[Mansoura Engineering Journal](https://mej.researchcommons.org/home)

Volume 8 | Issue 2 Article 6

12-1-2021

Energy Monitoring and Control Using New Linearized Power Flow Technique.

S. Farghal
Electrical Power & Machines Department, Faculty of Engineering, Mansoura University, Mansoura, Egypt.

Kamal Shebl
Electrical Power Engineering Department, Faculty of Engineering, Mansoura University, Mansoura, Egypt.

A. Abou El-Ela
Monofia University, Egypt.

ENERGY MONITORING AND CONTROL USING NEW LINEARIZED POWER FLOW TECHNIQUE

S.A.Farghal K.M.Shebl A.A.Abou El-Ela

Mansoura University Egypt

Monofia University Egypt

Abstract

The paper presents a proposed technique with linearized formula for computing the transmission line power flow in terms of injected power due to any change in power system loading conditions. The formula relates the line power flows to both loads and power generation directly for a transmission network configuration. Being in an integral form, new power flows on the lines can be obtained directly without running a complete load flow programs when the total system generation changes. This formula is a fairly general one as it is suitable for various energy monitoring and control applications such as generation shifts to alleviate the line overloads, the generation redispatch for an incremental change in loading conditions and the on-line load shedding programs as well as the fast contingency analysis.

INTRODUCTION

Among the major requirements placed upon security monitoring and control of bulk power systems are those of maintaining highly secure operation of interconnected system to prevent separation and failure of the system. Of the main functions of security monitoring and control is to maintain the active power flow in each line of the transmission network to be within a specified limits under the continuous changes in loading conditions and the possible outage of any loaded transmission lines. For such studies, the utility industry prefers faster approximate techniques to locate the potential trouble spots. However, among the various approximate techniques, the relative accuracy is still of major importance to reflect analytically the magnitude of potentially dangerous overloads as really occurs as possible.

The use of sensitivity methods in system security and contingency analysis remained very popular [1-4]. The linearized distribution factors was presented by MacArthur [5] and the mathematical setting was followed by Limmer [6]. The Generation Shift Distribution Factors (GSDF) [2] are the most sensitivity methods used to shift generation from one generator to any other generator, via the reference generator, to alleviate the network overloads. However, this method is limited to the case when the total system generation or load remains unchanged.

Mamandur and Berg [1] presented a sensitivity coefficient matrix obtained from the inverse of the Newton Raphson Jacobian matrix. This method is based on the assumption that the Jacobian matrix remains constant during the next operating conditions. Beside this limitation, the method is not suitable for formulating the power flow constraints in security constrained dispatch problems using mathematical programming.

Sauer [2] presented a Current Distribution Factors based on the Z-bus formulation with constant swing bus voltage. This method is limited to the application of generation shift process via the swing generator and does not guarantee with the economic dispatch problem which may require the swing generator to contribute to the load as well as the transmission losses for economic reasons.

Recently, Wai Y.Ng [3] presented the so called Generalized Generation Distribution Factors (GGDF) to replace the Generation Shift Distribution Factors (GSDF). This method is well applicable for cases when the total system generation changes providing that the loads are changed in the same rate at the different loading points. Although stated in his conclusion that his method is suitable to produce optimum generation schedules under security and contingency constraints, it is found through various tests that his conclusion is not completely correct because under security and contingency constraints the power variations in the different loading points are not necessarily varying in the same rate in large systems and sometimes mose of loads has to be shed under contingency situations.

This power presents a proposed technique with linearized formula for computing the transmission line power flow in terms of injected power due to any change in power system loading conditions. The formula relates the line power flows to both loads and power generation directly for a transmission network configuration. Being in an integral form, new power flows on the lines can be obtained directly without running a complete load flow programs when the total system generation changes.

MATHEMATICAL FORMULATION

Consider the Z-bus referred to certain bus as a reference bus. This Z-matrix representation can be obtained using the Z-matrix building algorithm [7]. All the shunt impedances in the transmission network are removed and their effect is represented by appropriate injected currents. The general load flow equation can be written as;

$$\left[V\right] = \left[Z_{bus}\right]\left[I\right] \qquad \ldots.(1)$$

where;

$$\left[V^t\right] = \left[V_1-V_R \;\; V_2-V_R \ldots V_{R-1}-V_R \;\; V_{R+1}-V_R \ldots V_N-V_R\right],$$

V_R = reference voltage,

N = number of buses.

$$\left[I^t\right] = \left[\left(\frac{S_1^*}{V_1^*}-y_1V_1\right) \quad \left(\frac{S_2^*}{V_2^*}-y_2V_2\right)\ldots \left(\frac{S_N^*}{V_N^*}-y_NV_N\right)\right]$$

where S^* is the conjugate of the complex power, and V^* is the conjugate of the bus voltage.
y_i = the shunt admittance at bus i.

For a base case operating condition, the current flowing in a transmission line connecting bus i to bus j can be written as;

$$I_{ij} = (V_i - V_j) / ZL_{ij} \quad \ldots(2)$$

where ZL_{ij} is the primitive impedance of line ij as shown in Fig.1.

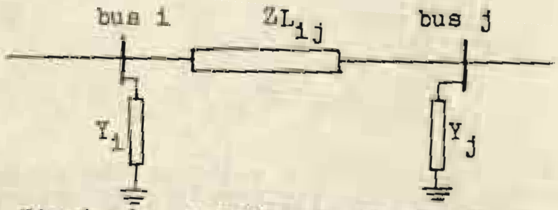

Fig.1 Line connecting two buses with shunt admittance.

Substituting eqn.(1) in eqn.(2);

$$I_{jk} = \sum_{k=1}^{N} \left[(Z_{ik} - Z_{jk}) / ZL_{ij}\right] I_k \quad \ldots(3)$$

where Z_{ik}, Z_{jk} are the ikth and jkth entry of the bus impedance matrix referred to the reference bus. I_k is the injected current at bus k including the current flowing in the shunt admittance at this bus. This currect can be given by;

$$I_k = I_{gk} - I_{Lk} - Y_k V_k \quad \ldots(4)$$

where; I_{gk} = generation current at bus k,
I_{Lk} = load current at bus k.

For an incremental change in the generation current and/or load current and assuming that the change in voltage magnitudes at all buses are very small,

$$\Delta I_k = \Delta I_{gk} - \Delta I_{Lk} \quad \ldots(5)$$

Therefore, the corresponding incremental change in line current I_{ij} can be given by;

$$\Delta I_{ij} = \sum_{k=1}^{N} \left[(Z_{ik} - Z_{jk}) / ZL_{ij}\right] \Delta I_k \quad \ldots(6)$$

For the general application of various security monitoring and control such as generation shift to alleviate the line overloads, generation redispatch for an incremental loading conditions, the on-line load shedding programs and the estimate of network power flow due to circuit contingencies, the reference bus is selected to be a transposed bus to enable the contribution of the slack generator in the incremental change according to the optimization requirements. At the transposed bus, the incremental change in injected current is zero and this is suitable for the assumption that the incremental change in transmission losses is neglected in security monitoring programs.

Using the assumption that the voltage magnitudes are held constants during the incremental active power flow can be given by;

$$\Delta P_{ij} = V_i \, \Delta I_{ij} = \sum_{k=1}^{N} \left[(Z_{ik} - Z_{jk}) / ZL_{ij} \right] \Delta P_k \qquad \ldots(7)$$

To obtain a linearized formula relating the incremental change in active power flow due to circuit contingency (outage of line connecting buses p , q) and assuming that the injected powers at all the buses are kept constant, the recursive bus impedance matrix [8] is used to modify the bus impedance matrix as;

$$\left[\Delta Z\right] = \frac{\left[\left[Z_p\right] - \left[Z_q\right] \cdot \left[Z_p\right] - \left[Z_q\right]\right]^t}{Z_{pp} - Z_{qq} - 2Z_{pq} - ZL_{pq}} \qquad \ldots(8)$$

where;

$\left[Z_p\right]$, $\left[Z_q\right]$ are the pth and qth coulumn vectors of the bus impedance matrix,

Z_{pp}, Z_{qq}, Z_{pq} are the ppth , qqth and pqth entry of the bus impedance matrix,

ZL_{pq} is the self impedance of the removed line.

The incremental change in active power flow due to circuit contingency can be written as;

$$\Delta P_{ij} = \frac{\partial P_{ij}}{\partial Z} \Delta Z + \sum_{k=1}^{N} \frac{\partial P_{ij}}{\partial P_k} \Delta P_k \qquad \ldots(9)$$

but;

$\Delta P_k = 0$ for $k=1,2,\ldots,N$, then;

$$\Delta P_{ij} = (\partial P_{ij} / \partial Z) \Delta Z \qquad \ldots(10)$$

Using eqn.(2), we can write;

$$P_{ij} = \sum_{k=1}^{N} \left[(Z_{ik} - Z_{jk}) / ZL_{ij} \right] P_k \qquad \ldots(11)$$

Taking the partial derivative w.r.t Z;

$$\Delta P_{ij} = \sum_{k=1}^{N} \left[(\Delta Z_{ik} - \Delta Z_{jk}) / ZL_{ij} \right] P_k \qquad \ldots(12)$$

where ΔZ_{ik}, ΔZ_{jk} are the ikth, jkth entry of the matrix ΔZ given in eqn.(8).

APPLICATIONS

Test System

The IEEE 30-bus test system with 6 generators and 41 transmission lines is used to test the accuracy of the proposed formula for linearized power flow applications. Simulations of different cases are made with comparison with a complete load flow, Generalized Generation Distribution Factors (GGDF), and Generation Shift Distribution Factors (GSDF).

Results

Tables 1,2 show the results of applying the proposed technique compared to the Newton-Raphson (N.R) load flow, GSDF, and GGDF, for the percentage change in active power flow in the network for generation shift of 5 MW between generator No.13 and the slack generator No.1 and 8 MW between generators No.13 and No.8. Table 3 shows the results of applying the proposed techniques compared to the N.R. load flow, GSDF and GGDF for the percentage change in network active power flow due to an increase in load demands at buses 3, 10, 26, 23, and 29 by 1, 1, 1, 0.5, and 1.5 MW respectively and these loads are supplied by increasing generation at bus No.13 by 5 MW. Table 4 shows the results of applying the proposed technique compared to the N.R. load flow, and GGDF for the percentage change in network active power flow due to increasing the load demand at buses 3, 10, 23, 26, and 29 by 1, 1, 1.5, 2, and 2.5 MW respectively and these loads are supplied through increasing the total generation by 8 MW and this increase is distributed among the generators according to the economical dispatch. Table 5 shows the percentage change in network active power flow, applying the proposed technique compared to the N.R. load flow, due to the outage of line No.31.

Comments

From tables 1 and 2, the proposed technique is shown to be accurate as the other existing methods. In case of changing the load demands, the proposed method is shown to be more accurate compared to the existing linearized techniques. The proposed method is applicable for the case of circuit contingency compared to N.R. load flow. As shown in table 5, there is good accuracy for the heavily loaded lines.

TABLE 1 - Percentage change in active power flow in case of generation shift between generator No.13 and the slack generator No.1.

Line No.	Percentage change in active power flow in transmission lines			
	Load flow	GGDF	GSDF	Proposed formula
1	-3.010249	-3.600486	-3.600486	-3.49962
2	-3.349120	-3.866204	-3.866204	-3.78455
3	-3.740916	-4.410810	-4.410810	-4.34968
4	-3.453715	-4.103178	-4.103178	-4.03830
5	-0.804388	-1.029330	-1.029330	-0.99766
6	-2.835879	-3.563971	-3.563971	-3.49848
7	0.835253	0.200368	0.200368	0.11795
8	3.438102	4.432457	4.432457	4.38574
9	1.332906	1.595023	1.595023	1.59676
10	-0.764936	-0.251036	-0.251036	-0.00647
11	-4.059079	-5.472932	-5.472932	-5.42866
12	-3.188157	-4.316657	-4.316657	-4.28680
13	-0.055577	-0.014927	-0.014927	-0.00587
14	-2.314991	-2.964474	-2.964474	-2.95059
15	-8.381167	-9.072093	-9.072093	-9.03646
16	29.516581	29.656345	29.656345	29.64673
17	2.218018	2.220419	2.220419	2.23554
18	3.615241	3.430329	3.430329	3.44674
19	10.900578	10.985232	10.985232	11.00289
20	6.153308	7.899031	7.899031	7.91961
21	18.204851	18.885898	18.885898	18.90203
22	8.805061	9.098111	9.098111	9.11435
23	18.027244	19.595559	19.595559	19.70457
24	-6.872094	-8.211062	-8.211062	-8.20403
25	-4.945940	-6.051806	-6.051806	-6.03843
26	-20.966510	-22.303551	-22.303551	-22.30522
27	-0.444718	-1.242588	-1.242588	-1.22745
28	-0.670291	-1.505828	-1.505828	-1.48839
29	-3.450137	-4.735520	-4.735520	-4.68977
30	3.832092	3.960681	3.960681	3.98174
31	-1.912545	-2.653307	-2.653307	-2.63277
32	5.089551	5.562167	5.562167	5.58322
33	0.345817	0.061947	0.061947	0.03628
34	0.209173	0.047024	0.047024	0.02784
35	0.180412	0.050820	0.050820	0.02961
36	0.106076	0.052736	0.052736	0.02937
37	0.076641	0.031038	0.031038	0.01810
38	0.017957	0.020936	0.020936	0.01221
39	-0.067755	-0.005867	-0.005867	-0.00342
40	-0.317262	-0.107391	-0.107391	-0.00273
41	-4.329948	-1.539722	-1.539722	-0.03958

TABLE 2 - Percentage change in active power flow in case of generation shift between generator No.13 and the generator No.8

Line No.	Percentage change in active power flow in transmission lines			
	Load flow	GGDF	GSDF	Proposed formula
1	0.983690	0.275217	0.275217	0.302362
2	0.235217	0.599751	0.599751	0.578115
3	-0.834256	-1.513722	-1.513722	-1.497568
4	0.239270	0.634600	0.634600	0.616398
5	0.571906	0.379515	0.379515	0.387771
6	2.106784	1.311286	1.311286	1.328657
7	13.899170	12.473375	12.473357	12.495482
8	-2.362786	-1.619213	-1.619213	-1.632519
9	-0.814565	-0.589782	-0.589782	-0.589398
10	-161.831820	-160.676100	-160.676100	-160.740880
11	-7.971566	-9.415823	-9.415823	-9.405618
12	-6.183111	-7.437010	-7.437010	-7.430135
13	-0.055984	-0.007198	-0.007198	-0.005100
14	-4.442547	-5.121072	-5.121072	-5.117883
15	-13.132040	-13.746240	-13.746240	-13.737930
16	47.278166	47.434127	47.434127	47.431902
17	3.575071	3.863903	3.863903	3.868178
18	5.936308	5.927191	5.927191	5.932145
19	18.590796	18.913550	18.910550	18.918822
20	10.146706	13.544228	13.544228	13.551551
21	31.297943	32.320756	32.520756	32.525574
22	14.813367	15.679403	15.679403	15.684081
23	30.865564	33.887868	33.887868	33.890363
24	-12.235116	-14.105116	-14.105116	-14.102993
25	-8.937525	-10.590350	-10.390350	-10.386434
26	-36.328664	-38.405323	-38.405323	-38.406066
27	-1.223850	-2.109982	-2.109982	-2.105464
28	-1.598719	-2.558407	-2.558407	-2.553458
29	-6.258072	-8.060764	-8.060764	-8.047493
30	6.312567	6.858992	6.858992	6.865325
31	-3.499765	-4.514845	-4.514845	-4.508490
32	8.501697	9.516679	9.616679	9.623053
33	0.327209	0.056387	0.056387	0.048567
34	0.206859	0.043741	0.043741	0.037576
35	0.178899	0.045780	0.045870	0.039481
36	0.103872	0.043256	0.043256	0.037757
37	0.075972	0.028021	0.028021	0.024159
38	0.019022	0.018903	0.018903	0.016298
39	0.060601	0.005302	0.005302	0.004571
40	-157.734670	-159.844440	-159.844440	-159.816680
41	-172.846620	-171.097240	-171.097240	-171.494770

TABLE 3 - Percentage change in active power flow in case of changing the load demand to be compensated by generator No.13.

line No.	Percentage change in active power flow in transmission lines			
	Load flow	GGDF	GSDF	Proposed formula
1	1.154106	0.302531	3.600486	0.077965
2	1.384523	0.724455	3.866240	0.145420
3	0.930415	1.930025	4.410810	0.342052
4	-0.747148	-0.876606	-4.153178	-2.039335
5	0.411750	1.350665	1.029330	0.019831
6	1.353821	0.840670	3.563971	0.066689
7	3.008230	3.477218	0.200368	1.682235
8	-1.677512	-3.075177	-4.432457	-0.074911
9	-0.543252	-3.465023	-1.595023	-0.031794
10	-1.032225	-13.674250	-0.251036	-0.018738
11	4.507608	6.048757	5.472932	2.008822
12	3.427619	2.083977	4.316657	1.586855
13	-0.073293	-3.436168	-0.014927	-0.001177
14	2.373102	1.404497	2.964474	1.092962
15	-3.026407	-9.949426	-9.072093	-4.714012
16	29.485342	26.204485	29.656345	29.658459
17	5.696551	3.934115	2.220419	5.086885
18	8.853453	5.131807	3.430329	7.669791
19	15.145793	12.624029	10.985232	14.537389
20	16.273988	9.554717	7.899031	17.193654
21	25.399591	20.462466	18.885895	24.946314
22	9.057767	10.753736	9.098111	9.528961
23	18.693825	21.259945	19.695559	20.572238
24	-7.241539	-9.861091	-8.211062	-8.553650
25	-5.095306	-4.274803	-6.051806	-6.261760
26	-29.159245	-20.406641	-22.303551	-29.405188
27	5.329118	0.496791	1.242588	3.364241
28	6.343102	0.236893	1.505828	4.075491
29	18.480815	2.951719	4.735520	12.802336
30	16.276462	5.661882	3.960681	14.320526
31	9.883047	0.897810	2.653307	6.949709
32	16.052219	7.250751	5.562167	14.143257
33	17.030191	1.673782	0.061947	14.039264
34	18.713662	1.685112	0.047014	18.279681
35	14.707418	1.682445	0.050820	13.085179
36	-4.586031	-1.761303	-0.052736	-5.413964
37	18.171977	1.694647	0.031038	17.304742
38	6.429209	1.705418	0.020936	5.946029
39	-11.446412	-1.717011	-0.005867	-11.353872
40	0.748211	1.381131	0.107391	0.007995
41	-4.878562	-13.694861	-1.539722	-0.114853

TABLE 4 - Percentage change in active power flow in case of changing load demand to be compensated from the different generators by the economical dispatch.

Line No.	Percentage change in active power flow in transmission lines		
	Load flow	GGDF	Proposed formula
1	19.047	11.035	19.252
2	17.731	8.879	17.579
3	16.022	7.353	16.540
4	16.013	9.407	16.539
5	4.453	2.408	4.767
6	15.325	7.256	16.686
7	12.065	6.842	17.187
8	-18.579	-8.612	-20.873
9	-6.799	-2.642	-7.604
10	-21.444	-4.061	-99.676
11	34.295	18.433	30.620
12	20.760	9.355	18.473
13	-25.195	25.845	-25.174
14	7.247	1.013	5.272
15	22.480	11.532	20.020
16	-29.212	29.803	-29.135
17	6.404	0.637	4.729
18	9.450	1.203	6.887
19	2.401	4.709	0.484
20	18.286	3.298	14.824
21	3.674	8.368	0.791
22	-4.432	-3.832	-5.016
23	-10.013	-8.776	-10.922
24	4.654	3.506	4.587
25	3.906	3.182	3.446
26	-3.433	10.449	-0.881
27	12.382	0.960	9.502
28	14.878	1.091	11.514
29	44.956	2.690	36.193
30	24.615	1.427	19.746
31	24.267	1.641	19.869
32	15.432	2.168	9.896
33	30.865	0.453	25.404
34	35.132	0.423	34.700
35	25.879	0.431	22.956
36	-16.211	-0.224	-17.592
37	30.417	0.392	28.910
38	10.813	0.372	9.859
39	-19.012	0.342	-18.910
40	-17.489	-2.527	-99.079
41	-24.440	-7.341	-106.430

TABLE 5 - Change in active power flow due to outage of transmission line No.31.

Line No.	Active power flow before line outage (MW)	Percentage change in active power flow due to line outage	
		Load flow	Proposed formula
1	100.21	0.06	0.10
2	52.54	-0.17	-0.34
3	31.87	-0.42	-0.88
4	49.17	-0.20	-0.42
5	60.90	0.28	0.90
6	41.49	-0.17	-1.15
7	43.23	0.63	-1.89
8	14.47	-0.71	-3.04
9	35.94	0.80	5.92
10	4.46	14.10	00.00
11	11.13	7.10	23.70
12	12.35	-1.37	-3.15
13	23.17	-4.00	-17.26
14	30.50	1.27	7.44
15	28.49	-2.63	-1.82
16	17.64	-2.89	7.93
17	8.23	00.00	-0.36
18	18.72	-0.32	-1.49
19	7.81	1.66	-7.55
20	1.84	-1.63	-6.95
21	4.17	3.63	-15.34
22	6.42	1.86	-5.29
23	3.09	6.79	-12.29
24	7.31	2.46	-4.51
25	8.71	-1.45	5.05
26	5.01	-1.39	15.37
27	15.87	1.26	2.26
28	7.59	1.71	2.63
29	1.94	7.73	8.76
30	5.46	-4.21	-3.29
31	5.51	-100.00	-100.00
32	2.17	-11.52	-10.60
33	1.31	00.00	0.76
34	3.61	0.27	1.08
35	4.99	0.40	1.20
36	3.06	0.32	1.40
37	6.31	0.47	1.42
38	7.24	0.41	1.38
39	3.79	0.26	1.32
40	3.81	-2.09	1.57
41	14.69	1.02	1.29

CONCLUSIONS

The paper presents a proposed technique with linearized formula for computing the transmission line power flow in terms of injected power due to any change in power system loading conditions. The formula relates the line power flows to both loads and power generation directly for a transmission network configuration.

The proposed technique is based on the bus impedance matrix and the reasonable assumption of having the system bus voltages constant at 1 p.u. The proposed technique is tested on standard power systems and a comparative study is made with other methods to show the good accuracy of computations during different applications. Each of the other methods is limited to a special case of application, but the proposed formula guarantees a good accuracy in application for the different cases.

REFERENCES

[1] K.R.C.Mamandur and G.J.Berg, "Economic shift in electric power generation with line flow constraints", IEEE Trans., Vol. PAS-97, Sep./Oct. 1978, pp. 1618-1626.

[2] P.W.Saure, "On the formulation of power distribution factors for linear load flow methods", IEEE Trans., Vol. PAS-100, Feb. 1981, pp. 764-769.

[3] Wai Y. Ng, "Generalized generation distribution factors for power system security evaluations", IEEE Trans., Vol. PAS-100, March 1981, pp. 1001-1005.

[4] F.D.Galiana and M.Banakar, "Approximation formula for dependent load flow variables", IEEE Trans., Vol. PAS-100, March 1981, pp. 1123-1137.

[5] C.A.MacArthur, "Transmission limitations computed by superposition", AIEE Trans., Vol. PAS-80, Dec. 1961, pp. 827-831.

[6] H.D.Limmer, "Techniques and applications of security calculations applied to dispatching computers", Third Power System Computational Conference, Rome, Italy, 1979.

[7] H.E.Brown, "Solution of large networks by matrix methods", John Wiley & Sons, Inc., 1975.

[8] M.A.Pai, "Computer techniques in power system analysis", McGraw-Hill, 1979.