TRANSIENT SECURITY AND ECONOMIC DISPATCH

السيطرة الآمنة والمؤكدة لمنظومة القوى الكهربائية

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Abstract:-

Security assessment requires that the power system must be capabable of suitably – supplying the connected loads in both steady state and contingency conditions.

In economic dispatch, normal security constraints for bus voltages, active power of generators, and line flows are specified. However, the results of this dispatch may give rise to an increase in the vulnerability of some lines.

For such a situation, vulnerable line becomes transiently weak and line – or generator – outage may occur during contingency. Vulnerability indices of line – outsets belonging to some selected contingencies, can be included in the economic dispatch program. The results obtained clarify that a better choice of the weighting factors of the augmented cost function, gives rise to substantial improvement of transient stability of the power system while keeping the total generation cost at a minimum.

The DFP (Davidon- Flitcher- powell) - method used, had proved to be a highly convergent economic dispatch algorithm.

List of Symbols

$\overline{X}$	set of active power injected at generator buses
J	iteration count of the economic dispatch algorithm
$\overline{X}^{j}$	j–th value of $\overline{x}$
$\overline{C}(x^{j})$	total generation cost $/hr

$\overline{G}^{j}$	j–th value of the gradient of the cost function
$\overline{D}^{j}$	j–th value of the direction of liner search
$\overline{H}^{j}$	j–th value of the positive definite matrix
$\overline{O}^{j}$	j–th value of the optimum change in control variables
APF	active power flow in transmission line
B_m, D_m	sine and cosine amplitudes of the line active power
Θ^{o}_{ik}	initial angle between bus I and bus k
DA	deceleration area
AA	acceleration area
C_i	outward outset of lines connected to bus i
VI	vulnerability index
K_g	cost weighting factor
K_i	line–contingency weighting factor
K_s	bus–contingency weighting factor
Θ^{s}	set of line angles during bus–contingency
Θ^{i}	set of line angles during line–contingency
I	number of line contingency
S	number of bus–contingencies
ACF	augmented cost function

1. Introduction

With generation and transmission plans of expansion, Large area power systems are being built. In such a cost, both economy and security become increasingly urgent.

Secure operation means, shortly, that the service must not be interrupted nor even unsuitably deteriorated for all consumer centers. The insecure conditions usually exist during severe contingencies like; loss of some generating units, loss of loads, short circuits and outage of transmission lines [1]. Unfortunately, these contingencies are in most cases unavoidable and it is the responsibility of the dispatcher to restore the power system to more secure state.

On–line security monitors are often available for dispatcher and he continuously tests the vulnerability level of the power system after a postulated contingency.

Increased vulnerability may subject the system, during emergency state, to insecure events like; (a) line overload and subsequent line–outage, (b) loss of synchronism of some generating units due to the impact of contingency and (c) bus voltage violations at load centers and the probable load curtailment [2].

Economic operation is also an urgent requirement for large power systems. The existence of large capacity computers in the power system control center, enables the inclusion of both security and economics in a single program. The economic dispatch algorithm must be efficient and satisfactorily convergent, since this program has to be run every half an hour or even every five minutes, due to the unevitable change of system loads[3].

It was suggested by[2] that the high vulnerability of a power system after contingency can be decreased through a corrective procedure for generation schedule.

This procedure included; rescheduling of power generation, shedding of some interruptible loads, and suitable change or network configuration. Liner programming was used to choose the system corrections in the least costly manner.

The economic dispatch results in outputs of generators and line flows which keeps the total system generation cost at its minimum. When a line or a generator is operating near its stability limit, it may lose its stable operation when fault occurs. When economically_ dispatched at steady state, the vulnerable power system may be less secure during a contingency because of great probability of a line- separation and consequent line-outage, and/or loss of synchronism of some generators.

In a companion paper [4],the authors presented a security dispatch which keeps the economic operation of the system before and after a line contingency.

In this paper an improvement of transient stability during a contingency is included in the economic dispatch.

Transient stability can be improved by increasing the vulnerability indices of some selected line outsets.

The vulnerability indices defined by [6] give direct test of transient stability assessment and it can be included in the total generation cost of the system. An augmented cost function is being built in a way similar to that suggested by [6]. However, the later reference had used d.c.

Load flow model in which no schedule can be made for bus voltages nor reactive powers and line losses.

The DFP –procedure [7] is utilized to schedule the power generations through the augmented cost function. A better solution of a set if weighting factors can give pronounced increase in vulnerability indices of selected, while keeping the total generation cost at a minimum.

2.Alignment Cost Function

The active power flow in a transmission line connected between bus i and bus k ,Fig(1),is given by;

$$AFP = D_m \cos\theta_{ik}^{0} + B_m \sin\theta_{ik}^{0} \qquad ---(1)$$

Deceleration and acceleration areas of the line become,

$$DA = 2D_m[\sin\theta^0_{ik} - \theta^0_{ik}\cos\theta^0_{ik}] + 2B_m[\cos\theta^0_{ik} + (\theta^0_{ik} - \frac{\Pi}{2})\sin\theta^0_{ik}] \quad \text{---(2)}$$

$$AA = 2D_m[\sin\theta^0_{ik} + (\Pi - \theta^0_{ik})\cos\theta^0_{ik}] + 2B_m[\cos\theta^0_{ik} + (\theta^0_{ik} + \frac{\Pi}{2})\sin\theta^0_{ik}] \quad \text{---(3)}$$

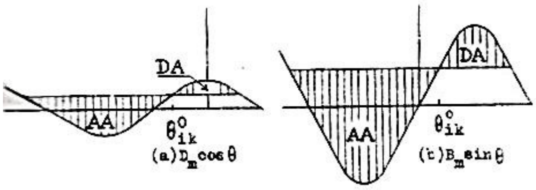


Fig (1) MW-Flow in a line

For a cutest C_i comprising more than one line, the vulnerability index is the algebraic sum of deceleration and acceleration areas for all lines belonging to this cutest;

$$VI = \sum_{alllineinCi}[DA - AA] \quad \text{-- (4)}$$

However, the vulnerability index represented by the sum of deceleration areas for all lines of a cutest during the contingency can be included in the generation cost, to from an augmented cost function;

$$ACF = k_g C(\bar{x}^j) + \sum_{\text{all } l}\left[\frac{k_l}{VI(\theta^l)}\right] + \sum_{\text{all } S}\left[\frac{k_s}{VI(\theta^s)}\right] \quad \text{---(5)}$$

3. Economic dispatch algorithm

The DFP (Davidon-Flitcher-powell)-procedure had proved to be efficient and highly convergent algorithm for power system dispatch[7] .the algorithm utilized the DFP method of unconstrained optimization [11] as well as Powell's quadratic interpolation [12] as a tool of linear search. A summary of the DFP- procedure is given.

1 - choose an initial basic value for the system set of control variables.thses variables are represented by the active power of generation, voltage of generator bus,MVA of

reactive power source installed at load buses, and/or transformer tap ratios.

2 - Evaluate the gradient for the j-th iteration of the total cost function.

$$\bar{g}^j = \frac{\partial(\mathrm{ACF})}{\partial \mathrm{x}^{\mathrm{j}}} \quad \ldots\ldots\ldots\ldots.(6)$$

The reader is referred to [7] for more details.

3 - The j-th value of the direction of linear search $\mathrm{d}^{-\mathrm{j}}$is evaluated. The DFP-method relates $\mathrm{d}^{-\mathrm{j}}$with $\mathrm{g}^{-\mathrm{j}}$

$$\bar{d}^j = \bar{H}^j \bar{g}^j \quad \ldots\ldots\ldots\ldots. (7)$$

4-Perform Powell's quad ratio interpolation along the direction $\mathrm{d}^{-\mathrm{j}}$ to find the optimum change in system control variables, denoted by ${}_{6}^{-\mathrm{j}}$,which reduces the total generation cost to a minimum. The new set of variables becomes;

$$\bar{x}^{j+1} = \bar{x}^j + \bar{\sigma}^j \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(8)$$

5 - Two decisions are essentially tested:

A -first the new value $\mathbf{x}^{-\,\mathbf{j+1}}$ must satisfy both load flow equation as well as system constraints.

B -second, values $\mathrm{d}^{-\mathrm{j}}$ and ${}_{6}^{-\mathrm{j}}$ are tested. If both quantities lie in the prescribed tolerance, cost – minimization comes to its end.

6-A new iteration can be tried by updating $\mathrm{H}^{-\mathrm{j}}$ and minimization procedure continues

A flow chart of the economic dispatch program is illustrated in Appendix.

4.Results

Two test systems are examined, the 5-bus system, fig(2),and a 9-bus system, fig(3).systems data like line impedences,cost coefficients, systems loads and rated powers are summarized in appendix. The 5-bus system has no tap-changing transformers. At each of the load buses 2 and 3 is connected a reactive power source while generators are connected to buses 1,4 and 5.The 9-bus system has three generators at buses 1,2 and 3,and three load centers at buses 5,6 and 8.

Base case optimum

The results of an optimum dispatch of both systems are first computed so that it can be used as a base for comparison when vulnerability indices are later improved. The results of the 5-bus system are illustrated in table 1 under the name "base case" dispatch. Results of the base case dispatch of the 9-bus system are presented in table 2.

Improvement of vulnerability indices

For each test system a number of oriented cut sets are chosen for which vulnerability indices are to be evaluated of the consequently improved. Three cut sets passing outwards of the buses 1,3 and 4 are selected for the 5-bus system. For the 9-bus system, nine cut sets are considered one for each bus.

Beginning from the results of the base case dispatch a large scale optimization is being run. This includes the minimization of the augmented cost function.

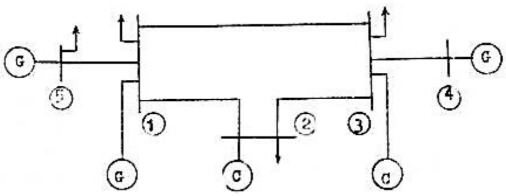


Fig (2), The 5-bus system.

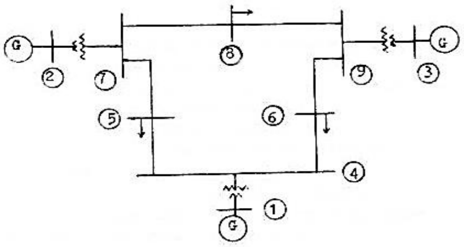


Fig (3), The 9-bus system.

Table 1. Base case optimum dispatch of the 5-bus system

Optimum Cost $/hr	Control				variables				
	Generated power At bus no				Generator voltage At bus no				
	2 MVAR	3 MVAR	4 MW	5 MW	1	2	3	4	5
1000 37	-30	-30	1035	866	104	100	987	103	102

Preliminary results obtained reflect the effect of weighting factors k_g,k_s and k_l on the final solution.

A set of weighting factors was tested and the following observations are abstracted.

1- For certain k_g,the value of $k_{l,}$linecontingency weighting factor, and k_s bus contingency weighting factor, shows direct influence on the final minimum cost.

A value of K_l or K_s may reinforce (increase the vulnerability indices of) some cut sets while weakening others in the same test system.

2- Increase of k_g,generation cost weighting factor, shifts the cost – minimization towards cost – saving at the expense of the vulnerability indices.

However suitable values of weighting factors can be properly selected. The selection depends on the sub standing compromise, to be made by the dispatcher, for obtaining the best minimum generation cost with appropriate increase in vulnerability indices of specific cut sets belonging to the most severe system contingencies.

5. bus system

Table 3 shows vulnerability indices obtained for the both the base case and after the large scale minimization of augmented cost function. With better selection of weighting factors for the 5 – bus system, it was possible to reach a minimum generation cost of 1011.6$/hr,Table 4 ,and increase the vulnerability indices of chosen cutsets.however the new generation cost becomes 1.1 percent above the base case value

9. bus system

For a bus – contingency including a symmetrical short circuit, assumed to be cleared and instantly reclosed, the system control variables are rescheduled through the augmented cost function. A better set of weighting factors resulted in a minimum cost of 909.51 $/hr,Table 5, While volunerability indices are increased for all cut sets at generator and load bused, table 6.

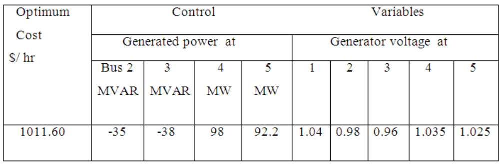
Table 2 . Base case optimum dispatch of the 9- bus system

Optimum Cost $/ hr	Control			variables		
	Generated power at			Generator voltage at		
	Bus 1 MW	2 MW	3 MW	1	2	3
888.78	75	160.5	180.5	1.02	1.041	1.O35

Table 3 . Volunerability indices of the 5 - bus system.

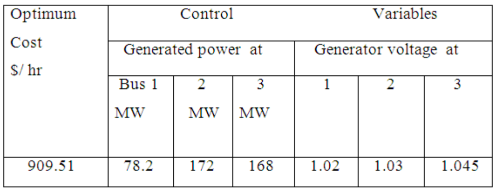
For cutest At bus no	Vulnerability indices after:	
	Base case optimum dispatch	improvement
1	31.35	38.20
3	23.03	27.00
4	2.72	3.80

Table 4 . After Minimization of the augmented cost , 5 – bus



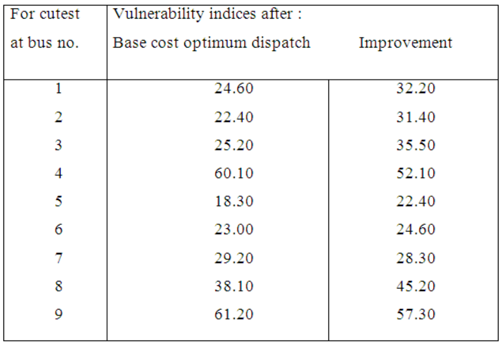
Optimum Cost $/ hr	Control				Variables				
	Generated power at				Generator voltage at				
	Bus 2 MVAR	3 MVAR	4 MW	5 MW	1	2	3	4	5
1011.60	-35	-38	98	92.2	1.04	0.98	0.96	1.035	1.025

Table 5 . After Minimization of the augmented cost , 9 bus



Optimum Cost $/ hr	Control			Variables		
	Generated power at			Generator voltage at		
	Bus 1 MW	2 MW	3 MW	1	2	3
909.51	78.2	172	168	1.02	1.03	1.045

Table 6 . Vulnerability indices of the 9 – bus system



For cutest at bus no.	Vulnerability indices after : Base cost optimum dispatch	Improvement
1	24.60	32.20
2	22.40	31.40
3	25.20	35.50
4	60.10	52.10
5	18.30	22.40
6	23.00	24.60
7	29.20	28.30
8	38.10	45.20
9	61.20	57.30

5. Discussion and Conclusions

In economic dispatch, normal security constraints are specified for control and state variables . Here is the summary of these constraints:

1- Bus voltage being (–+5%) of nominal rated value.

2- An upper and lower limit is specified for active and reactive power output for each generator.

3- A maximum value for both MVA – flow as well as line angle is assumed for each line.

4- Higher and lower limits for the ratio of transformer taps are specified.

Usually, economic dispatch result in a set of system control and state variables that (i) lie within predetermined boundaries and (ii) minimize the generations cost. Some line may possess a ME – flow near or even equal to their maximum limiting value while other lines may have MW – flow extremely below their maximum limits.

The former lines considered relatively vulnerable than later lines.

A contingency involving vulnerable line may cause an outage of that line or even outage of a generator connected to it. Less vulnerable line, however, has sufficient vulnerability margin which decreases the probability for the outage. Thus security, expressed as the alleviation of the line outage due to transient instability during contingency, can be improved by decreasing the power flow in vulnerable lines.

The volunerability level in a line can be improved when the volunerability index defined by (4) is increased .

Recalling the results in table 6, the volunerability indices of generator – bus outsets 1,2 and 3 and load – bus outsets 5,6 and 8 where increased . It is the responsibility of the weighting factors which enable the dispatch algorithm reinforce some outsets and weaken others.

Of course, the dispatcher has an open chance to select a suitable set of such factors witch preserves the volunerability indices of some previously chosen outsets at an improved level during contingency. rescheduling to increase transient stability bu increasing volunerability indices, however, raises the total minimum cost by 1.1% for the 5 – bus system and by 2.33% for the 9 – bus system. Compare tables 1,4 and tables 2,5.

1. Normal security constraints like the limitations put on bus voltage, output of generators, and flow in transmission lines, serve to assess steady state security. However, economically dispatched power system may have line

flows near or even equal to the maximum limit. These vulnerable lines are transiently weak.

2. Improvement of transient stability, expressed as prevention of existence of line having low volunerability index, can be assessed by including the volunerability indices of some selected contingenoles in the cost of function of the system.
3. Better choice of the weighting factors in the augmented cost faction responsible for increasing transient stability, while keeping the total generations cost at its minimum.

الخلاصة:ـ

السيطرة الآمنة والمؤكدة لمنظومة القوى الكهربائية

إن إضافة دليل (القضيب - خط) للأمان يمكن إن يكون دالة رياضية جديدة صالحة جراء السيطرة المثلى على منظومة القدرة الكهربائية.

إن قيمة هذا الدليل للأمان متناسبة رياضياً مع مجموع مربعات الحيود لكل من فولتية قضبان وتدفق القدرة بالمنظومة. وبذالك يمكن إجراء سيطرة ناجحة لمنظومة القدرة الكهربائية، سواء إثناء الحالة الاعتيادية أو إثناء الحالات الحرجة للتشغيل.

أن نتائج التي تم الحصول عليها إثناء الحالة الاعتيادية لتشغيل منظومتي ستة فضبان وثلاثون قضيباً، قد أوضحت انخفاضاً مقبولاً في كلفة التوليد الكلية أما في الحالات الحرجة مثل "انفصال خطوط النقل عن المنظومة" فقد تم التوصل إلى نتائج هامة تفيد إمكانية تحقيق السيطرة المثلى لمنظومة القوى وبدون فصل لأي من الأحمال الكهربائية المتصلة بها.

إن استخدام طريقة السيطرة المستخدمة في هذا البحث، يزيد كل من أمان وتأكيد اعتماد على منظومة القدرة في تغذية الأحمال بدون انقطاع.

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Appendix

Table 7. Cost coefficients and power limits of generators,5 – bus.

Bus no	a_i S/Hr/MW^2	b_i S/Hr/MW	e_i S/Hr	Active min	Power max
1	0.0070	1.8	80	10	100
4	0.0075	1.5	120	50	200
5	0.0060	2.0	140	10	100

Table 8. Cost coefficients and rated MVA of generators,9 – bus.

Bus No	a_i S/Hr/MW^2	b_i S/Hr/MW	e_i S/Hr	Rated MWA
1	0.00773	0.456	77.3	150
2	0.00745	0.730	59.4	247.5
3	0.00393	0.489	155.5	192

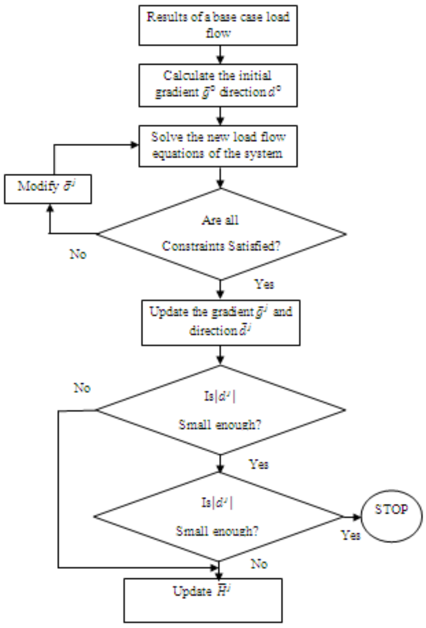

Fig 4 Flow chart of the DFP-procedure

Table 9 Line impedances of the 5-bus system

Bus i-j	Impedance p.u.
1-5	0.03+J0.103
2-1	0.08+J0.262
3-1	0.105+J0.347
2-3	0.33+J0.118
3-4	0.106+J0.403

Table 10 Transformer and line impedances of the 9-bus

Bus i-j	Impudence p.u.
2-7	0.0+J0.0625
3-9	0.0+J0.0586
1-4	0.0+J0.0576
7-8	.0085+J0.0720
8-9	0.0119+J0.1008
9-6	0.0390+J0.1700
6-4	0.0170+J0.0920
4-5	0.0100+J0.0850
5-7	0.0320+J0.1610

Table 11 Sample system loads,9-bus system

Bus no.	MW	MVAR
5	150	-100
6	150	-80
8	100	-60

Table 12 Sample system loads,5-bus system

Bus no.	MW	MVAR
1	80	-10
2	30	-12
3	70	-30
4	0	0
5	86	-20