{m,i} &= \frac{\partial P_m}{\partial PG_i} \\ &= \frac{X_{li} - X_{ki}}{X_m} \qquad m = 1, ..., NL \end{aligned} \tag{1}$$

where l and k are initial bus and terminal bus of line m respectively. The new line flows after shifting can be expressed in an incremental form as:

$$P_m = P_m^0 + \sum_{i=1}^{NG} A_{m,i} \Delta PG_i \qquad m = 1, ..., NL \tag{2}$$

Since all generation changes are absorbed by the reference bus,the total system generation remains unchanged. If not, because the initial line flows are known quantities,a new load flow must be excuted to reestablish the initial values. That is, the solution accuracy of GSDF is guaranteed only when the total system generation remains unchanged.Ng[9] proposed the generalized generation shift distribution factor(GGDF) from the concept of GSDF to overcome this limit. The GGDF can completely replace GSDF and calculates line flows in an integral form. It can be defined by the following equation:

$$P_m = \sum_{i=1}^{NG} D_{m,i} PG_i \qquad m = 1, ..., NL \tag{3}$$

where $D_{m,i}$ is the GGDF and can be calculated by:

$$D_{m,i} = D_{m,r} + A_{m,i} \tag{4}$$

and

$$D_{m,r} = \frac{P_m^0 - \sum_{i=1}^{NG} A_{m,i} PG_i}{\sum_{j=1}^{NG} PG_j} \qquad for \ \ i \neq r \tag{5}$$

where $D_{m,r}$ denotes GGDF for line m due to the generation of referece bus.

EXPRESSION FOR POWER LOSS

In the economic dispatch approaches, the penalty factors or the incremental losses are always the key points in solution algorithm and the B-coefficient method is possibly the most popular technique. The power loss expressed by using B-coefficients and bus generations in a quadratic form was first developed by George[10] as:

$$PL = \sum_{i=1}^{NG}\sum_{j=1}^{NG} B_{ij} PG_i PG_j \tag{6}$$

The incremental loss can be derived as:

$$\frac{\partial PL}{\partial PG_i} = 2\sum_{j=1}^{NG} B_{ij} PG_j \tag{7}$$

Taking the derivative of $\partial PL/\partial PG_i$ with respect to PG_j ,we acquire the B-coefficients as:

$$B_{ij} = \frac{1}{2}\frac{\partial^2 PL}{\partial PG_i \partial PG_j} \tag{8}$$

Power system delivers unit generations to customers via transmission lines and produces power loss.There exists a relation among power loss, transmission lines and unit generations,and the B coefficients or incremental losses will be immediately calculated if we can find out this relation. Under the dc approximation, the power loss of line m can be expressed in terms of resistance and line flow ,as follows (see Appendix A):

$$PL_m = R_m P_m^2 \tag{9}$$

The system power loss is expressed by the summation over all transmission lines as:

$$PL = \sum_{m=1}^{NL} R_m P_m^2 \quad (10)$$

Substituting eq.(3) into (10),this relation can be written as:

$$PL = \sum_{m=1}^{NL} R_m [\sum_{i=1}^{NG} D_{m,i} PG_i]^2 \quad (11)$$

Finally,the new loss coefficients formula is obtained by substituting eq.(11) into (8):

$$B_{ij} = \sum_{m=1}^{NL} R_m D_{m,i} D_{m,j} \quad (12)$$

TRANSMISSION LINE OUTAGE

The B-coefficients will be changed if the transmission line outage occurs and will be obtained if we can find out the GGDF after outage. As shown in eq. (4) and (5), the base flow on line m ($P_m{}^0$) and the GSDF ($A_{m,i}$) are the factors which make the GGDF change, because the unit generations remain unchanged except swing bus generations changing due to the change in system loss. The GSDF after line outage can be calculated from the concept of power transfer distribution factor (PTDF), $\rho_{m,i}$, which represents the change of complex power on line m due to the power injection change in bus i [11]. The PTDF after outage of line f is :

$$\rho'_{m,i} = \rho_{m,i} - \frac{Z_f^*(\rho_{f,l} - \rho_{f,k})\rho_{f,i}}{Z_m^*(\rho_{f,s} - \rho_{f,e} - 1)} \quad (13)$$

where s and e are initial bus and terminal bus of line f respectively, and the symbol $'$ refers to the condition where the line f is removed from the system. From the dc approximation , the PTDF can be reduced to GSDF. So, the GSDF after outage of line f is :

$$A'_{m,i} = A_{m,i} - \frac{X_f(A_{f,l} - A_{f,k})A_{f,i}}{X_m(A_{f,s} - A_{f,e} - 1)} \quad (14)$$

The modification of base flow can be acheived[8] by :

$$P'_m = P_m + d_{m,f} P_f \quad (15)$$

where $d_{m,f}$ is ODF and can be expressed as :

$$d_{m,f} = \frac{\frac{X_f}{X_m}(X_{ls} - X_{ks} - X_{le} + X_{ke})}{X_f - (X_{ss} + X_{ee} - 2X_{se})} \quad (16)$$

The computation of ODF is usually performed off-line and NL$\times$NL elements of ODF array are needed. The storage requirement is excessive and the computation performed off-line is time consuming for a large system[12]. These shortcomings will be avoided if we can evaluate ODF from GSDF, as following(see Appendix B):

$$d_{m,f(1)} = A'_{m,s} - A'_{m,e} \quad (17)$$

Substituting eq. (14) and (15) into (4) and (5), the GGDF after outage can be calculated and the B-coefficients will be found by eq.(12).

SOLUTION ALGORITHM

An initial dispatch without considering power loss is first executed to reach an approximate optimum economic operating point for promotting accuracy. The initial flows on which the sensitivity factors are based are then built by using the dc load flow method :

$$P_m = \frac{\theta_i - \theta_j}{X_m} \quad (18)$$

and

$$\mathbf{\Theta} = \mathbf{XP} \quad (19)$$

where θ_i and θ_j are the voltage angles of initial bus and terminal bus on line m. The reactance matrix $\mathbf{X}$ and the GSDF's can be built in advance. The power loss is then obtained by substituting (18) into (10). Since the dc load flow model is involved in the process of establishing GSDF, it doesn't increase any assumption using this model to evaluate base flows.

The convergence speed can be accelerated by applying a smoothing factor which smooths the change of penalty factor during iterations[13]:

$$PF'_{i(new)} = PF_{i(old)} + \alpha[PF_{i(new)} - PF_{i(old)}] \quad (20)$$

The starting values of all penalty factors are unity. The solution algorithm of economic dispatch by determining loss coefficients from sensitivity factors is comprised of the following steps:

Step 1. Read in system information.
Step 2. Execute initial dispatch without considering power loss.
Step 3. Calculate base flows by (18) and (19).
Step 4. Calculate the system power loss by (10) and absorb it with the reference unit.
Step 5. Calculate GGDF by eq.(4) and (5).
Step 6. Calculate B-coefficients by eq.(12).
Step 7. Execute generation dispatch by using the iterative technique.

If any transmission line outage takes place, the B-coefficients can be calculated from the computation of GGDF's by modifying base flows and GSDF's. The dispatch results which come from step 2 are used as base generations. The following steps are carried out after step 4:

Step 4.1. Modify GSDF's by eq.(14).
Step 4.2. Modify base flows by eq.(15) and (17).
Step 4.3. Calaulate system power loss by eq.(10) and absorbed the loss change by the reference unit.

EXAMPLES AND RESULTS

The proposed method is tested on 14- and 30-bus systems and compared with the exact results based on AC load flow (ACLF) method[13] (termed as "LFED") as shown in Table 1. The dispatch results of both the proposed method and the LFED method are in close agreement. For both cases, the maximum errors of loss and cost are limited within 1.9476% and 0.0378% ,respectively. However, the execution time of the former is much less than that of the latter.

In order to demonstrate the execution time and the solution accuracy of the proposed method compared with the real-time base case database method[14] and the conventional B-coefficient method[7] for real-time application , the IEEE 14-bus system is chosen as an example. Table 2 shows the load demands and their percentage deviations. A is a base case point of which the dispatch result is shown in Table 1. B,C,D, and E are four forecasting operation points of which the demands are 93%,95%,105% and 107% referring to A,respectively.The system demands for each point are 2.4087 p.u.(B), 2.4605 p.u.(C) , 2.7195 p.u.(D) and 2.7713 p.u.(E). The bus load demands are shown in Table 3. In each point except base case, the first column is the load demand and the second column is the demand deviation from base case in each bus. It is noted from the Table that the deviations are very nonconformable.

The data base of the database method and the B-coefficients of the A_{jn}-factor method in base case are prebuilt by the LFED method for maintaining accuracy. The dispatch results are shown in Table 4 and compared with the exact solution of LFED method. From column 7 to the last are their relative errors. Due to the assumption of linear loss change as load demands varying, the database method has the largest errors. The relative errors of the A_{jn}-factor method are smaller than the database method, but it doesn't account for the nonconformable loading changing. So, its accuracy in system loss is inferior to that of the proposed method. It is obvious from Table 4, the accuracy of system loss in the proposed method is superior to those of the other two and shown in Fig. 1 (a). Fig. 1 (b) shows the relative errors in operating cost.

Table 1. Economic dispatch solutions for IEEE 14- and 30-bus systems

IEEE	14	bus	system	IEEE	30	bus	system
Method	LFED (W)	Prop. (Z)	1-$\frac{Z}{W}$ (%)	Method	LFED (W)	Prop. (Z)	1-$\frac{Z}{W}$ (%)
PG_1	1.5963	1.5905	0.3633	PG_1	1.6611	1.6386	1.3545
PG_2	0.6894	0.6977	-1.2039	PG_2	0.7533	0.7509	0.3186
PG_6	0.4004	0.3968	0.8991	PG_{11}	0.5253	0.5483	-4.3785
Loss	0.09611	0.09494	1.2174	Loss	0.10577	0.10371	1.9476
Cost	1138.020	1137.590	0.0378	Cost	1245.881	1245.748	0.0107
CPU (sec)	1.93	0.06	—	CPU (sec)	15.27	0.11	—

For a complete comparison with actual loss, the ACLF method is used to calculate power loss(termed as "PFL") in accordance with the scheduling generations of the forcasting points in each method and the PFC is the corresponding cost. It is noted that the actual loss and operating cost in the proposed method are all less than those of the conventional B-coefficient method and the accuracy is superior. The relative accuracy errors in PFL and PFC from the proposed method, although not zero, have the feature of remaining almost constant within a very small range throughout variations in system loading, as shown in Fig. 2. Due to the assumptions of linear loss change as load demands varying in the database method and not considering the nonconformable loading change in the A_{jn}-factor method, their accuracy are inferior.

Table 5 shows CPU times and test system. There are two CPU times in the A_{jn}-factor method, the first is computation time of calculating B-coefficients from the A_{jn}-factor built by the ACLF method and the second is that of economic dispatch using B-coefficients by the iterative technique. It is obvious that the solution method in this paper has rapid computation time, only 0.06 second as fast as the real-time basecase method. The B-coefficient calculation in the A_{jn}-factor method is very time cosuming, 3.13 second. The smoothing factor and the convergence tolerance in the iterative technique for these example systems are set to 0.85 and 0.001 p.u. respectively.

Table 6 shows three cases of line outages. In each case the results by the generation change method are listed from column 1 to 3. The first two columns are the GSDF's corresponding to both ends of faulted line after outage, column 3 is the ODF of proposed method and the last column is that of conventional method. It is obvious that the ODF's computed by these two methods are almost the same. However, the proposed one is more practical than the other due to extra storage and off-line computation being not required.

Table 2. Load demands for IEEE 14-bus system

Point	A	B	C	D	E
Demand(p.u.)	2.590	2.4087	2.4605	2.7195	2.7713
Demand_Dev.(%)	100	93	95	105	107

DISCUSSIONS AND CONCLUSIONS

In the approaches of economic dispatch stated in literatures a load flow technique can obtain a accurate result but the solution algorithm is repetitive and time consuming, therefore it is not suitable for on-line operation. Although the real-time base case database method has rapid computation time, it assumes that load demands change conformitily and the transmission loss changes linearly. These assumptions will be inconvenient in practical application. In particular, this method will be invalid if the on-line units alter when the system loading conditions in the load pick-up and drop-down periods are the same. The usage of conventional B-coefficients for on-line dispatch is also rapid, but it results poor accuracy when the operating points are shifted from base case due to a large of assumptions. Besides, the database and the B-coefficients must be recomputed when transmission line outage occurs. Two method calculating the B-coefficients from the DC approximation as made in the proposed method are discussed in ref. 15. The problem of load change can be eliminated, but still suffer from the changes of system structure.

This paper has presented a fast economic dispatch method by evaluating loss coefficients from sensitivity factors and only requires dc assumptions. It overcomes the drawbacks, described above, which have suffered the research workers for a long time. The dc assumptions will result in higher errors in the network with higher R/X ratio. This can

Table 3. Bus load demands for forecasting points

Bus	A	B		C		D		E	
no.	(p.u.)	(p.u.)	(%)	(p.u.)	(%)	(p.u.)	(%)	(p.u.)	(%)
1	0	0	0	0	0	0	0	0	0
2	0.217	0.2047	94	0.2123	98	0.2344	108	0.2396	110
3	0.942	0.8622	92	0.8751	93	0.9565	102	0.9709	103
4	0.478	0.4601	96	0.4695	98	0.5273	110	0.5364	112
5	0.076	0.0697	92	0.0712	94	0.0776	102	0.0798	105
6	0.112	0.1043	93	0.1064	95	0.1203	107	0.1227	110
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0.295	0.2751	93	0.2833	96	0.3162	107	0.3235	110
10	0.090	0.0822	91	0.0832	92	0.0915	102	0.0930	103
11	0.035	0.0334	95	0.0345	99	0.0382	109	0.0393	112
12	0.061	0.0555	91	0.0570	93	0.0625	103	0.0646	106
13	0.135	0.1278	95	0.1320	98	0.1458	108	0.1492	111
14	0.149	0.1337	90	0.1360	91	0.1492	100	0.1523	102

Table 4. Dispatch results of forecasting points for IEEE 14-bus system

Point		LFED(W)	Database(X)	A_{jn}-fact.(Y)	Prop.(Z)	$1-\frac{X}{W}$(%)	$1-\frac{Y}{W}$(%)	$1-\frac{Z}{W}$(%)
B	PG_1	1.5378	1.5374	1.5616	1.5311	0.0260	-1.5477	0.4357
	PG_2	0.6219	0.6242	0.6307	0.6298	-0.3698	-1.4150	-1.2703
	PG_6	0.3335	0.3365	0.3014	0.3320	-0.8995	9.6252	0.4498
	Loss	0.08446	0.08938	0.08505	0.08419	-5.8252	-0.6986	0.3197
	Cost	1057.905	1059.969	1057.592	1057.882	-0.1951	0.0296	0.0022
	PFL	—	0.08424	0.08616	0.08430	0.2605	-2.0128	0.1894
	PFC	—	1057.930	1058.019	1057.928	-0.0024	-0.0108	-0.0022
C	PG_1	1.5543	1.5457	1.5787	1.5479	0.5533	-1.5698	0.4118
	PG_2	0.6408	0.6471	0.6501	0.6489	-0.9831	-1.4513	-1.2640
	PG_6	0.3525	0.3589	0.3199	0.3504	-1.8156	9.2482	0.5957
	Loss	0.08716	0.09130	0.08817	0.08670	-4.7499	-1.1588	0.5278
	Cost	1080.407	1082.319	1080.260	1080.299	-0.1770	0.0136	0.010
	PFL	—	0.08660	0.08890	0.08704	0.6425	-1.9963	0.1377
	PFC	—	1080.401	1080.565	1080.433	0.0006	-0.0146	-0.0024
D	PG_1	1.6373	1.6383	1.6641	1.6320	-0.0611	-1.6368	0.3237
	PG_2	0.7362	0.7360	0.7476	0.7447	0.0272	-1.5485	-1.1546
	PG_6	0.4488	0.4462	0.4127	0.4439	0.5793	8.0437	1.0918
	Loss	0.10286	0.10091	0.10484	0.10115	1.8958	-1.9249	1.6625
	Cost	1195.363	1194.495	1195.551	1194.682	0.0726	-0.0157	0.0570
	PFL	—	0.10322	0.10494	0.10302	-0.3500	-2.0222	-0.1555
	PFC	—	1195.477	1195.616	1195.423	-0.0095	-0.0212	-0.0050
E	PG_1	1.6538	1.6400	1.6812	1.6488	0.8344	-1.6568	0.3023
	PG_2	0.7553	0.7623	0.7672	0.7639	-0.9268	-1.5755	-1.1386
	PG_6	0.4683	0.4719	0.4313	0.4627	-0.7687	7.9009	1.1958
	Loss	0.10612	0.10283	0.10839	0.10410	3.1003	-2.1391	1.9035
	Cost	1218.709	1217.578	1219.003	1217.883	0.0928	-0.0241	0.0678
	PFL	—	0.10583	0.10828	0.10635	0.2733	-2.0354	-0.2167
	PFC	—	1218.833	1218.964	1218.807	-0.0102	-0.0209	-0.0080

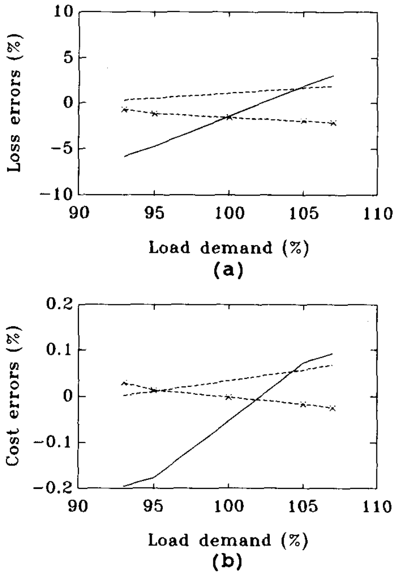

Fig.1 Relative errors in (a) system loss (b) operating cost

——— : the database method
-x--x-- : the Ajn-factor method
- - - - : the proposed method

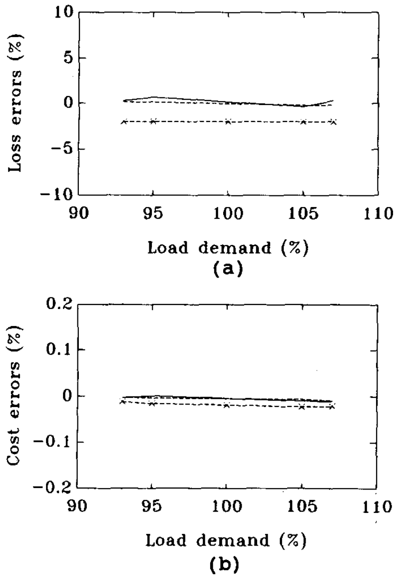

Fig.2 Relative errors in (a) PFL (b) PFC

——— : the database method
-x--x-- : the Ajn-factor method
- - - - : the proposed method

Table 5. Computation times (in sec.) for dispatch

Method	NTED	Database	Prop.	A_{jn}	
CPU time	1.93	0.06	0.06	3.13	0.05
Test Sys.	IBM/PC 386				

be verified in the results of IEEE 14-bus and 30-bus systems as shown in Table 1. The accuracy of the latter is inferior to that of the former, since their average ratios of R/X are 0.306 and 0.381 respectively.

In order to modify B-coefficients after line outage and improve some deficiencies of conventional ODF, we calculate ODF from GSDF by mean of using the generation change model to simulate transmission line outage. The extra memory requirements are only less than 2NL, while those of conventional ODF are NL×NL. If we recompute base flows and GSDF's by modifying the elements of reactance matrix, the amount of these elements will be (NB-1)×(NB-1)+NL(NG-1) and the modification is demanding much time. However, they are less than 2NL+NL(NG-1) in the presented method. The accuracy of new ODF is almost the same as that of conventional one.

The complicated approach of reference frame transformations based upon kron's tensor analysis,the normalization of data procedure by the method of least squares and the evaluation of slope by plotting θ_j versus PG_n are not necessary in this paper. It is very easy for an implementation of a computer program. Because of building database, maintaining many sets of loss coefficients and executing ac load flow are not necessary, storage requirements are reduced greatly and computation is rapid. The nonconformity condition of demand changing which the database method can't handle and doesn't meet the assumption of conventional B-coefficient method can be treated easily. The situation of line outage which can't be settled in the conventional B-coefficient application and the database method is taken into account in this paper. Two standard sysems are tested to demonstrate the effectiveness of the proposed method and the results show that it maintains the advantages of rapid calculation and good accuracy. This method is very suitable for on-line application in power system.

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APPENDIX A

The complex power flow from bus i to j is expressed as:

$$\begin{aligned} S_{ij} &= v_i[\frac{vi - v_j}{Z_m}]^* \\ &= \frac{1}{Z_m^*}(V_i^2 - V_iV_j\angle\theta_{ij}) \\ &= \frac{1}{|Z_m|^2}[V_i^2 - V_iV_j(cos\theta_{ij} + jsin\theta_{ij})][R_m + jX_m] \end{aligned} \quad (21)$$

The real part of eq.(21) is the active power flow from i to j:

$$P_{ij} = \frac{1}{|Z_m|^2}[V_i^2 R_m - V_iV_j(R_m cos\theta_{ij} - X_m sin\theta_{ij})] \quad (22)$$

Table 6 Outage distribution factors with line 6 ,12,18 off

Line	Outage	Line	=	6	Outage	Line	=	12	Outage	Line	=	18
No.	$A'_{m,s}$	$A'_{m,e}$	$d_{m,f(1)}$	$d_{m,f}$	$A'_{m,s}$	$A'_{m,e}$	$d_{m,f(1)}$	$d_{m,f}$	$A'_{m,s}$	$A'_{m,e}$	$d_{m,f(1)}$	$d_{m,f}$
1	-0.869694	-0.653770	-0.215924	-0.215924	-0.648347	-0.652234	0.003887	0.003887	-0.676206	-0.640791	-0.035415	-0.035417
2	-0.161936	-0.372225	0.210289	0.210290	-0.377669	-0.373872	-0.003797	-0.003797	-0.349873	-0.385150	0.035277	0.035276
3	-1.027923	-0.001024	-1.026898	-1.026899	-0.123685	-0.126984	0.003299	0.003300	-0.147894	-0.117179	-0.030715	-0.030713
4	0.071355	-0.391106	0.462461	0.462461	-0.255016	-0.261804	0.006787	0.006786	-0.304215	-0.241732	-0.062483	-0.062483
5	0.088409	-0.254761	0.343170	0.343171	-0.263588	-0.257395	-0.006193	-0.006192	-0.218461	-0.275753	0.057292	0.057293
6	—	—	—	—	-0.119707	-0.122883	0.003176	0.003176	-0.142398	-0.113544	-0.028855	-0.028857
7	0.066373	0.585486	-0.519113	-0.519110	-0.020869	0.033133	-0.054001	-0.053997	0.371561	-0.126751	0.498312	0.498316
8	0.002264	0.021719	-0.019455	-0.019455	-0.209102	-0.251059	0.041956	0.041957	-0.530430	-0.124367	-0.406063	-0.406061
9	0.001297	0.012461	-0.011163	-0.011163	-0.119966	-0.144037	0.024071	0.024072	-0.304317	-0.071348	-0.232969	-0.232967
10	-0.003556	-0.034182	0.030625	0.030625	-0.670934	-0.604903	-0.066030	-0.066031	-0.165252	-0.804297	0.639045	0.639043
11	-0.002499	-0.019011	0.016513	0.016512	0.218287	0.149678	0.068609	0.068609	-0.002081	-0.998225	0.996143	0.996139
12	-0.000335	-0.002795	0.002460	0.002460	—	—	—	—	-0.041758	0.048756	-0.090514	-0.090514
13	-0.001306	-0.009818	0.008512	0.008511	0.138320	-0.734028	0.872348	0.872347	-0.157266	0.185208	-0.342474	-0.342471
14	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
15	0.002256	0.021717	-0.019461	-0.019461	-0.209108	-0.251067	0.041959	0.041959	-0.530434	-0.124349	-0.406085	-0.406082
16	0.002430	0.019372	-0.016941	-0.016941	-0.215133	-0.148314	-0.066819	-0.066820	-1.002150	0.001849	-1.003999	-1.003996
17	0.001624	0.012677	-0.011053	-0.011052	-0.137486	-0.268925	0.131439	0.131440	0.198144	-0.232643	0.430787	0.430786
18	0.002468	0.019190	-0.016722	-0.016722	-0.216723	-0.149002	-0.067721	-0.067720	—	—	—	—
19	-0.000423	-0.002823	0.002401	0.002400	0.002685	1.098691	-1.096007	-1.096009	-0.049075	0.058334	-0.107409	-0.107406
20	-0.001630	-0.012637	0.011007	0.011008	0.138016	0.269694	-0.131678	-0.131678	-0.198822	0.233610	-0.432432	-0.432431

In similar manner, the active power flow from j to i can be expressed as:

$$P_{ji} = \frac{1}{|Z_m|^2}[V_j^2 R_m - V_i V_j (R_m cos\theta_{ij} + X_m sin\theta_{ij})] \quad (23)$$

So, the power loss of line m can be obtained:

$$\begin{aligned} PL_m &= P_{ij} + P_{ji} \\ &= \frac{1}{|Z_m|^2}[(V_i^2 + V_j^2)R_m - 2V_i V_j R_m cos\theta_{ij}] \end{aligned} \quad (24)$$

Under the assumption of near unity bus voltage:

$$\begin{aligned} PL_m &= \frac{2R_m}{|Z_m|^2}[1 - cos\theta_{ij}] \\ &= \frac{2R_m}{|Z_m|^2}[2sin^2\frac{\theta_{ij}}{2}] \\ &= \frac{4R_m}{|Z_m|^2}sin^2\frac{\theta_{ij}}{2} \end{aligned} \quad (25)$$

Assumed $R_m << X_m$ and $\frac{\theta_{ij}}{2}$ is very small,

$$\begin{aligned} PL_m &= \frac{4R_m}{X_m^2}(\frac{\theta_{ij}}{2})^2 \\ &= R_m(\frac{\theta_{ij}}{X_m})^2 \end{aligned} \quad (26)$$

Substituting eq.(18) into (26), the power loss of transmission line can be approximated by:

$$PL_m = R_m P_m^2 \quad (27)$$

APPENDIX B

In conventional method a line outage is modeled by adding two power injections to a system, one at each end of the line to be removed[8]. On the other hand , it can be modeled by adding generations into these buses and the changes of line flows due to generation changes are computed by GSDF. The procedure of derivation is illustrated as following. Suppose line f from bus s to e were the line to be outaged. The power flow of line f before outage is denoted P_f, as shown in Fig.3(a), and can be modeled by simulated generations $PG_s(=-P_f)$ and $PG_e(=P_f)$, as shown in Fig.3(b). After outage, the simulated generations are changed to zero, that is ΔPG_s=P_f and ΔPG_e=$-P_f$, as shown in Fig.3(c). From the definition of GSDF stated above, since the total generation remains unchanged , the power flow on line m after generation change can be expressed as:

$$\begin{aligned} P'_m &= P_m + \sum_{i=1}^{NG'} A'_{m,i}\Delta PG_i \\ &= P_m + \sum_{i=1}^{NG} A'_{m,i}\Delta PG_i + A'_{m,s}\Delta PG_s \\ &\quad + A'_{m,e}\Delta PG_e \quad m = 1,...,NL \end{aligned} \quad (28)$$

Assuming that the generations are unchanged when the line outage arises, the summation term in eq.(28) is zero and line flow is:

$$\begin{aligned} P'_m &= P_m + A'_{m,s}P_f + A'_{m,e}(-P_f) \\ &= P_m + d_{m,f(1)}P_f \qquad m = 1,...,NL \end{aligned} \quad (29)$$

where $d_{m,f(1)}$ is the ODF by the generation change method and expressed as:

$$d_{m,f(1)} = A'_{m,s} - A'_{m,e} \qquad m = 1,...,NL \quad (30)$$

The GSDF's of eq.(30) are the values after outage and can be found from eq.(14).

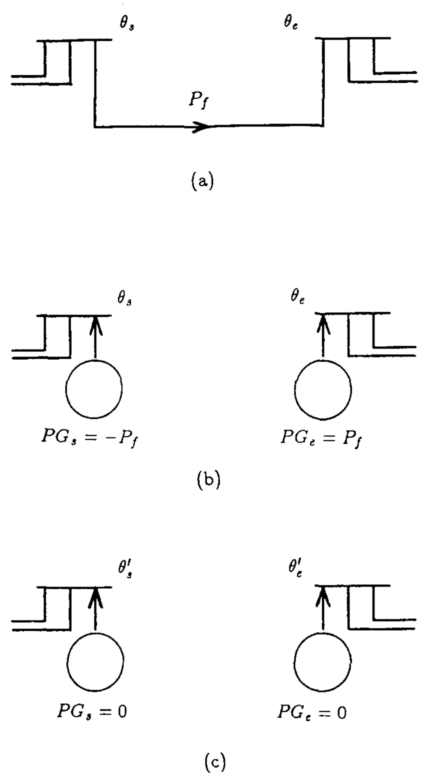

Fig.3 Line outage simulation using generations.
(a): Line f before outage
(b): Outaged line flow simulation with generations at bus s and bus e
(c): System after outage

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