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Constrained Optimal Power Flow Considering Distributed Generations in power Systems

O. M. Bakry,A. M. Ewais, and A. M. Hemeida
Electrical Engineering Department, Faculty of Energy Engineering
Aswan University, Aswan, 81825, Egypt
E –Mail corresponding :ashgawad@yahoo.com

Abstract:

The operating costs of electric power systems can be minimized through the application of optimal power flow. In this paper, an interior point based optimization algorithm is implemented to solve the optimal power flow (OPF) problems with multiple objective functions. This algorithm takes into consideration Security Constrained Optimal Power Flow (SCOPF), which known as an extension of optimal power flow (OPF). SCOPF helps to maintain the combined goal of economy and security of the power system. The improvement in system performance is developed based on cost reduction of power generation and power loss. The obtained results from the proposed technique have been compared with other results reported in the literature. To validate the proposed approach, IEEE-30 bus system has been studied.

الملخص:

سريان القدرة المثلي يساهم بشكل أساسي في تخفيض تكاليف التشغيل لنظم القوى الكهربية، وقد تم تطبيق خوارزميات كثيرة جدا للوصول إلي أنسب نموذج لسريان القدرة الكهربية بغرض تخفيض تكاليف التشغيل، يقدم هذا البحث تطبيق خوارزمية النقطة الداخلية للوصول للحل الأمثل لسريان القدرة، وقد تم تطبيق التقنية المقترحة لنظام مكون من ٣٠ قضيب IEEE-30-bus للتأكد من جدوى تطبيق التقنية المقترحة. وقد تم التركيز على معوقات الأمان مع السريان الأمثل للقدرة. وقد تم مقارنة النتائج المستخلصة مع نتائج اخرى وقد أثبتت النتائج المستخلصة دقة وكفاءة الخوارزمية المقترحة للوصول إلي معوقات الأمان مع الحل الأمثل لسريان القدرة، مع اعتبار الحدود المسموحه للنظام .

Keywords: Optimal power flow, optimization, SCOPF, interior point algorithm, distributed generation, power loss, generation costs.

1. Introduction

The heart of economically efficient and reliable Independent System Operator (ISO) power markets is the alternating current optimal power flow (ACOPF) problem [1-3]. The problem of optimal power flow(OPF) has received much attention. It has been marked as one of the most operational needs[4-5]. Nowadays, OPF become an indispensable tool for solving such optimization problems with various efficient search algorithms. The essence of optimal power flow problem resides in reducing the objective function and simultaneous satisfying the load flow equations (equality constraints)without violation the inequality constraints. In other words, the optimal power flow problem seeks to find an optimal profile of active and reactive power generations along with voltage magnitudes in such a manner as to minimize the total operating costs of a thermal electric power system, while satisfy network security constraints. It was later named optimal power flow (OPF) by Dommel and Tinney[2]. The optimal power flow computation has received widespread attention. It is interested to many power utilities, and has been identified as one of the most important operational tools of the power industry. Up to the present time, several researches have been reported in the literature [6-7].

The principal methods employed are the Newton based method and the linear programming method which have emerged as the dominant optimization methods for solving OPF. OPF method, had several drawbacks including slow convergence due to zigzagging in the search direction, difficulties involved in handling constraints, adaptation of the algorithm to different problems, and obtaining different optimal solutions(depending on the starting point of the solution). Several approaches have been proposed to overcome the above-mentioned drawbacks of the classical OPF problem. Some of these methods have been based on successive linear programming, successive quadratic programming [8-10].The optimization technique based on economical and technical considerations is presented. Also, an automation of the DG system is performed using a matlab software considering the load, and the availability of the system's generating units. Also, the optimal power dispatch is presented [11-12]. Distributed generation is characterized by some features, which have not been present in traditional centralized systems:

- rather free location in the network area;
- relatively small generated power and variation of generated power dependent on the availability and variability of primary energy [13-14].

One of the main advantages of DG is its close proximity to the consumer loads. DG can play an important role in:

- improving the reliability of the grid;
- reducing the transmission losses;
- providing better voltage support;
- improving the power quality.

The Interior Point (IP) methodology has been very much popular among researchers to obtain the SCOPF. In interior point OPF, the computation of gradient, Jacobian, and Hessian matrices of objective functions are used as a constraint functions. This method allows for easy handing of simple bounds on the primal variables. This also incorporates free variables in solution implementation. The IP method has been extensively applied to solve large-scale OPF problems due to its fast computational speed and robustness[15-17]. the interior-point method (IPM) becomes in the early 90’s a very appealing approach to the OPF problem due to three reasons: (i) ease of handling inequality constraints by logarithmic barrier functions, (ii) speed of convergence and (iii) a strictly feasible initial point is not required.

This paper study the implementation of interior point algorithms for solving the security constrained optimal power flow problem (SCOPF). The algorithms is applied to IEEE 30-Bus power system. The obtained results is compared to the results reported in the literature. The IP algorithms has better response compared with that reported in the literature.

2. Optimal Power Flow Problem

The purpose is to minimize two objective functions, generation cost and power loss of the system, while satisfying equality and inequality constraints. The problem can be formulated as follows:

$$\text{Min } \{F = C(P) + \Delta S\} \qquad (1)$$

Where:

- C(P) – generation costs;
- ΔS – total power losses of the system.

The generation cost C(P) is expressed as:

$$C(P) = a \cdot P_{Gi}^2 + b \cdot P_{Gi} + c \qquad (2)$$

where:

- P_{Gi} - output of the generating unit;
- a, b, and c- are constants.

The total power losses of the system can be expressed as:

$$\Delta S = P_L + jQ_L = \sum V_i \cdot I_i^* = V_{\text{bus}}^T \cdot I_{\text{bus}}^* \qquad (3)$$

where:

- P_L, Q_L are the active and reactive power losses of the system;
- V_{bus} is the column vector of the bus voltages;
- I_{bus} is the column vector of the injected bus currents.

The function is subjected to the following constraints:

$$\begin{aligned} &P_i(V,\theta) = P_{Gi} - P_{Di} \\ &Q_i(V,\theta) = Q_{Gi} - Q_{Di} \\ &P_{Gmin} \le P_G \le P_{Gmax} \\ &Q_{Gmin} \le Q_G \le Q_{Gmax} \\ &V_{imin} \le V_i \le V_{imax} \\ &S_l \le S_{lmax} \end{aligned} \qquad (4)$$

where:

- P_{Gi}- the real power output of the generator connected to bus i;
- Q_{Gi}- the reactive power output of the generator connected to bus i;
- P_{Di}- the real power load connected to bus i
- Q_{Di}- the reactive power load connected to bus i;
- P_i- the real power injection at bus i;
- Q_i- the reactive power injection at bus i;
- V_i- the voltage magnitude at bus i;
- S_l–the apparent power flow at the line l from bus j to bus k.

3. Application

3.1 Test system

The optimal power flow (OPF) is analyzed for the IEEE 30- bus test system presented in Fig. 1, in which three DG sources are added:

- A 3 MW wind turbine (WT) at bus 30;
- A 0.3 MW photovoltaic plant (PV at bus 10;
- A 4 MW hydro generator (HYDRO) at bus 7.

The OPF is performed using the Matlab software, in the cases when the distributed generators are connected to the system will on-grid, and in the cases when the distributed generators are not connected to the system will off-grid.

The data for the system are formulated in table 1,3 and 5 [18]

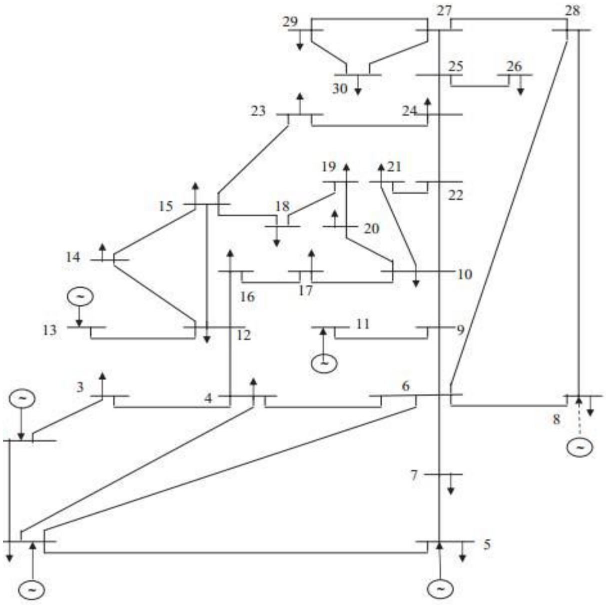


Fig1. One-line diagram of the IEEE 30- bus test system

The total load of the IEEE 30 bus test system is 283.4 MW. The corresponding load-scaling factor(LSF) is 1.0. The daily load demands of the IEEE 30 bus test system is given in table 4 and graphically represented in Fig. 2. The data for the load demand is formulated in [18].

Table 1. Loads Data

Load	$P_{Dimin}(MW)$	$Q_{Dimax}(MVAR)$	Load	$P_{Dimin}(MW)$	$Q_{Dimax}(MVAR)$
1	0	0	16	3.5	1.8
2	21.7	12.7	17	9	5.8
3	2.4	1.2	18	3.2	0.9
4	7.6	1.6	19	9.5	3.4
5	94.2	19	20	2.2	0.7
6	0	0	21	17.5	11.2
7	22.8	10.9	22	0	0
8	30	30	23	3.2	1.6
9	0	0	24	8.7	6.7
10	5.8	2	25	0	0
11	0	0	26	3.5	2.3
12	11.2	7.5	27	0	0
13	0	0	28	0	0
14	6.2	1.6	29	2.4	0.9
15	8.2	2.5	30	10.6	1.9

Table 2. Generators Data

Generator	$P_{Gimin}(MW)$	$P_{Gimax}(MW)$	$Q_{Gimin}(MVAR)$	$Q_{Gimax}(MVAR)$
1	50	200	-20	250
2	20	80	-20	100
5	15	50	-15	80
8	10	35	-15	60
11	10	30	-10	50
13	12	40	-15	60
HYDRO	0.1	4	0	0
PV	0.01	0.29	0	0
WT	0.6	2.7	0	0

Table 3. Generators cost coefficients

Generator	$a[EUR/MWh]$	$b[EUR/MWh]$	$c[EUR/h]$
1	0.00375	2.00	0
2	0.0175	1.75	0
5	0.0625	1.00	0
8	0.0083	3.25	0
11	0.0250	3.00	0
13	0.0260	3.00	0
HYDRO	0	3.00	0
PV	0	8.00	0
WT	0	4.10	0

Table 4. Load scale factor Data

Hour[h]	LSF	Hour[h]	LSF	Hour[h]	LSF
1	0.9	9	1.30	17	1.50
2	0.96	10	1.15	18	1.55
3	1.00	11	1.10	19	1.40
4	1.05	12	1.05	20	1.20
5	1.10	13	1.16	21	1.12
6	1.15	14	1.30	22	1.03
7	1.30	15	1.40	23	0.96
8	1.40	16	1.45	24	0.90

Table 5. Branch data(S_{BASE}=100 MVA)

Branch Number	Sending bus no.	Receiving bus no.	R (pu)	X (pu)	B (pu)	Flow [MVA]
1	1	2	0.0192	0.0575	0.0528	130
2	1	3	0.0452	0.1652	0.0408	130
3	2	4	0.57	0.1737	0.0368	65
4	3	4	0.0132	0.0379	0.0084	130
5	2	5	0.0472	0.1983	0.0418	130
6	2	6	0.0581	0.1763	0.0374	65
7	4	6	0.0119	0.0414	0.009	90
8	5	7	0.046	0.116	0.0204	70
9	6	7	0.0267	0.082	0.017	130
10	6	8	0.012	0.042	0.009	32
11	6	9	0	0.208	0	65
12	6	10	0	0.556	0	32
13	9	11	0	0.208	0	65
14	9	10	0	0.11	0	65
15	4	12	0	0.256	0	65
16	12	13	0	0.14	0	65
17	12	14	0.1231	0.2559	0	32
18	12	15	0.0662	0.1304	0	32
19	12	16	0.0945	0.1987	0	32
20	14	15	0.221	0.1997	0	16
21	16	17	0.0524	0.1923	0	16
22	15	18	0.1073	0.2185	0	16
23	18	19	0.0639	0.1292	0	16
24	19	20	0.034	0.068	0	32
25	10	20	0.0936	0.209	0	32
26	10	17	0.0324	0.0845	0	32
27	10	21	0.0348	0.0749	0	32
28	10	22	0.0727	0.1499	0	32
29	21	22	0.0116	0.0236	0	32
30	15	23	0.1	0.202	0	16
31	22	24	0.115	0.179	0	16
32	23	24	00.132	0.27	0	16
33	24	25	0.1885	0.3292	0	16
34	25	26	0.2544	0.38	0	16
35	25	27	0.1093	0.2087	0	16
36	28	27	0	0.396	0	65

37	27	29	0.2198	0.4153	0	16
38	27	30	0.3202	0.6027	0	16
39	29	30	0.2399	0.4533	0	16
40	8	28	0.636	0.2	0.0428	32
41	6	28	0.0169	0.0599	0.013	32

3.2 RESULTS and comments

The Interior Point (IP) method is applied to 30-bus test system . two objective functions are used to obtain the SCOPF without and with considering the DG sources (off-grid and on-grid). The simulation results show in Fig 3 which indicates the important of DG as on-grid , to reduce power losses compared to the previous results [19] . in this Fig, the power generation costs is decreased ,when the DG is considered , compared to the previous results[19] .But, the power generators costs including DG costs are increased compared to its cost without including DG, as off-grid, because of the high costs of the DG supplies ,specially PV.

The graphic in Fig. 2 highlights that the maximum demands are very cleared that corresponds at the morning and at night. The maximum load demand is 439.27 MW (1.55 LSF) at hr 18:00, while the minimum load demand is 255.06 MW (0.9 LSF) at hr24:00 and hr 1:00.

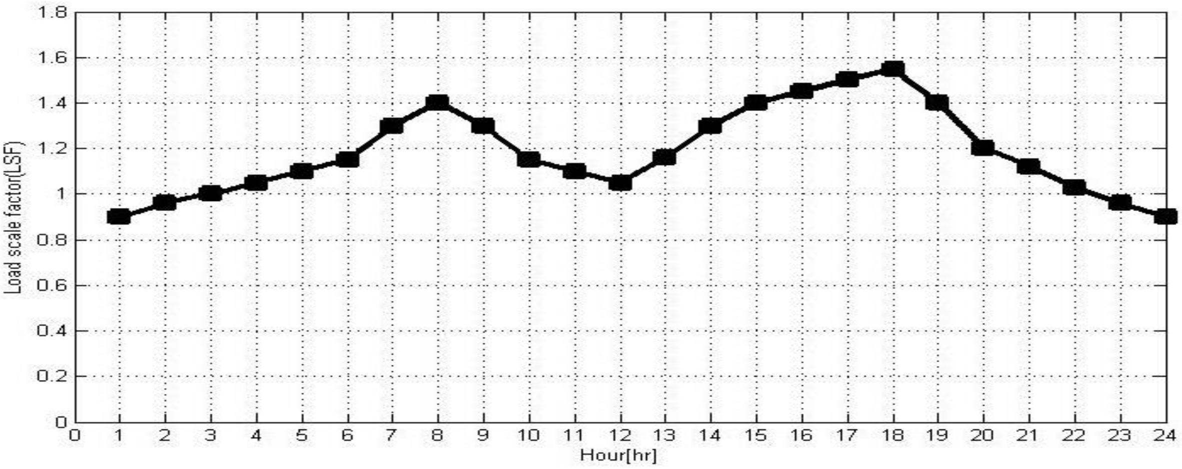
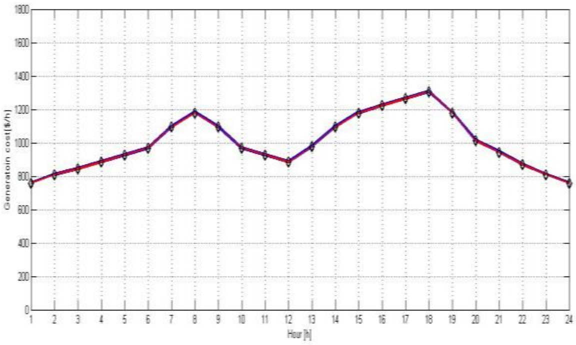
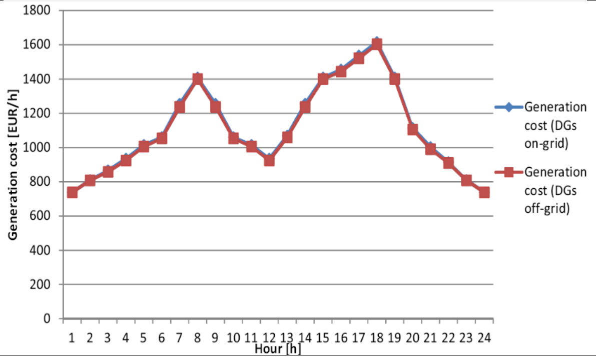


Fig.2 .Load Scale Factor during 24- hour.

<table>
<tr><th rowspan="2">Objective function</th><th colspan="2">results</th></tr>
<tr><th><i>obtained results</i></th><th><i>Previous results[19]</i></th></tr>
<tr><td>Generation cost</td><td>
</td><td>
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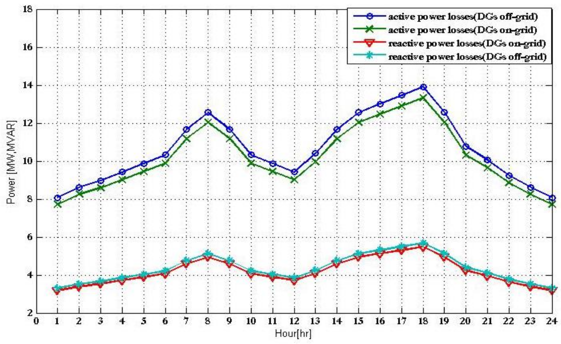
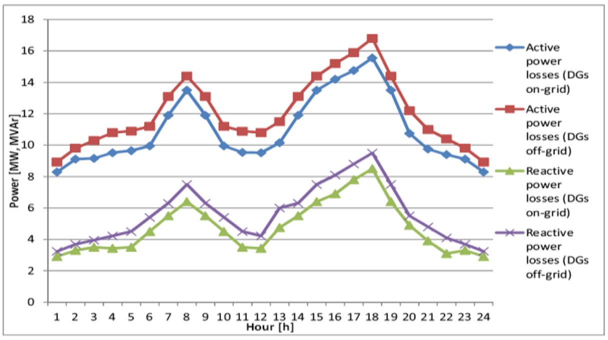
Objective function	results	
	obtained results	*Previous results[19]*
power loss		

Fig. 3. The obtained results compared with literature results

The simulation results is as given in Fig. 3, Which emphasizes that if distributed generators are on-grid, they help reduce active power losses in the power system (from 8.97 MW to 8.59 MW), and reactive power losses (from 3.66 MVAR to 3.53 MVAR)but the generation cost increases. The cost increases because of the high cost coefficients of the power supplied by the distributed generators, especially the PV.

4. CONCLUSIONS

An efficient IP method has been proposed to reduce the power generation cost and the power losses ,when considering DG units ,compared to the previous methods[19]. The SCOPF has been obtained considering two objective functions while the system constraints are considered .SCOPF helps to maintain the combined goal of economy and security of the power system. Different types and rates of DG units have been taken in this paper. A combined between the DG units and the conventional generations units has been presented to improve the whole system performance.

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