Optimal Power Flow of the Manokwari Power Grid Regarding Penetration of 20 MW Combined Cycle Power Plant

by Adelhard Rehiara

Optimal Power Flow of the Manokwari Power Grid Regarding Penetration of 20 MW Combined Cycle Power Plant

Adelhard Beni Rehiara
Department of Electrical Engineering
University of Papua
Manokwari, Indonesia
e-mail: a.rehiara@unipa.ac.id

***Abstract*—Optimal power flow (OPF) is used to calculate the optimal power in to a power grid under some constraints. As a heuristic optimization method, particle swarm optimization (PSO) has been used to obtain optimal solution of penetration of 20 MW Combined Cycle Power Plant (CCPP) of PT. SDIC into 36 bus of Manokwari power grid owned by PT. PLN P2B. Results of simulation show that power loss is about 6.9749 MW by occupying the CCPP power plant at maximum of 20 MW while the minimum cost is reached in generation of 4.6298 MW of the CCPP generator when the other generators of micro-hydro and diesel power plants are work at maximum operation.**

***Keywords*—OPF, PSO, CCPP, PLN P2B, Power grid.**

I. INTRODUCTION

Optimal Power Flow (OPF) is one of the most important issues in power systems operation and planning [1]–[3]. In the OPF problem, generating cost, transmission loss and/or power plants emission is optimized by means of an objectives function under limitation of equality and inequality constraints. The OPF problem typically adjusts the control variables for a given a power system network, so that its operation is optimized while satisfying system constraints and equipment limitation [4].

Some of traditional optimization techniques have been used to solve OPF problem *i.e.* Linear Programming, Nonlinear Programming, Interior Point Method, Newton-Raphson Method and Quadratic Programming. Those methods are developed with some theoretical assumptions and fail to deal with non-smooth, non-convex and non-differentiable objective functions and constraints which are impossible to use them in practical systems. This problem then was solved by meta-heuristic optimization algorithm such as grey wolf optimization [5], hybrid differential evolution and harmony search algorithm [6], enhanced flower pollination [3], particle swarm optimization [2], etc.

Manokwari is the capital city of West Papua province that has its own local grid which is supplied by 14 diesel power plant units from a generator bus and a micro-hydro power plant. This power grid is operated by the electrical government company namely PT. PLN P2B [7].

PT. SDIC Cement Papua Indonesia (SCPI) Company which is a cement corporation in Manokwari has 3x20MW Combined Cycle Power Plant (CCPP) for supporting their work. Because of the large capacity of power plant, the company may sell their excess power to the local grid. This study will perform a review about the effect of the excess power penetration to the power grid of Manokwari by optimizing it using particle swarm optimization.

II. OPTIMAL POWER FLOW CONCEPT

Optimal power flow problem has been introduced by Carpentier in 1962 while it takes decades to improve its algorithm since it consists of a large-scale, constrained, nonlinear and non-convex optimization problem. The OPF deals with allocating demand loads to generators at low cost while respecting the network constraints. The variants of the optimization techniques have been applied to solve the OPF problems which model both objective and constraints in many ways. In general, the OPF problem formulated as follows [2]–[6], [8]:

$$Min\ f(x, u) \tag{1}$$

subjected to

$$g(x, u) = 0 \tag{2}$$

$$h(x, u) \le 0 \tag{3}$$

Where, f is the objective function, g is the equality constraints representing power flow equations and h is the system operating constraints. x is the vector of dependent variables. The x vector consists of voltage magnitude of load buses, phase angle of all buses except the slack bus, active power of slack generator and generators reactive power. The control variable vector, u, includes the generators active power at PV buses (P_G), terminal voltage magnitude at generation bus bars (V_G), output of shunt VAR compensators (Q_C) and tap setting of the tap regulating transformers (T).

Therefore, u can be modeled as in the following:

$$u^T = [P_{G1},\dots,P_{GN},V_{G1},\dots,V_{GN},Q_{C1},\dots,Q_{Cm},T_1,\dots,T_j] \tag{4}$$

Where N, m and j denote the number of generators, shunt VAR compensators and regulating transformers respectively.

A. Objective function

In this paper, the goal is to minimize the generators' fuel costs in the system. The fuel cost function is the function of operating cost again output power and it expresses the variation of fuel cost with generated power. The operating cost is remarkably complex and it can include fuel, labor and maintenance costs. Typical operating cost for power plants is provided in following table [9].

TABLE I. TYPICAL OPERATING COSTS FOR POWER PLANTS

Technology	Operating Cost ($/kWh)
Coal-fired combustion turbine	0.20 — 0.04
Natural gas combustion turbine	0.04 — 0.10
Coal gasification combined-cycle (IGCC)	0.04 — 0.08
Natural gas combined-cycle	0.04 — 0.10
Wind turbine (includes offshore wind)	Less than 0.01
Nuclear	0.02 — 0.05
Photovoltaic Solar	Less than 0.01
Hydroelectric	Less than 0.01

The total fuel cost function (F_t) for a number of generating units can be represented by a quadratic function as follows [1]–[8]:

$$F_t = \sum_{i=1}^{N_G} F_i(P_{Gi}) = \sum_{i=1}^{N_G} [a(P_{Gi})^2 + b(P_{Gi}) + c] \tag{5}$$

Where, N_G is the number of generating units and a_i, b_i and c_i are the coefficient of fuel cost model.

B. Constraints

Two constraints in (2) and (3) are equality and inequality constraints. The equality constraint, denoted by g in (2), includes load flow equations as follows [1]–[6], [8].

$$P_{Gi} - P_{Di} = \sum_{i=1} \left(V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i)\right) \tag{6}$$

$$Q_{Gi} - Q_{Di} = -\sum_{i=1} \left(V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i)\right) \tag{7}$$

Where P_{Gi}, Q_{Gi}, P_{Di} and Q_{Di} are the active and reactive power and demand of i^{th} generator and i^{th} bus respectively. V_i and V_j are the voltage magnitudes at bus i and j with angles δ_i and δ_j. Y_{ij} denotes the element of Y_{bus} matrix at the row i and column j with angle θ_{ij}.

On the other hand, the inequality constraints (h) represented by (3) are the system operating limits as follows:

1. Generator constraints include active and reactive power, and terminal voltage magnitude of generators within their lower and upper limits.

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \quad i = 1, \ldots, N_G \tag{8}$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \quad i = 1, \ldots, N_G \tag{9}$$

$$V_{Gi}^{\min} \le V_{Gi} \le V_{Gi}^{\max} \quad i = 1, \ldots, N_G \tag{10}$$

Where N_G is the number of generator, P_{Gi}^{min}, P_{Gi}^{max}, Q_{Gi}^{min}, Q_{Gi}^{max} denote the minimum and maximum of active and reactive power of i^{th} generator, respectively.

2. Security constraints are the limits on the voltage magnitude of load buses and line flow.

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{11}$$

$$S_{ij} \le S_{ij}^{\max} \tag{12}$$

Where, S_{ij} and S_{ij}^{max} are MVA flow and those maximum amount between buses i and j.

III. OPTIMIZATION USING PSO

Particle Swarm Optimization is introduced by James Kennedy and Russell Eberhart in 1995 that modeled the behaviours of bird flocking. Suppose a group of bird is trying to find a piece of food in an unknown area. Most of the bird may not know where is the food location but they know how far the food in every loop searching. The effective way to find the food is by following the bird that closes to the food. In PSO, each particle is represented by a bird. Once the bird is finding the food, every bird will be landed to the food.

PSO has closed similarities with Genetic Algorithms (GA) which is an evolutionary computation technique. It will start with initial random population and then search for optimal solution by updating generations. However, PSO has no evolution operators such as crossover and mutation. Therefore, PSO is easy to implement and only few parameters need to be adjusted.

In PSO algorithm, the velocity and position of each particle, as well as several algorithm parameters (e.g. inertia weight wand learning parameters) are firstly initializes before staring the iteration. In an iteration t, the fitness of particles are evaluated individually by the objective function. By attracted toward $pbest_i$ and $gbest$, the particle moves according to the following formula [2], [10], [11]:

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{13}$$

where v_i^{t+1} is the velocity, expressed as:

$$v_i^{t+1} = wv_i^t + \alpha\varepsilon_1(x_i^t - gbest^t) + \beta\varepsilon_1(x_i^t - pbest_i^t) \tag{14}$$

Typically, α≈β≈2. The random vectors ε₁ and ε₂ are in the range ½-1. The w is the inertia weight, used to balance global and local search abilities, can be taken neither as a constant from 0.5 to 0.9 for simplicity, or a linear function in terms of iteration t. The linearly decreasing value of w is defined as:

$$w^t = w_{\max} - (w_{\max} - w_{\min})\frac{t}{t_{\max}} \tag{15}$$

Where w_{max} and w_{min} represent the maximum and minimum of the w, respectively. Usually, lower and upper boundaries are set to ensure particles are within the predetermined range. The PSO will continue to search for better solutions until it meets the stopping criterion. This algorithm can also be drawn as flow chart in Fig.1 where NR and TL are Newton Rapson and Transmission Losses respectively [12].

IV. RESULT AND DISCUSSION

A. Buses and Lines Data

The local power grid of Manokwari has a power distribution grid base on 20 kV voltages and it consists of 36 buses of generation and/or load and also 36 lines that connect each bus using AAAC cable and total lines. The CCPP power plant is noted as bus 36th and not appeared in normal operation calculation. There is no constraint provided for the lines but it can be found using data-sheet of the AAAC cable in [13]. Data of the grid can be shown in table II and III and single line of the grid can be drawn in the Fig. 2 as follows.

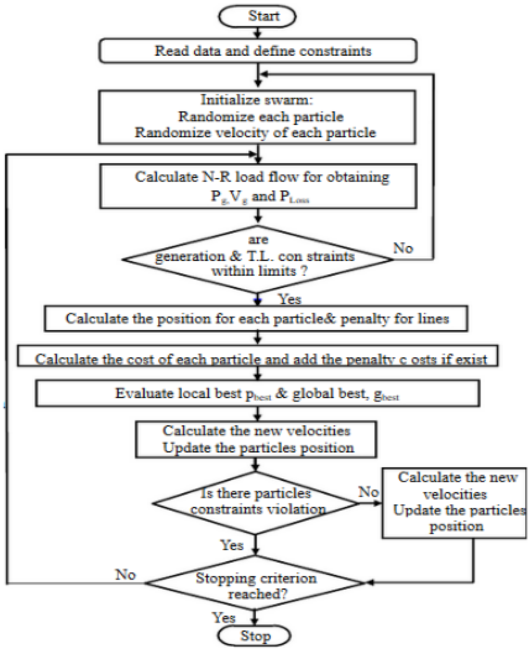

Fig. 1. PSO flow chart

TABLE II. LINE AND BUS DATA

No	From	To	R	X	Rating (MVA)
1	1	2	0.2081	0.3181	26.4
2	1	31	0.0297	0.0454	26.4
3	1	32	0.1513	0.2313	26.4
4	1	33	0.0459	0.0702	26.4
5	1	34	0.1513	0.2313	26.4
6	1	35	0.0146	0.0223	26.4
7	2	3	0.7949	0.6162	16.68
8	3	4	0.0922	0.0714	16.68
9	4	5	0.0058	0.0045	16.68
10	5	6	0.2016	0.1563	16.68
11	6	7	0.1440	0.1116	16.68
12	7	8	0.0230	0.0179	16.68
13	8	9	0.2027	0.3098	26.4
14	9	10	0.1152	0.0893	16.68
15	10	11	0.0135	0.0207	26.4
16	11	12	0.0622	0.0950	26.4
17	12	13	0.0405	0.0620	26.4
18	13	14	0.1703	0.2603	26.4
19	13	18	0.1703	0.2603	26.4
20	13	36	0.9461	1.7571	30.24
21	14	15	0.2938	0.2277	16.68
22	15	16	0.0922	0.0714	16.68
23	16	17	0.0115	0.0089	16.68
24	17	23	0.1728	0.1339	16.68
25	18	19	0.1324	0.2024	26.4
26	19	20	0.1243	0.1900	26.4
27	20	21	0.1162	0.1776	26.4
28	21	22	0.5300	0.2179	11.1
29	22	23	0.2984	0.1701	13.32
30	23	24	0.2258	0.1287	13.32
31	24	25	0.0899	0.0697	16.68
32	25	26	0.1521	0.1179	16.68
33	26	27	0.2223	0.1723	16.68
34	27	28	0.2707	0.2099	16.68
35	28	29	0.1838	0.2809	26.4
36	28	30	0.2000	0.3057	26.4

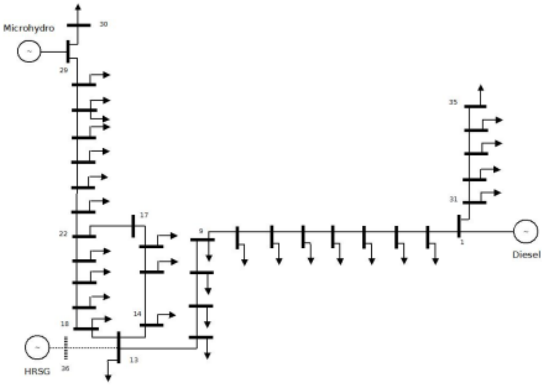

Fig. 2. Single line diagram

TABLE III. VOLTAGE AND POWER DATA

Bus No	Voltage	Power		Bus Type
		MW	MVar	
1	1.06	(0.0000)	(0.0000)	Slack
2	1.00	(0.0000)	(0.0000)	Load
3	1.00	(0.0450)	(0.0218)	Load
4	1.00	(0.0900)	(0.0436)	Load
5	1.00	(0.1800)	(0.0872)	Load
6	1.00	(0.0900)	(0.0436)	Load
7	1.00	(0.0450)	(0.0218)	Load
8	1.00	(0.0900)	(0.0436)	Load
9	1.00	(0.0450)	(0.0218)	Load
10	1.00	(0.0900)	(0.0436)	Load
11	1.00	(0.0900)	(0.0436)	Load
12	1.00	(0.0450)	(0.0218)	Load
13	1.00	(0.3600)	(0.1744)	Load
14	1.00	(0.0450)	(0.0218)	Load
15	1.00	(0.0450)	(0.0218)	Load
16	1.00	(0.0450)	(0.0218)	Load
17	1.00	(0.0000)	(0.0000)	Load
18	1.00	(0.0225)	(0.0109)	Load
19	1.00	(0.0225)	(0.0109)	Load
20	1.00	(0.0450)	(0.0218)	Load
21	1.00	(0.0000)	(0.0000)	Load
22	1.00	(0.0450)	(0.0218)	Load
23	1.00	(0.0135)	(0.0065)	Load
24	1.00	(0.1440)	(0.0697)	Load
25	1.00	(0.0450)	(0.0218)	Load
26	1.00	(0.0135)	(0.0065)	Load
27	1.00	(0.0450)	(0.0218)	Load
28	1.00	(0.0450)	(0.0218)	Load
29	1.02	2.5000	0.0000	Gen.
30	1.00	(4.1670)	(2.0182)	Load
31	1.00	(7.5870)	(3.6746)	Load
32	1.00	(3.8655)	(1.8721)	Load
33	1.00	(7.8210)	(3.7879)	Load
34	1.00	(2.9475)	(1.4275)	Load
35	1.00	(2.8980)	(1.4036)	Load
36	1.04	20.0000	0.0000	Gen.

The next power plant is located far away from slack bus and it has good function as distributed generator. The power plant is micro-hydro power plant with 2x1.25MW main generators.

The other power plant is a CCPP power plant that operated by PT. SCPI. The power plant consists of 3x20MW power plant. Because the production of cement also needs a lot of energy, the company may not sell total generated power. Therefore at least one of the generators will be connected to the grid.

Fuel cost function of slack bus is generated using real data under assumption that diesel fuel will cost $2.52/gallon. The cost function of the micro-hydro power plant will close to zero since the fuel is free, so that it only includes maintenance cost. It is not easy to create the cost function of CCPP power plant since it has complex operation cost. Based on that condition, the cost function of micro-hydro power plant and the CCPP power plant will be built by using standard cost in Table 1. The cost functions of power plants for three generator buses can be written as follows.

$$F_1 = 954(\mathrm{P}_1)^2 + 18308(\mathrm{P}_1) + 2\mathrm{e}^6 \quad \therefore 2.58 \leq P_1 \leq 24.4MW$$
$$F_2 = -4e^{-6}(\mathrm{P}_2)^2 + 0.0002(\mathrm{P}_2) + 0.00123 \quad \therefore 0.25 \leq P_2 \leq 2.5MW$$
$$F_3 = 0.0543(\mathrm{P}_3)^2 + 9.3514(\mathrm{P}_3) + 190.56 \quad \therefore 2 \leq P_3 \leq 20MW$$

B. *OPF Calculation*

OPF calculation for normal condition, diesel power on slack bus will supply 28.9937 MW while micro-hydro power plant will produce 2.5 MW and transmission loss is about 0.4617 MW. Therefore operation cost is about USD 3,333,000/hour to produce 31.4937 MW. Voltage profile of the power grid before penetration can be shown in Fig.3.

Fig. 3. Voltage Profile of normal operation

It is shown in Fig.3 that only voltage of bus 30 is under 1 p.u. On the other hand, bus voltages of buses 31 to 35 are closed to the slack bus because those are connected to slack bus together with bus 2.

Figure 2 shows that there are three generator connected to the power grid. The slack bus consists of 13 diesel power plants and micro-hydro power plant has two 1.25 MW generators while CCPP is a power plant with capacity 3x20MW.

While penetration of the CCPP power plant, PT. PLN P2B as the owner of the power grid, may face two possibilities regarding power loss and/or operation cost. Both possibilities will be reviewed for the best solution.

Optimal operation cost is calculated using particle swarm optimizer and the best operation cost solved with the PSO is about USD 2,570,000.00/hour under transmission losses about 7.9707 MW. In this case, 39.0027 MW of the power has been generated by power generators of 1 to 3 about 16.5027 MW, 2.5 MW and 20 MW respectively. The voltage profile is shown in red curve on Fig. 4.

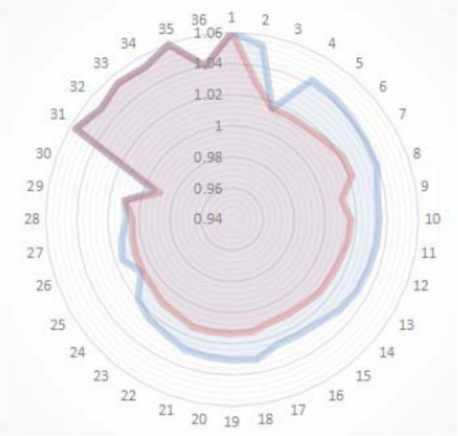

Fig. 4. Voltage profile of optimal operation (red) and recommendation operation (blue)

Considering the transmission loses, the recommendation solution is given with 0.498MW loses by costing operation about USD 3,010,000.00/hour. Total generation is about 31.5298 MW by occupying generators 1, 2 and 3 with 24.4 MW, 2.5 MW and 4.6298MW respectively. Voltage profile of this solution is provided in Fig. 4.

Fig. 4 shows that bus voltages for recommendation operation are higher than optimal operation except in bus 1, 31-36 that relatively constant. On the other hand, even for optimal operation, voltage in bus 30 is still under 1 p.u.

PT. PLN P2B may apply less transmission losses in their operation by operating most of their own generator under consequence of high operation cost. In the same idea, PT. SCPI may not sell only a little amount of the CCPP power plant since operation costs for small and full capacity produced of their power plant may not significantly different.

The best solution may be applied to optimal operation with high transmission loses but a little operation cost at maximum capacity of CCPP. On the other hand, PT. PLN P2B may standby their machine while saving money in their operation. In addition, PT. PLN P2B may need to upgrade their grid line from bus 2 to 10 so that it can improve the system ability to deliver more power from the CCPP power plant.

V. CONCLUSION

Penetration of 20 MW CCPP power plants may solve limitation of electrical energy supply in Manokwari but it may also cause some problem. Due to limitation of transmission line, the energy may be transferred to consumer connected to the grid of Manokwari in very high losses.

The most economical solution for this grid is by buying all the excess power from CCPP power plant rather than focus on transmission losses. Besides lower prize, the other advantage by buying this energy is PT. PLN P2B can stop their machine at peak load and may work only in day operation while the CCPP power plant is shutdown.

REFERENCES

[1] S. Surender Reddy and P. R. Bijwe, "Efficiency improvements in meta-heuristic algorithms to solve the optimal power flow problem," *Electrical Power and Energy Systems*, vol. 82, pp. 288–302, 2016.

[2] C. Su and Z. Chen, "An Optimal Power Flow (OPF) Method with Improved Power System Stability," in *the 45th International Universities Power Engineering Conference*, 2010, pp. 1–6.

[3] C. Shilaja and K. Ravi, "Multi-Objective Optimal Power Flow Problem Using Enhanced Flower," *Journal of Science*, vol. 30, no. 1, pp. 79–91, 2017.

[4] H. D. Abatari, M. S. S. Abad, and H. Seifi, "Application of Bat Optimization Algorithm in Optimal Power flow," in *24th Iranian Conference on Electrical Engineering (ICEE) Application*, 2016, pp. 793–798.

[5] D. P. Ladumor, I. N. Trivedi, R. H. Bhesdadiya, and P. Jangir, "Optimal Power Flow problems solution with SVC using meta-heuristic algorithm," in *3rd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics*, 2017, pp. 283–288.

[6] S. Surender Reddy, "Optimal power flow using hybrid differential evolution and harmony search algorithm," *International Journal on Machine Learning and Cybernetics*, vol. 10, no. 2, pp. 1077–1091.

[7] A. B. Rehiara, S. Setiawidayat, and E. K. Bawan, "Optimal Operation Scheme for Diesel Power Plant Units of PT. PLN-Manokwari Branch using Lagrange Multiplier Method," *Procedia Environmental Sciences*, vol. 17, pp. 557 – 565, 2013.

[8] J. Liu, J. Chen, and Q. Zhang, "Optimal power flow calculation for power system with UPFC considering load rate equalization Optimal power flow calculation for power system with UPFC considering load rate equalization," in *3rd International Conference on Advances in Energy, Environment and Chemical Engineering*, 2017, pp. 1–8.

[9] S. Blumsack, "Energy Markets, Policy, and Regulation," in *https://www.e-education.psu.edu/eme801/*, 2016.

[10] Y. Zhang and L. Wu, "Crop Classification by Forward Neural Network with Adaptive Chaotic Particle Swarm Optimization," *Sensors*, vol. 11, no. 5, pp. 4721–4743, 2011.

[11] S. N. Omkar, D. Mudigere, G. N. Naik, and S. Gopalakrishnan, "Vector evaluated particle swarm optimization (VEPSO) for multi-objective design optimization of composite structures," *Computers and Structures*, vol. 86, pp. 1–14, 2008.

[12] A. Abaza and A. Azmy, "Demand-side management-based dynamic pricing within smart grid environment," in *IEEE International Conference on Smart Energy Grid Engineering*, 2013.

[13] Anonymous, "Overhead Line Conductors," in *http://omancables.com/brochure/Overhead_Line_Conductor.pdf*, 2016.

Optimal Power Flow of the Manokwari Power Grid Regarding Penetration of 20 MW Combined Cycle Power Plant

ORIGINALITY REPORT

20%	8%	20%	7%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	H. Delkhosh Abatari, M. Seydali Seyf Abad, H. Seifi. "Application of bat optimization algorithm in optimal power flow", 2016 24th Iranian Conference on Electrical Engineering (ICEE), 2016 Publication	11%
2	Jieming Ma, Ziqiang Bi, Tiew On Ting, Shiyuan Hao, Wanjun Hao. "Comparative performance on photovoltaic model parameter identification via bio-inspired algorithms", Solar Energy, 2016 Publication	4%
3	Submitted to International Islamic University Malaysia Student Paper	1%
4	Andrea Bersano, Stefano Segantin, Nicolò Falcone, Bruno Panella, Raffaella Testoni. "Evaluation of a potential reintroduction of nuclear energy in Italy to accelerate the energy transition", The Electricity Journal, 2020 Publication	1%

5	journals.plos.org Internet Source	1%
6	Akula Venkata Naresh Babu, Sirigiri Sivanagaraju. "A solution to the optimal power flow problem: A new approach based on two step initialization", 2011 Annual IEEE India Conference, 2011 Publication	1%
7	Wen Shuhua, Zhang Xueliang, Li Hainan, Liu Shuyang, Wang Jiaying. "A Modified Particle Swarm Optimization Algorithm", 2005 International Conference on Neural Networks and Brain, 2005 Publication	1%
8	Submitted to The Hong Kong Polytechnic University Student Paper	1%
9	article.nadiapub.com Internet Source	1%
10	Chaib, A.E., H.R.E.H. Bouchekara, R. Mehasni, and M.A. Abido. "Optimal power flow with emission and non-smooth cost functions using backtracking search optimization algorithm", International Journal of Electrical Power & Energy Systems, 2016. Publication	1%

Exclude quotes	On	Exclude matches	< 1%
Exclude bibliography	On		