บทความทางวิชาการ

Optimal Allocation of Biomass Power Plant by Simulated Annealing Approach

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Abstract

This paper presents the simulated annealing (SA) approach for finding the optimal number, size and location of biomass power plants (BOMP) to minimize the total power loss subject to power balance constraints, reactive and active power generation, and voltage limits. The evaluation results on the IEEE 7 bus system of SA compare with an artificial intelligence technique i.e. genetic algorithm (GA).The results shown that when compare with SA can get the optimal solution with less computational time as 71.82% GA. For there more optimally the placed of BOMP can significantly reduce the system losses from 1.61 MW to 1.08 MW or about 32.92%. This implies that the annual energy consumption can reduced about 6.15% or emission of 1,906.50 MT carbons can be avoided per year, when BOMP are optimally allocated in power system of Thailand.

Keywords: Optimal Allocation**,** Simulated Annealing , Biomass Power Plant, Loss Minimization.

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1. Introduction The history of electric power generation system has been derived from large central station plants due to the economies of scale [1]. Fossil fuel plants have represented the majority of this power generation. According to tradition, there was strong yearly demand growth, which was stable 6.0-7.0% and more. Environmental issues and the oil crisis began to introduce new problems for the power industry in 1970s. In the 1980s, these factors and changing in the economy had led to much smaller demand growth around 1.6-3.0 % [2]. Simultaneously, investment cost of transmission and distribution have grown from a historical level of 25% to around 150% of investment costs of generation and now represent almost two thirds of the capital expenditure budget for the utility industry. Thus, the result of the reduced demand growth, increased investment costs of transmission and distribution, intensified environmental concerns and various regulatory and technological improvement, large central station plants are often impractical. The utility industry's generation paradigm is shifting from economies of scale to something that has been coined economies of mass production [3]. Distributed generation (DG) is electricity generation sited close to the load it serves and affect the electric power system at the system and, more directly, at the distribution level. Power system deregulations have led to increased interest in distributed generation sources**.**

Renewable electricity generation has emerged as one of the favored options for dealing with fossil fuel depletion, green house gas emissions and subsequent adverse effects like global warming. As an outcome of the Kyoto protocol, one of the Thailand objectives is to increase the contribution of renewable energy sources to 12% of the total energy supplied by 2010**.** There are many types of renewable power in Thailand's power network. The contribution of renewable energy to electricity generation is shown in Table 1. It shows that biomass power plant (BOMP) is highest potential of renewable power plant, which the accumulative installed capacity is 2,223.8 MW, 6,475.8 MW and 13,288.8 MW in 2005, 2011 and 2016, respectively.

Table 1. Contribution of renewable energy generation in Thailand

Energy Source	**Installed capacity (MW_e)**			**GWh Production**		
	2005	2011	2016	2005	2011	2016
National total	26,400	37,443	48,000	134,826	197,482	259,659
Biomass						
- Ethanol	-	-	-	-	-	-
- Biodiesel	-	-	-	-	-	-
- Residues for Heat						
- Residues for Power	2,191	3,229	4,938	9,596	14,143	21,628
- Short rotation plants	0	519	1,298	0	3,182	7,955
- Biogas for H&P	28.8	181	193	227	1,475	1,580
- Solid wastes for H&P	4	323	384	33	2,688	3,196
Small hydro	53	338	338	204	1,308	1,308
Wind	0.19	194	1,783	0	255	2,343
Solar						
- PV	26	60	120	36	84	168
- SWH (Fuel Oil Equivalent)	-	-	-	-	-	-
- Dryer	-	-	-	-	-	-
Sub-total	**2,303**	**4,844**	**9,054**	**10,096**	**23,135**	**38,178**
%NRE	**8.7%**	**12.9%**	**18.9%**	**7.5%**	**11.7%**	**14.7%**

Source: Energy Policy and Planning Office, Ministry of Energy, Thailand

BOMP is one of the promising renewable source in Thailand, but more research is required to prove that power generation from BOMP is both technically and economically viable. The main advantages of BOMP generation are that the cycle of growth and combustion of the biomass has a net zero level of CO_2 production.

The concept of installing BOMP in a utility distribution or sub-transmission system is gaining interest in the customer. Research has suggested that the benefits of distributed resources could be substantial [4]. Proper capacity and location of BOMP to be installed in the power network is important for obtaining their maximum potential benefits [5-6]. This paper proposes the artificial intelligence techniques of search for finding the optimal number, size and location of BOMP to minimize the total system power loss subject to power balance constraints, reactive and active power generation and voltage limits.

In this paper, the efficiency method that is simulated annealing (SA) to investigate optimal allocation of BOMP from a view point of loss minimization is evaluated. SA to determine optimal multi solution of location, size and number of BOMP the principle of algorithm to minimize the total power is illustrated.

SA is shown in Section 3. In Section 4, simulation result that BOMP optimal placement in view point of loss minimization is demonstrated. The validity of the solution algorithm is verified by comparing the searching results with those by the SA method.

2. Problem Formulation

The power loss of line *k* can be calculated by equation (1) as given below:

$$P_{Lk} = g_k[|V_i|^2 + |V_j|^2 - 2|V_i||V_j|\cos(\theta_i - \theta_j)] \quad k = 1,...,N_l \,. \tag{1}$$

The problem is formulated as follows:

$$Minimize \qquad P_L \;=\; \sum_{k=1}^{N_l} P_{Lk} \tag{2}$$

Subject to power balance constrains :

$$P_i \;=\; \sum_{j=1}^{n} |V_i||V_J|Y_{IJ}\, cos(\theta_{ij} - \delta_{iJ}) \tag{3}$$

$$Q_i \;=\; -\sum_{j=1}^{n} |V_i||V_j|Y_{i_j}\, sin(\theta_{ij} - \delta_i \;) \tag{4}$$

$$P_{Gi,\min} \;\le\; P_{Gi} \le P_{Gi,\max} \;, \forall i \in NG \tag{5}$$

$$Q_{Gi,\min} \le Q_{Gi} \le Q_{Gi,\max} \;, \;\; \forall i \in NG \;. \tag{6}$$

$$|Sl_i| \le Sl_{i,\max} \;, \quad \forall i \in N_l \tag{7}$$

$$V_{i,\min} \le V_i \le V_{i,\max} \;, \quad \forall i \in N \tag{8}$$

Where

P_{Lk}	:	is power loss of line *k*,
g_k	:	is series conductance of line *k* ,
θ_i	:	is phase angles at buses *i* ,
θ_j	:	is phase angles at buses *j* ,
P_L	:	is total active power loss in the system,
N_l	:	is the total number of line,
k	:	is the index of line *k*,
P_i	:	is the active power at bus *i* ,
Q_i	:	is the reactive power at bus *i* ,
$\|V_i\|$	:	is the voltage magnitude at bus *i* ,

$\lvert V_j \rvert$	:	is the voltage magnitude at bus j ,
Q_{Gi}	:	is the reactive power generation at generator number i ,
P_{Gi}	:	Is the active power generation at generator number i ,
Sl_i	:	Is the power flow in line number i ,
θ_{ij}	:	Is the angle of the ij element in Y_{bus} ,
Y_{ij}	:	Is the ij element in Y_{bus} ,
δ_{ij}	:	Is the voltage angle difference between bus i and bus j,
NG	:	Is the total number of power generation,
N	:	Is the number of bus.

3. Simulated annealing

3.1 SA Implementation for BOMP Placement:

SA can sometimes be classified as an Evolutionary algorithms(EAs). The method can be seen as mimicking the random behavior of molecules during an annealing process, which involves slow cooling from a high temperature. As the temperature cools, the atoms line themselves up and form a crystal, which is the state of minimum energy in the system. By using SA, almost all kinds of design variables including binary codes can be applied. The search procedure of SA starts with an initial solution, which will be called the parent. The parent is then mutated in some manner leading to a set of children or offspring. The best offspring is said to be a candidate to challenge its parent. For minimization, if the candidate has a lower objective value than that of the parent, the parent is replaced by the candidate. In cases where the candidate has a higher objective function value than its parent, it still has a chance to replace the parent if accepted by a Boltzmann probability. Since on each loop the worse candidate may replace its parent, the best solution and the parent may not be the same solution. Therefore, the best individual on each loop should be kept along with a parent ensuring that the best solution of the search is not lost. The best solution can also be used in the mutation strategy of SA.

3.2 SA Procedure

The SA algorithm used for loss minimization in this paper can be detailed as

Step 1 : Input line and bus data, and bus voltage limits.
Step 2 : Calculate the loss using load flow.
Step 3 : Initialization: initial solution $\mathrm{x}_{\mathrm{parent}} = \mathrm{x}_{\mathrm{best}}$, $f_{\mathrm{parent}} = f_{\mathrm{best}}$ initial temperature T.
Step 4 : Generate ns design solutions $\{\mathrm{x}_1^1, \mathrm{x}_2^1, ..., \mathrm{x}_{\mathrm{ns}}^1\}$ and their corresponding function values $\{f_1^1, f_2^1, ..., f_{\mathrm{ns}}^1\}$ by mutating on $\mathrm{x}_{\mathrm{parent}}$.

Step 5: Generate *ns* design solutions $\{x_1^2, x_2^2, ..., x_{ns}^2\}$ and their corresponding function Values $\{f_1^2, f_2^2, ..., f_{ns}^2\}$ by mutating on x_{best}.

Step 6 : Find $f_{candidate} = \min(\{f_i^1\} \cup \{f_i^2\})$ and its corresponding design solution $x_{candidate}$.

Step 7 : If $f_{candidate} \_ f_{parent}$:

7.1. Set $x_{parent} = x_{candidate}$, $f_{parent} = f_{candidate}$.

7.2. If $f_{candidate\_} f_{best}$, $x_{best} = x_{candidate}$, $f_{best} = f_{candidate}$

7.3. Go to step 9

Step 8 : If $f_{candidate} > f_{parent}$,find $P_B = \exp(\frac{f_{parent} - f_{candidate}}{T})$, and generate a random number $rand$.

8.1. If $rand \_ P_B$,set $x_{parent} = x_{candidate}$, $f_{parent} = f_{candidate}$ and x_{best} and f_{best} are not changed. Go to step 9

8.2. If $rand > P_B$, x_{parent}, f_{parent}, x_{best} and f_{best} are not changed. Go to step 9.

Step 9 : Reduce the temperature *T* if the condition is fulfilled.

Step10 : If the termination criterion is met, stop the procedure.Otherwise,go to step 4

On each iteration *ns* individuals are created by mutating on $\mathbf{x}_{parent}$ and other *ns* individuals are obtained from mutating on $\mathbf{x}_{best}$. The solutions $\mathbf{x}_{best}$ and $\mathbf{x}_{parent}$ are the same initially but they can be different during the optimization process. The parameter $rand \in [0, 1]$ is a uniform random number sampled every time the computational step 6 is operated. The reduction of temperature can be scheduled by a designer. The use of SA for energy system optimization has been studied by several researchers e.g.

4. Simulation Results

4.1 Optimized Solution Results

In order to test the proposed algorithm, different experiment with different random trial iteration were carried out to investigate the performance of the proposed algorithm, which the optimized parameter of each algorithm. It was found that the proposed algorithm of SA performs better than the individual GA which is 72% factor in total CPU time average and 71% faster in best total CPU time.

Table 2. comparison SA with GA

Heuristic Approach	Average total CPU Time (sec)	Best total CPU Time (sec)
GA	10.76	1.06
SA	3.03	0.31

The computing time of SA optimization comparing with GA has been shown in Table 2.

Case 1: System losses without BOMP units;
Case 2: System losses with placement of BOMP units 5% of loading level,
Case 3: System losses with placement of BOMP units 10% of loading level,
Case 4: System losses with placement of BOMP units 15% of loading level.

Table 3. Total power loss of the 7 bus system without BOMP

Load factor %	Total power loss (MW)
80	1.44
100	1.61
105	1.68
110	1.75
115	1.82
120	1.89

The simulation result of system without BOMP (Case 1) is shown in Table 3.The total power loss is 1.440 MW, 1.610 MW and 1.890 MW when system loading level is 0.80, 1.00 and 1.20, respectively.

The simulation results of each case of system with BOMP are shown in Table 4. The summary results show that the optimal placement of each case is as follows:

1. BOMP rated 5% of system load level is of applying 4 BOMP, rated 1.25% each, to each bus of 1, 2, 6 and 7.
2. BOMP rated 10% of system load level is of applying 2 BOMP, rated 5% each, to each bus of 3 and 4.
3. BOMP rated 15% of system load level is of applying only 1 BOMP, rated 15%, to bus 3.

Table 4. Summary data of power system loss with BOMP

BOMP 5% of load 200 MW				
Number of unit	Min Loss (MW)	Location (Bus)	Max Loss (MW)	Location (Bus)
1	1.51	4	3.77	2
2	1.52	3,4	3.92	2,5
3	1.86	3,5,7	4.57	1,5,6
4	1.08	1,2,6,7	4.54	1,4,5,6

BOMP 10% of load 200 MW				
Number of unit	Min Loss (MW)	Location (Bus)	Max Loss (MW)	Location (Bus)
1	1.54	3	3.86	2
2	1.54	3,4	3.93	1,6
3	1.81	3,5,7	4.58	1,5,6
4	1.77	1,2,3,6	4.56	1,4,5,6
BOMP 15% of load 200 MW				
Number of unit	Min Loss (MW)	Location (Bus)	Max Loss (MW)	Location (Bus)
1	1.73	3	4.12	2
2	1.74	3,4	4.06	1,6
3	1.79	3,5,7	4.64	1,5,6
4	1.8	3,4,5,7	4.6	1,4,5,6

The simulation results can also be summarized that:

1. If BOMP with improper ratings and numbers are placed in the improper locations, the total power loss will increase, i.e. 72%, 20% and 4% when BOMP 5%, 10% and 15% respectively of load level are applied in the system.

2. At the same load level, more increase BOMP capacity in the system, more increase system losses, i.e. applying 10% and 15% BOMP in the system will increase losses of 40% , 60% respectively comparing with losses of applying 5% BOMP in the system.

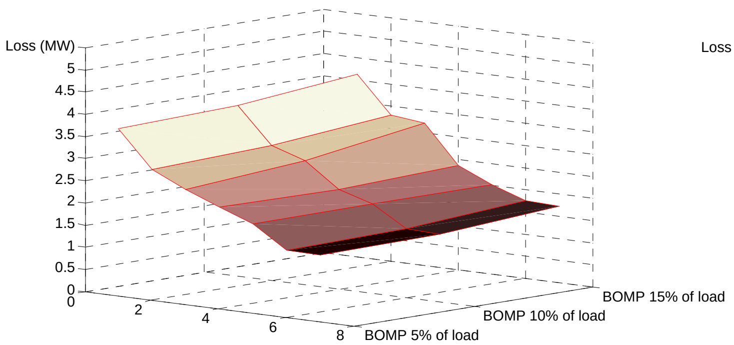

Fig. 1. Total power loss of 1 BOMP

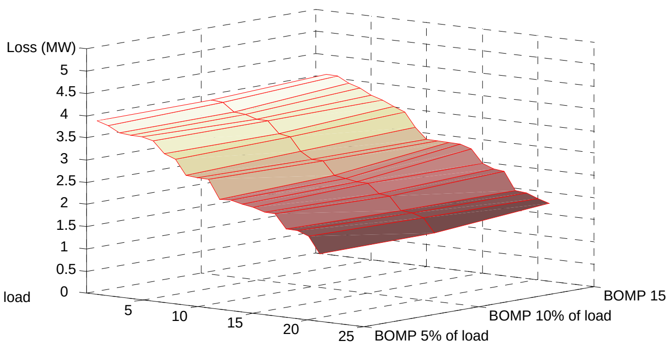

Fig. 2. Total power loss of 2 BOMP

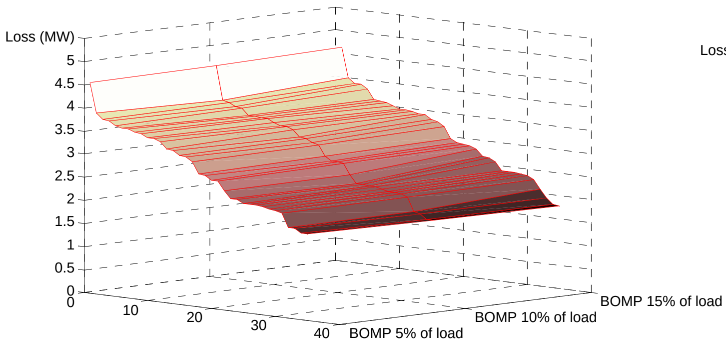

Fig. 3. Total power loss of 3 BOMP

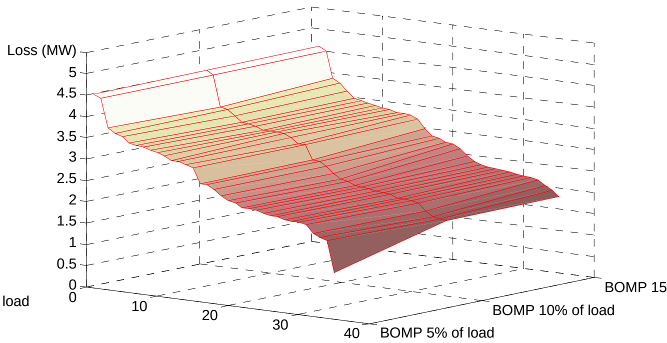

Fig. 4. Total power loss of 4 BOMP

The optimal placement of BOMP is very important to significantly reduce the total power loss. Improper placement of BOMP in the system will increase of the total power loss by means of not necessary. It is observed that the loss reduction by optimal BOMP allocation of rating, number and location with smaller BOMP capacity will be more than that of larger BOMP capacity. BOMP can reduce about 6.15% or emission of 1,906.50 MT carbons can be avoided per year, when BOMP are optimally allocated in power system of Thailand.

5. Conclusion

In this paper, implementation of SA to the optimal only allocation of BOMP has been illustrated. The effectiveness of the SA to solve the BOMP allocation problem has been demonstrated through the numerical example. The example of the IEEE distribution test feeders has been solved with the SA and GA algorithms. The result proves that the SA is better than GA in term of solution quality and number of iteration.

Appendix

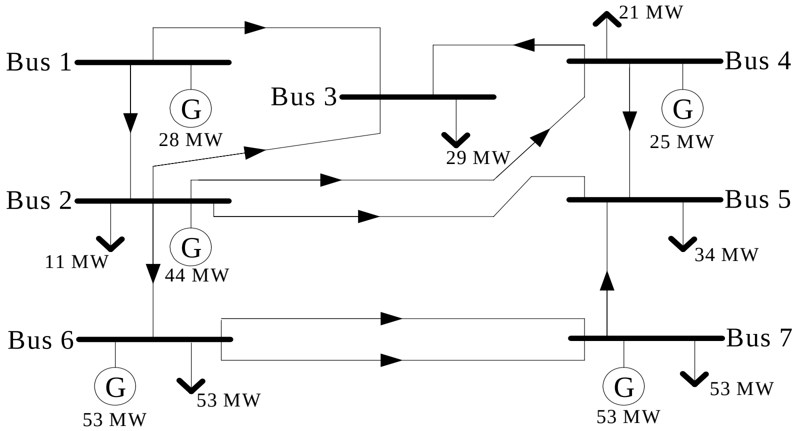

Fig. 5. Topology of the 7 bus system

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