Generation Rescheduling Using Generation Distribution Factors for Over-load Alleviation

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Abstract:

The contingency stresses the power system devices and results in transmission lines overload. Corrective action is very important for power system security.

Over-load alleviation is a critical problem in power system operation. Generation shift distribution factors (GSDF's) for generation rescheduling is discussed as a proposed method for over-load alleviation in this paper. This method is applied to the National Grid of Sudan (NGS) 77-bus system during medium and light load. The proposed method is found to be effective for this task and the obtained results are found to be good.

Key words: contingency, rescheduling, alleviation, medium load, light load

مستخلص:

نجد أن الاضطراب يعمل على اجهاد مكونات منظومة القدرة و يعمل عللى زيادة حمولة خطوط النقل. تصحيح الوضع مهم جدا لأمان منظومة القدرة. يعتبر تخفيف زيادة الحمولة مشكلة حرجة لتشغيل منظومة القدرة.

تم استخدام معاملات توزيع ازاخة التوليد لاعادة جدولة التوليد كنظرية مقترحة لتخيف زيادة الحمولة فى هذه الورقة. تم تطبيق هذه النظرية على جزء من الشبكة السودانية للكهرباء ب 77 قضيب خلال الحمل المتوسط و المنخفض.

النظرية المقترحة وجدت أنها فعالة لهذا الغرض و أعطت نتائج جيدة.

1- Introduction:-

Power systems are subjected to many types of disturbances during their operation. This results in overloads in one or more transmission lines taking the system to emergency operating state. Over-load alleviation is needed to stop the splitting of the power system and minimize the impact of the disturbances.

The direct methods for line overload alleviation are generation rescheduling and load shedding schemes [7].

Generation rescheduling is superior to above mentioned methods, as the new secure operating point is obtained for all line overload cases efficiently. Moreover applying this method enable making a quick decision to alleviate element overloads and turn back the power system to a secure operating point. Many methods can be used for generation rescheduling such as; rule based optimum power flow [3] and linear programming and particle swarm optimization [4]. C.Vyjayanthi, and D.Thukaram, proposed a model applying relative electrical distance (RED) to identify the optimum generation reschedule values [5]. Generation Rescheduling can be used to limit the variations in generation cost in a power system under normal and contingent state. This explained by Sawan Sen, Sandip Chanda, S. Sengupta, and A. Chakrabarti [6]. Jagabondhu Hazra, and Avinash K. Sinha presented a multi objective particle swarm optimization method for generation rescheduling [8]. Congestion management based on particle swarm optimization is reported in [9]. Effective methods for generation rescheduling for congestion management are reported in [10, 11].

For generation rescheduling using the proposed method, a load flow analysis is done before the outage to determine whether there are overloaded lines. The

direction of active power flow is determined and the generation shift distribution factors are calculated and stored. Maximum current flows of lines are given from the relay and circuit breaker settings, while the maximum active power flows depend on the system state which changes due to the contingency occurrence. A load flow analysis is done during each contingency to determine the amount of current and active power overloads.

2- Determination of Over-loads Amount and Generation Correction Schedule:-

The lines currents overload (ΔIL) and active power overload (ΔPL) can be found using equations (21-) and (22-) respectively.

$\Delta ILC = ILC - ILmax$ (21-)

Where:

ΔI LC: The amount of current overload on line L due to the contingency.

I LC : The current flow on line post contingency.

ILmax : The maximum current flow on line L.

$\Delta PLC = PLCmax - PLC$ (22-)

Where:

ΔPLC: The amount of active power overload on line L due to the contingency.

PLC: The active power flow on line L

post contingency.

PLmax : The maximum power on line L.

The generation correction schedule ΔPg is expressed in matrix form as follows:

$[H] = [A] [\Delta Pg]$ (23-)

$[\Delta Pg] = [A]^{-1} [H]$ (24-)

Where [A] is the GSDF vector, and [H] is the vector of the line power over load amount, and is defined as follows:-

$H_i = P_{i\,max} - PL_{ci}$ (25-)

According to (24-) to obtain the vector [ΔPg], the inverse of vector [A] must be found. But [A] is not square matrix, so the pseudo-inverse of matrix [A] is of great interest which can be found as follows:-

$[A^*] = [A^t] [A.A^t]^{-1}$ [1] (26-) Where [A*] is the pseudo-inverse of matrix [A] and [At] is the transpose of matrix [A].

3- Generation Shift Distribution Factors (GSDF's)

The generation shift distribution factors are linear estimates of the change in flow at a line with a change in power at a bus.

GSDF's are designated aLi and have the following definition:

$$a_{Li} = \frac{[X_{mi} - X_{ni}]}{X_L} \quad [1]\ (31\text{-})$$

Where:

Xmi and Xni are element of matrix [x].

XL: Is reactance connected between buses m and n.

aLi : Is the sensitivity of the flow of line L to a change in generation at bus i.

Matrix [x] can be obtained using the following steps:-

- step 1: Build matrix [B'] with dimension (NB*NB), and its elements are found as follows:

$B'_{ii} = \sum 1/X_{ij}$, j = 1,…..n, j ≠ i (3-2)

$B_{ij} = - 1/X_{ij}$ (3-3)

Where:

Xij ; Is the reactance of the line (and transformer) between buses i and j.

NB ; Is the number of buses.

- Step 2: Determine the slack bus, and then eliminate its column and row, so the matrix [B'] will be with dimension (NB-1 *NB-1).

- step 3: Obtain the inverse of matrix [B'] above with dimension (NB-1 *NB-1). This inverse implement the matrix [x].

- step 4: Return the row and column of the reference bus as zero elements to complete the dimension of matrix [x] to be again (NB*NB).

4-Computational Algorithm:-

The main steps in the computational algorithm of over load alleviation by generation rescheduling using generation shift distribution factors are as follows:-

Step 1: Perform the load flow solution using the specified load and generation.

Step 2: Calculate the generation shift distribution factors and store their values.

Step 3: From the results of contingency analysis, calculate the lines current violation ΔI and active power violation ΔP and, if no line is overloaded go to step 9, otherwise continue.

Step 4: Identify the set of the overloaded lines and form the vector[H].

Specify the set of control variables, then, form matrix[A].

Step 5: Find the inverse of matrix [A].

Step 6: Find the generation schedule correction(ΔPg).

Step 7: Obtain the new generation schedule.

Step 8: Using the new generation schedule perform a load flow solution. If there are still overloaded lines go to step 4. Otherwise continue. If there are new overloaded lines, reduce ΔPgi to be (γ ΔPg) - where $0 < \gamma < 1.0$ – and using (γ ΔPg) instead of ΔPg and go to step 7. Otherwise continue.

Step 9: stop

The flow chart for generation rescheduling using generation shift distribution factors for over-load alleviation is shown in fig (41-)

5- Application of Generation Shift Distribution Factors Method in NGS:-

NGS interconnects the central region and the capital via long transmission lines using transmission voltage levels 500 KV, 220 KV and 110 KV. The method is applied to NGS with ten generating plant in (Merwoe, Roseires, Sennar ,El Girba , Jebel Aulia, Garry, Khartoum North A, Khartoum North B, Kilo Xand Kassala), 77 buses and 91 transmission lines and transformers. The 77 buses in this work are numbered from 1 to 77, the bus number 1 is the slack one and it is Merwoe generating plant. The other 9 generating plants are numbered from 2 to 10 and represent the generation buses. The other buses are numbered from 11 to 77 representing the load buses.

Table (51-) shows the busses names and numbers of the case study. Where table (52-) presents its transmission lines and transformers [12].

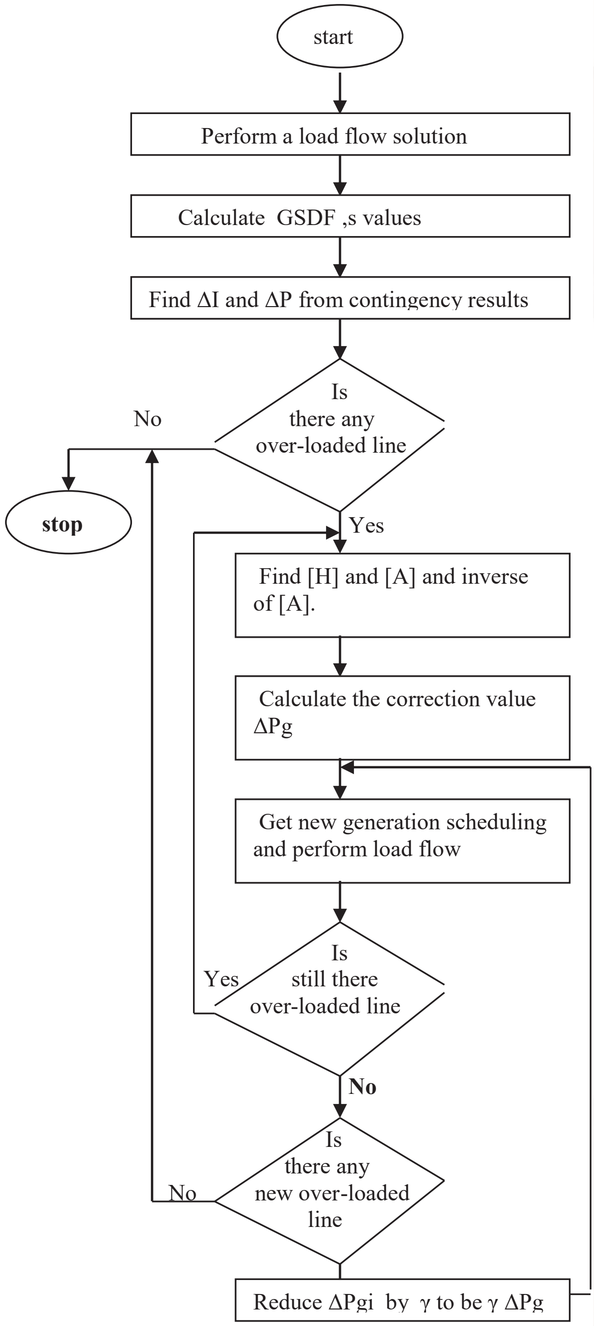
start
Perform a load flow solution
Calculate GSDF ,s values
Find ΔI and ΔP from contingency results
Is there any over-loaded line
No
stop
Yes
Find [H] and [A] and inverse of [A].
Calculate the correction value ΔPg
Get new generation scheduling and perform load flow
Is still there over-loaded line
Yes
No
Is there any new over-loaded line
No
Reduce ΔPgi by γ to be γ ΔPg

Fig (4-1)

. Table (51-) NGS Busbars names and numbers:

Busbar Name	Busbar Number
Merowe power plant	1
Sennar power plant	2
Garry power plant	3
Khartoum North A power plant	4
Khartoum North B power plant	5
Kilo X power plant	6
Jebel Aulia power plant	7
El Girba power plant	8
Kassala power plant	9
Roseires power plant	10
Roseires 220 Kv	11
Sennar 220 kV	12
Rank 220 kV	13
Rabak 220 kV	14
El Obeid 220 kV	15
Mashkur 220 kV	16
Getaina 220 kV	17
Meringan 220 kV	18
Gedaref 220 kV	19
El Girba 220 kV	20
Kassala 220 kV	21
Giad 220 kV	22
Jebel Aulia 220 kV	23
Magirus 220 kV	24
Kilo X 220 kV	25
Garry 220 kV	26
Eid Babiker 220 kV	27
Mahadia 220 kV	28
Omdurman 220 kV	29
Gamuaiya 220 kV	30

Shendi 220 kV	31
Atbra (NEC) 220 kV	32
Sennar 110 kV	33
Sennar hydro 110 kV	34
Meringan 110 kV	35
Haj AbdallahkV 110 kV	36
Managil 110 kV	37
Mina Sharif 110 kV	38
Rabak 110 kV	39
Gedaref 110 kV	40
El Fau 110 kV	41
Busbar Name	Busbar Number
Hassa Heisa 110 kV	42
Giad 110 kV	43
El Bager 110 kV	44
Manshia 110 kV	45
Farok 110 kV	46
Kilo X 110 kV	47
Kuku 110 kV	48
Khartoum North 110 kV	49
Magirus 110 kV	50
Forest 110 kV	51
Omdurman 110 kV	52
Mahadia 110 kV	53
Izergab 110 kV	54
Eid Babiker 110 kV	55
Gedaref 66 kV	56
Rwashda 66 kV	57
Showak 66 kV	58
El Girba 66 kV	59
Kilo 3 66 kV	60

Halfa 66 kV	61
Kassala 66 kV	62
Giad 33 kV	63
Kuku 33 kV	64
Khartoum North 33 kV	65
Merowe damp 500 kV	66
Markhiyat 500 kV	67
El Kabashi 500 Kv	68
Atbara 500 kV	69
El Kabashi 220 kV	70
Marhkiyat 220 kV	71
Merowe damp 220 kV	72
Merowe town 220 kV	73
Dabba 220 kV	74
Dongla 220 kV	75
Atbara 220 kV	76
Port Sudan 220 KV	77

Table (52-): Case Study Transmission Lines and transformers:

Transmission Line No	Beginning Bus	Ending Bus
1	1	66
2	2	33
3	3	26
4	4	49
5	5	65
6	6	47
7	7	23
8	6	59
9	9	62
10	10	11
11	25	22
12	22	18
13	18	12
14	12	11
15	27	25
16	47	48
17	48	49
18	49	55
19	54	55
20	54	53
21	53	52
22	52	51
23	51	50
24	50	47
25	47	44
26	44	43
27	43	42
28	42	35

29	35	36
30	36	34
31	34	38
32	33	39
33	33	34
34	35	41
35	41	40
36	56	57
37	57	58
38	58	59
39	59	62
40	59	60
41	60	61
Transmission Line No	Beginning Bus	Ending Bus
42	64	65
43	66	67
44	66	69
45	67	68
46	26	31
47	31	32
48	11	13
49	13	14
50	14	16
51	16	17
52	17	23
53	22	23
54	23	30
55	23	24
56	30	71
57	70	27

58	70	26
59	14	15
60	71	28
61	30	29
62	76	77
63	72	73
64	72	74
65	74	75
66	12	19
67	19	20
68	20	21
69	35	37
70	47	45
71	45	46
72	27	55
73	12	33
74	18	35
75	48	64
76	14	39
77	24	50
78	29	52
79	22	63
80	22	43
81	49	65
82	25	47
83	19	56
84	40	56
Transmission Line No	Beginning Bus	Ending Bus
85	28	53
86	20	59

87	21	62
88	69	76
89	68	70
90	67	71
91	66	72

51- Results of Over-load Alleviation during Medium Load:-

The most severe contingencies from the results of contingency analysis in case of medium load condition are:

1- Outage of Khartoum North 110kV/33 kV sub-station transformers connected between buses (Khartoum- North 33 kV; 65) & (Khartoum- North 110 kV ; 49) (causes over-load at Khartoum North (B) power plant transformers connected between buses (Khartoum- North(B) power plant ;5)& (Khartoum- North 33 kV; 65) and transmission line connected between buses (Kuku 33 kV ;64) & (Kh- N 33 kV; 65)), 2- Outage of the transformers at Kuku 110kV/33 kV sub-station connected between buses (Kuku 33 kV; 64) & (Kuku 110 kV; 48) (causes over-load at transmission line connected between buses (Kuku 33 kV; 64) & (Khartoum North 33 kV; 65).

The correction of Khartoum North 110kV/33 kV transformers outage case requires generation increase at (Khartoum North (A) power plant; G4) and (Roseires power plant; G10), and generation decrease at the remaining generators. Alleviation of this overload depends highly on (G4) output increase, but its upper limit is reached just applying an increase of (34 %) from the complete correction obtained as solution. The amount of overload is reduced but not completely alleviated. Due to the limitations of the generators that oppose the correction, there is no way but load shedding to complete the solution. Load is shed at buses directly fed through Khartoum North Substation transformer. Those are Kilo X 110 kV, Khartoum North 33 kV and Kuku 33 kV buses. It is the operator's choice to determine the buses and the amount of shedding at each bus.

Table (53-) shows the overloaded line current flow during contingency and after correction in case of line 81 outage.

Table (53-): Over-loaded lines currents incase of line 81 outage (medium load).

Over-loaded lines	I max (pu)	I (pu) during contingency	I(pu) after correction
5	0.575	0.634	0.509
42	0.487	0.635	0.477

The correction of Kuku 110kV/33 kV transformers outage case requires generation increase at Khartoum North (B) (power plant; 5), Khartoum North (A) (power plant; G4), Garry (power plant; 3), Kilo X (power plant; G6), Jebel Aulia (power plant; G7) and Roseires (power plant; G10), and generation decrease at the remaining generators. Alleviation of this overload depends highly on (G4) and (G5) outputs increase, but their upper limits is reached before applying the complete correction value that is obtained from solution. The amount of overload is reduced but not completely alleviated. Due to the limitations of the generators that oppose the correction, there is no way than to do load shedding to complete the solution. Load is shed at buses directly fed through Kuku substation. Those are Kilo X 110 kV, Khartoum North 33 kV and Kuku 33 kV buses. It is the operator's choice to determine the buses and the amount of shedding at each bus. Table (54-) shows the overloaded line current flows during contingency and after correction in cass of transmission line 75 outage.

Table (54-) Over-loaded lines currents incase of line 75 outage (medium load).

Over-loaded line	I max (pu)	I (pu) during contingency	I(pu) after correction
42	0.487	0.492	0.480

52- Results of Over-load Alleviation during Light Load:-

The most severe contingency from the results of contingency analysis in case of light load condition is the outage of Khartoum North 110kV/33 kV sub-station transformers connected between buses (Khartoum- North 33 kV; 65) & (Khartoum- North 110 kV; 49), which causes over-load at line connected between buses (Kuku 33 kV ;64) & (Kh- N 33 kV; 65).

The correction of this case requires generation increase at (Garry power plant; 3), (Khartoum North (A) power plant; 4) and (Khartoum North (B) power plant; 5), and generation decrease at the remaining generators.

The amount of overload is completely alleviated by generation rescheduling only. The overloaded line current flow during contingency and after correction is shown in table (55-) in case of transmission line 81 outage.

Table (55-): Over-loaded lines currents incase of line 81 outage (light load).

Over-loaded line	I max (pu)	I (pu) during contingency	I(pu) after correction
42	0.487	0.615	0.482

6- Conclusion:-

This paper discusses the problem of over-load alleviation using generation rescheduling. NGS 77-bus is taken as case study. The values of [A] elements and its inverse and the overload amount during medium and light load have been calculated using a computer model using fortran. The results show that the correction of the most severe contingencies depends highly on the increase of the generation at Khartoum North (A) power plant and Khartoum North (B). It is highly recommended to increase the capacity of Khartoum North (A), Khartoum North (B) , Rosseries and Kassala power plants by installing new generators with the modification of the transformers and transmission lines. Also increase in the capacity of transmission line connected between; (Kuku 33 kV– Khartoum North 33 kV) is highly recommended. The proposed method is found to be efficient compared with the existing methods, since that it gives less computation time. Besides that using this method simplifies the problem of line overload alleviation such that the solution can be obtained in only one iteration. Given that, the generation shift distribution factors and the amount of line overload is known, the change in generation required at a generator to alleviate the overload lines can be determined. This method can easily be applied to any type of power systems grids at any where regardless of their sizes and less amount of load shedding will be obtained with systems having higher capacities. .

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