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TRANSMISSION CONGESTION MANAGEMENT USING FUZZY LINEAR PROGRAMMING TECHNIQUE IN COMPETITIVE MARKET

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ABSTRACT

This paper presents a proposed optimization technique (POT) for transmission congestion management problem in competitive power systems at normal and emergency conditions. The fuzzy linear programming (FLP) is used as intelligent optimization technique for solving transmission congestion management problem. Two shapes modeling of fuzzy memberships are used and compared with the linear programming technique, as a conventional optimization technique. The POT has two objectives which are: Minimizing the cost of generation, maximizing the profit. However the profit is the difference between the market revenue and market payment. A multi–objective function of fuzzy technique is used to find the maximum profit for different shapes of fuzzy membership models. Four standard test systems are used to extensive study of the POT. One of these test systems is a real system of the Egyptian United Network. Simulation results show that the POT is more accurate and efficient, especially with large scale power system.

يقدم هذا البحث طريقه مثلى متقدمه لإدارة مشكلة تحميل خطوط النقل في نظم القوى الكهربية التنافسية عند حالات التشغيل العادية والطارئة. تم استخدام طريقة البرمجة الخطية الغيميه كطريقه متقدمه للذكاء الاصطناعي لإيجاد حل لمشكلة إدارة زيادة التحميل لخطوط النقل الكهربي. حيث تم استخدام شكلين مختلفين لتمثيل نموذج شكل دالة البرمجة الخطية الغيميه ومقارنتها بطريقة البرمجة الخطية التقليدية. تم تحقيق هدفين عند تطبيق الطريقة المثلى المقترحة وهى : تقليل تكاليف القدرة المولدة من محطات التوليد وزيادة الربحية لهذه المحطات . حيث أن الربحية تمثل الفرق بين العائد والمدفوع لتوليد القدرة الكهربية.
في هذا البحث تم استخدام داله متعددة الأهداف لطريقة البرمجة الخطية الغيميه لإيجاد أقصى ربحيه لمختلف أشكال دوال هذه الطريقة.
تم استخدام أربعة نظم قياسيه لدراسة كفاءة الطريقة المثلى المقترحة حيث كان احد هذه النظم يمثل جزء حقيقي من الشبكة الموحدة لجمهورية مصر العربية. حيث ثبت من نتائج التطبيق دقة وكفاءة الطريقة المثلى المقترحة خاصة عند التطبيق على الشبكات الكهربية كبيرة الحجم.

Keywords: congestion, Deregulation, FLP, competitive, optimal dispatch and emergency.

1. INTRODUCTION

Congestion in a transmission grid occurs due to an operating condition that causes limit violations on one or more of the “flow gates” in the system [1]. Congestion or overload in one or more transmission lines of the system may occur as a result of unexpected outages of generation, sudden increase of demand, tripping of transmission lines, or failures of other equipments [2]. In deregulated power systems, congestion, which can also occur due to commercial reasons, has become a major concern. Fast, transparent, and effective tools are necessary for congestion management [2]. Many recent publications have proposed techniques for congestion management in the deregulated environment [3–6]. The importance of congestion relief as a transmission service is recognized by both the regulating bodies, especially by federal Energy Regulatory Commission FERC [7], and by utilities and North American Electricity Reliability Council NERC [8].

In recent years, rapid development of the electricity markets has been witnessed through radical changes due to deregulation process. The deregulation process decomposes the traditional vertical integrated system into individual companies to provide a suitable reduction level of consumer prices by means of competition. The competition in electricity market is constrained by the available transfer capabilities and the level of transmission congestion in a market.

Electric power systems around the world, have been forced to operate to almost their full capacities due to the economic constraints. The amount of electric power that can be transmitted between two locations through a transmission network is limited by security and stability constraints. Power flow in the lines and transformers should not be allowed to increase to a level where a random event could cause cascaded outages. When such a limit reaches, the system is said to be congested. Managing congestion to minimize the restrictions of the transmission networks in the competitive market has become the central activity of systems operators. It has been observed that the unsatisfactory management of transactions could increase the congestion cost which is an unwanted burden on customers.

Transmission congestion must be eliminated using corrective actions such as phase shifters/FACTS operations and redispatch of generation. In this paper the corrective actions have been used in congestion relief for generation power redispatch using fuzzy linear programming compared with other algorithms.

In this paper, a proposed sensitivity factors are presented to compute the power flows and transmission losses using different FLP membership models dependant on the collected experiences. Furthermore, a maximum profit is obtained using the proposed different FLP models compared with the LP technique as a conventional technique.

2. MARKET DISPATCH MODEL

An optimal power flow is formulated for congestion management combining the following two objectives:

Minimizing the cost of generation.

Maximizing the profit.

The market dispatch formulation may be stated as [9]:

$$MaxPR = \sum_{j=1}^{ND} B_j(PD_j) - \sum_{i=1}^{NG} C_j(PG_i) \quad (1)$$

Where;

Ci (PGi) is the generation unit payment function.

Bj (PDj) is the Benefit function of power demands.

PGi and PDj are the power generating and power demand for unit i, and a certain load bus j respectively.

NG and ND are the number of generating buses and number load of demand buses respectively.

PR presents the profit of power market which is the difference between the market revenue and market payment, (production cost of power generation units).

The market revenue is based on the forecasted market clearing price of electricity. Equation (1) is subjected to the set of system operating constraints including the system power flow equations and line flow limits. The cost and benefits functions are described by quadratic functions as [9]:

$$Ci(PG_i) = a_{Gi} PG_i^2 + b_{Gi} PG_i + c_{Gi}, \quad i \in G \quad (2)$$

$$B_j(PD_j) = a_{Dj} PD_j^2 + b_{Dj} PD_j + c_{Dj}, \quad i \in G \quad (3)$$

Where,

aGi, bGi, cGi are the payment coefficients,

aDj, bDj, cDj are the benefit coefficients,

G and D are the generators and load demand domains.

Power Balance Constraint

The total power generated by the generation companies should be equal to the forecasted system demand includes both of the actual system demands and power losses, Plosses.

The independent system operator(ISO) is responsible for supplying the system demand and to allocate the transmission losses for system users. The power balance constraint may be written as.

$$\sum_{i=1}^{NG} PG_i = \sum_{j=1}^{ND} PD_j + P_{losses} \quad (4)$$

$$P_{losses} = PF_{i-j} + PF_{j-i} \quad (5)$$

Where

PFi-j is the power flow form bus i to bus j

PFj-i is the power flow form bus j to bus i

Congestion Constraint

For NL-transmission lines, the power flows in transmission network must be less than the maximum bending limits. The ISO is responsible for supplying the system demands and to alleviate the congestion effects. The power in transmission line k, PFk must be less than its maximum limits as [9]:

$$|PFk| \le PFk_{\max}, k = 1,2,\cdots\cdots\cdots\cdots, NL \quad (6)$$

The generalized generation distribution factors (GGDF) are used to compute the power flow in transmission line k as [9]:

$$PF_k = \sum_{i=1}^{NG} (D_{k,i}.PGi) \quad k = 1,2,......., NL \quad (7)$$

Where $D_{k,i}$ are GGDF for line k and generation i.

NL is the number of load buses

Capacity (Physical) Constraints

The physical limitations of power generation scheduling must be with in maximum and minimum limits as:

$$PGi_{\min} \le PGi \le PGi_{\max} \qquad i = 1,2,3,\ldots\ldots, N \quad (8)$$

Also, the demand power must be with in maximum and minimum limits as:

$$PDi_{\min} \le PDi \le PDi_{\max} \qquad i = 1,2,3,\ldots\ldots, N \quad (9)$$

3. PROPOSED FLP MEMBERSHIP MODELS

The changes in membership models have an effect in the optimization problem. The shape of the membership function is constructed according to the nature of variable variations.

3.1 Modeling of Objective Function

The objective is to maximize a certain function (Max PR). The proposed shapes of fuzzy modeling are shown in Figs.1 and 2. The membership generation unit payment function, μ(Ci), can be written in the following form:

$$\mu(c)=\begin{cases}1 & c \le c_o \\ (c_1-c)/(c_1-c_o) & c_o \le c \le c_1 \\ 0 & c \ge c_1\end{cases} \qquad (10)$$

Where c is a point between co and c1

Figure 1 shows the proposed shape of fuzzy models for the power generation cost functions.

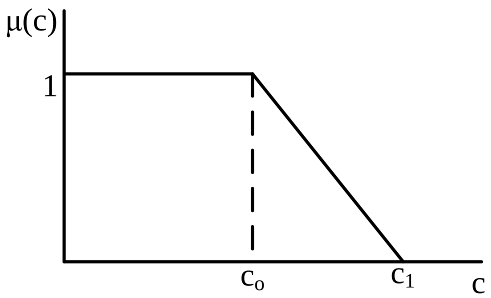

Fig. 1 Semi triangular membership of cost function

The membership benefit function of power demands (Bj) can be written in the following form:

$$\mu(B)=\begin{cases}(B-B_o)/(B_1-B_o), & B_o \le B \le B_1 \\ 0 & otherwise\end{cases} \qquad (11)$$

Where B is a point between Bo and B1

Figure 2 shows the proposed shape of fuzzy models for the benefits power demand.

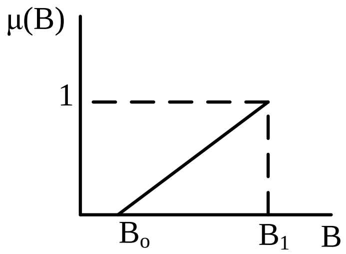

Fig.2 Semi triangular membership of benefit

3.2 Modeling of Power Generation

The proposed different shapes of power generation fuzzy membership function can be written in the following form:

$$\mu(PG)=\begin{cases}(PG-PG_{min})/(PG_{med}-PG_{min}), & PG_{min} \le PG \le PG_{med} \\ (PG_{max}-PG)/(PG_{max}-PG_{med}), & PG_{med} \le PG \le PG_{max} \\ 0 & PG \ge PG_{max}\end{cases} \qquad (12)$$

$$\mu(PG)=\begin{cases}(PG-PG_{min})/(PG_1-PG_{min}) & PG_{min} \le PG \le PG_1 \\ 1 & PG_1 \le PG \le PG_2 \\ (PG_{max}-PG)/(PG_{max}-PG_2) & PG_2 \le PG \le PG_{max} \\ 0 & PG \ge PG_{max}\end{cases} \qquad (13)$$

Where PG is a point between min and max values.

However the Power generation can be represented by two fuzzy membership models triangular model (FLP1) and trapezoidal model (FLP2) as shown in Fig.3 and Fig. 4 respectively.

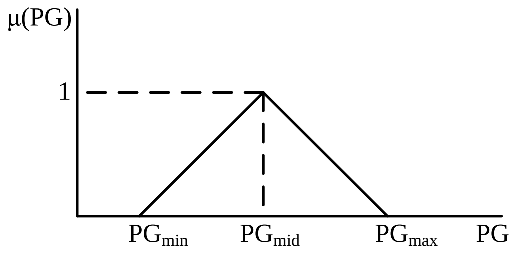

Fig. 3 Triangular membership of generation

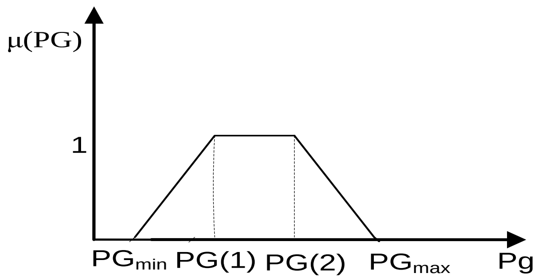

Fig.4 Trapezoidal membership of generation

3.3 Modeling of Power Demand

The proposed shape of power demand fuzzy membership function is shown in Fig.5. This function can be written in the following form:

$$\mu(PD)=\begin{cases}(PD-PD_{min})/(PD_{max}-PD_{min}), & PD_{min} \le PD \le PD_{max} \\ 0 & otherwise\end{cases} \qquad (14)$$

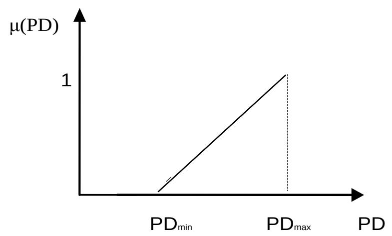

Fig. 5 Semi triangular membership of power demand

3.4 Modeling of Power Flow Constraint

The proposed shape of power flow fuzzy membership function is illustrated by Fig.6. This function can be written in the following form:

$$\mu(PF) = \begin{cases} (PF - PF_{min})/(PF_{max} - PF_{min}), & PF_{min} \le PF \le PF_{max} \\ 0 & otherwise \end{cases} \qquad (15)$$

Where, PF is a point between the minimum and maximum power flow limits.

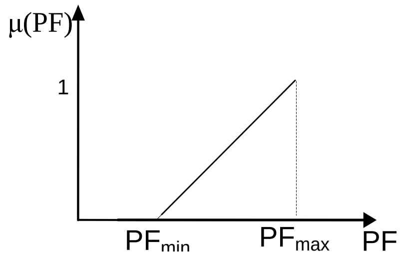

Fig. 6 semi triangular membership of power flow

4. PROPOSED OPTIMIZATION TECHNIQUE

Hence, the security constraint optimal power dispatch (SCOD) problem, (Equations (1)-(9)), can be solved using a multi objective optimization problem to find the values of PG, PD and PF and degrees of membership of generated power. The maximization of the degree of membership for objective function μ(PR), multi-objective optimization problem, can be solved by MAX_MIN [μ(PR)], which can be written as:

Max[Min (μ(Ci) , μ(Bj) , μ (PG) , μ(PF), μ(PD)………..)] (10)

Or Max α

Subject to:
μ (Ci) ≥ α
μ(Bj) ≥ α (11)
μ (pg) ≥ α
μ (PF) ≥ α

Where α ε [0, 1], α is the degree of the problem optimality.

5. APPLICATIONS

5.1 Test Systems

Four standard test systems are used to show the capability of the proposed technique for (SCOD) solving using the FLP. The first test system is 5-bus test system which contains 5 buses and 7 transmission lines [10]. The second test system is IEEE 14-bus test system [11], while the third test system is IEEE 30-bus test system [11].Added to that system, a real part of Egyptian United Network. Tables 1 and 2 illustrate the generation and lines data for the 5-bus system. The critical line in 5-bus system is line number 3. The line number 1 is the critical line in the other systems. The maximum power flow rating of the critical lines are equal to 35, 150, 50 MW for the 3 test systems, respectively.

Table 1, generation bus data for 5-bus test system

Bus No.	PG min (MW)	PG max (MW)	PG initial (MW)	Cost function ($/hr)
1	10	120	37.89	1.7P1 +.0001p12
2	10	90	90	2.3P2 +.002P22
5	10	60	60	2.2P5+ .0015P52

Table 2, line data for 5-bus test system

Line No.	Form bus	To bus	R + jx (p.u)	y/2 (p.u)	PF initial (MW)
1	1	2	.02+j.06	.06	-2.082
2	1	3	.08+j.24	.05	21.469
3	2	3	.06+j.18	.04	30.485
4	4	2	.06+j.18	.04	-30.795 *
5	2	5	.04+j.12	.03	25.221
6	3	4	.01+j.03	.02	4.595
7	4	5	.08+j.24	.05	-10.87

* Denotes the overflow in line.

Two different operation conditions are considered for congestion of lines, which are normal and emergency conditions.

The emergency conditions may be occurring in the three test systems which are:

1. Sudden increase in load demand.
2. Unexpected outage of lines.
3. Unexpected outage of units inside the generation plant.

5.2 Results and comments

Tables 3-5 show the comparison between the results obtained using different shapes of fuzzy membership models (FLP1 and FLP2) and linear programming techniques (LP). Table 3 shows a comparison between different optimization techniques for 5-Bus System at normal operation conditions with congestion of line 3.

Table 3, Comparison between LP, FLP1 and FLP2 optimization techniques for 5-bus system

Variables	Max limit	LP	FLP1	FLP2
PG 1(MW)	120	61.88	78.58	78.1
PG 2(MW)	90	65.93	55.01	49.86
PG 5(MW)	60	60	54.29	59.63
PD1(MW)	18.5	18.49	18.5	18.5
PD 3(MW)	46.25	46.23	46.25	46.25
PD 4(MW)	46.25	46.23	46.25	46.25
PD 5(MW)	74	73.97	74	74
PF1(MW)	34	18.5	32.51	32.38
PF2(MW)	32	25.34	28.39	27.98
PF3(MW)	35	28.79	28.19	27.68
PF4(MW)	30	-29.45	-29.24	-28.58
PF5(MW)	45	24.58	28.36	24.25
PF6(MW)	45	6.7	9.06	8.15
PF7(MW)	12	-10.18	-8.13	-9.69
profit(L.E/MW)		294.87	304.46	304.8
G(MW)		187.81	187.89	187.89
D(MW)		185	185	185

Table 4, Comparison between different optimization techniques for 14-bus system

	Max limit	LP	FLP1	FLP2
PG 1(MW)	260	195.85	203.07	216.52
PG 2(MW)	80	80	72.95	59.51
PD 2(MW)	21.7	21.68	21.7	21.7
PD 3(MW)	94.7	94.61	94.7	94.7
PD 4(MW)	47.8	47.76	47.8	47.8
PD 5(MW)	7.6	7.6	7.6	7.6
PD 6(MW)	11.7	11.7	11.7	11.7
PD 9(MW)	29.5	29.5	29.5	29.5
PD 10(MW)	9	8.99	9	9
PD 11(MW)	3.5	3.5	3.5	3.5
PD 12(MW)	6.1	6.09	6.1	6.1
PD 13(MW)	13.5	13.5	13.5	13.5
PD 14(MW)	14.9	14.9	14.9	14.9
PF1(MW)	150	126.23	132.31	143.66
Profit(L.E/MW)		634.61	644.07	660.81
G(MW)		275.85	276.03	276.03
D (MW)		260	260	260

Where G is power generation and D is the power demand.

Table 5, comparison between different optimization techniques for 30-bus system

	Max limit	LP	FLP1	FLP2
PG 1(MW)	80	32.93	29.63	30.98
PG 2(MW)	80	80	79.71	79.73
PG 5(MW)	40	40	40	39.86
PG 8(MW)	50	44.19	49.93	49.83
PG11(MW)	30	30	30	29.9
PG13(MW)	55	55	54.89	54.81
PF1(MW)	50	50	48.18	49.15
Profit(L.E/MW)		1304	1324	1325
G(MW)		284.5	284	285
D(MW)		280	280	280

Table 6, a comparison between different optimization techniques for 52-bus DELTA region with 8 generation buses and 57 lines with line 5 overflows with max value 50

	Max limit	LP	Flp1	Flp2
PG_1(MW)	250	16	242.11	242
PG_2(MW)	250	150.87	11.67	11.58
PG_3(MW)	250	150.87	48.93	48.83
PG_4(MW)	250	44.03	242.11	242.31
PG_5(MW)	375	226.31	12.67	12.6
PG_6(MW)	250	16	242.11	242.28
PG_7(MW)	250	150.87	94.57	92.67
PG_8(MW)	250	150.87	11.67	11.47
PF_5(MW)	50	-36.56	39.54	49.72
Profit(L.E/MW)		779	876.27	890.6
G(MW)		905	905	905
D(MW)		889	889	889

Tables (3-6) show the comparison of profit for two different fuzzy modeling and LP model. It can be noticed that: FLP2,FLP1 more profits are obtained than LP and the profits are increased with increasing of system size while all the overflows are removed.

Table 7 shows the profits which is obtained using all technique for four systems.

Table 7, A comparison between profits (L.E/MW) for the different optimization techniques

	Profit LP	Profit FLP1	Profit FLP2
5bus	304.8	304.46	294.87
14 bus	660.81	644.07	634.61
30 bus	1325	1324	1304
52 bus	890.6	876.27	779

The solution of FLP2 (trapezoidal shapes of generation) has maximum profit for all test systems.

5.3 Emergency conditions

Unexpected outage of transmission line

Tables 8, 9, 10, show the profit of POT using different optimization techniques (LP, FLP1, FLP2) of line outage compared profit using LP, FLP1andFLP2. FLP2 for four standard systems.

Table 8 A comparison between different optimization techniques for 5-bus system

Line Outage	Line outage of line 1		
Technique	LP	FLP1	FLP2
PG_1(MW)	34.47	34.48	34.4
PG_2(MW)	81.54	80.87	80.6
PG_5(MW)	59.02	59.99	59.95
PD1(MW)	17.32	22.2	22.2
PD3(MW)	43.29	54.99	55.5
PD4(MW)	43.29	37.03	36.78
PD5(MW)	69.26	59.25	58.59
PF1(MW)	0	0	0
PF2(MW)	17.12	17.09	17.05
PF3(MW)	29.52	29.49	29.42
PF4(MW)	-29.45	-29.42	-29.32
PF5(MW)	22.02	21.43	21.31
PF6(MW)	2.39	2.25	2.23
PF7(MW)	-11.45	-11.71	-11.71
Profit(L.E/M)	264.15	307.35	308.4
G(MW)	175.04	175.35	174.95
D(MW)	173	173	173

Table 9 A comparisons between different optimization techniques for 14-bus system

(L.E/MW)	L1	L3	L6	L7
Profit LP	1284.77	1236.91	1283.61	1286.58
Profit FLP1	1326.4	1378.85	1348.84	1317.9
Profit FLP2	1328.85	1381.11	1354.07	1335.39
G(MW)	287	275	278	279
D(MW)	282	269	274	274

Table 10 A comparison between different optimization techniques for 30-bus system

(L.E/MW)	L1	L2	L3
Profit LP	1284.77	1287	1236.91
Profit FLP1	1326.4	1345.82	1378.85
Profit FLP2	1328.85	1348.91	1381.1
G(MW)	287	282	275
D(MW)	282	275	269

Form Tables 8-10 maximum profit of POT are obtained using the proposed FLP2.

Sudden increase in load demand

Tables 11 and 12 show the profit of POT using different optimization techniques (LP, FLP1 and FLP2) for three test systems at different loading conditions.

Table 11 A comparison between different optimization techniques for 14-bus system

Load increase	5%	10%	15%
Profit LP(L.E/MW)	606.91	573.58	569.98
Profit FLP1(L.E/MW)	705.74	764.29	829.11
Profit FLP2(L.E/MW)	706.15	767.31	829.11
G(MW)	281	286	291
D(MW)	265	270	274

Table 12 A comparison between different optimization techniques for 30-bus system

Load increase	5%	10%	15%
Profit LP(L.E/MW)	1329.44	1329.65	1359.15
Profit FLP1(L.E/MW)	1410.66	1507.49	1593.48
Profit FLP2(L.E/MW)	1413.28	1515.08	1594.18
G(MW)	286	286	292
D(MW)	281	281	287

Unexpected outage of units form the generation plant

Tables 13 and 14 show the profit of POT using different optimization technique (LP, FLP1, FLP2) for two test systems at different unexpected outage of units form the generation plants.

Table 13 A comparison between different optimization techniques for 14-bus

%outage of units	10%	20%	30%
Profit LP	586.59	596.56	453.21
Profit FLP1	665.39	675.17	740.58
Profit FLP 2	667.85	676.68	741.19
G(MW)	269	269	237
D(MW)	253	253	224

Table 14 A comparison between different optimization techniques for 30-bus

%outage of units	10%	20%	30%
Profit LP	1228.56	1119.98	1020.08
Profit FLP1	1364.84	1416.67	1469.81
Profit FLP 2	1366.36	1419.28	1471.53
G(MW)	264	241	218
D(MW)	259	237	214

6. CONCLUSIONS

An efficient and accurate proposed optimization technique has been applied to solve the transmission congestion management problem in competitive market of power systems at normal and emergency conditions. Two shapes models of fuzzy linear programming memberships (FLP1 and FLP2) have been proposed to find the solution of the transmission congestion management problem. The trapezoidal shape of membership function of power generation FLP2 has the most efficient membership to obtain the maximum profit compared with the other techniques. A multi objective fuzzy linear programming technique has been successfully applied to obtain the maximum profit for different scale power systems, while all the overflows in the different transmissions lines has been removed. A real power system which is apart of Egyptian United Network has been to show the capability of the POT. To find out the maximal profit by maximizing the customers benefit and minimizing the payment of power generation.

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