

OPTIMIZING A TYPICAL BIOMASS FUELED POWER PLANT USING GENETIC ALGORITHM AND BINARY PARTICLE SWARM OPTIMIZATION

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Abstract- Over thousands tons of animal manures are produced in Iran. The major animal manures producers are located in central regions. Animal manures collection is an autochthonous and important renewable energy sources that in most cases are released in nature by ranchers. In this paper, a typical animal manure producer region (Taleghan) in Iran is considered and optimal location and size of a typical biomass fueled power plant is determined. Genetic algorithm (GA) and Binary particle swarm optimization algorithms are used as the major approaches of determination and effectively these approaches will make possible to determine the optimal location, biomass supply area and power plant size that offer the best profitability for investor.

Keywords: Renewable, Biomass Power Plant, Genetic Algorithm, Binary Particle Swarm Optimization.

I. INTRODUCTION

The ever increasing growth of demand for electric energy has provided energy crisis in the world. Renewable energy sources (RES) have been introduced as the best alternative solution for traditional fossil fuels [1]. It is usually mentioned that RES have a large potential to contribute to the sustainable development of specific territories by providing them with a wide variety of socioeconomic benefits, including diversification of energy supply, enhanced regional and rural development opportunities, creation of a domestic industry and employment opportunities [2].

The global production of liquid bio-fuels is now estimated to be over 35 mm³. Ethanol currently accounts for more than 90% of total biofuel production. Global fuel ethanol production more than doubled between 2000 and 2005, while production of biodiesel, starting from a much smaller base, expanded nearly fourfold. Some examples: Brazil has exported in 2004 2.5 billion liters of ethanol (same in 2005) with main destinations India (23.1%) and USA (20.2%) [3].

There are several options to produce electricity from biomass. Among combustion, gasification and pyrolysis, and gasification are being the most efficient one [4]. Gasification of biomass is a thermal treatment, which

ensues in a high production of gaseous products and small amounts of char and ash. Steam reforming of hydrocarbons, partial oxidation of heavy oil residues, selected steam reforming of aromatic compounds, and gasification of coals and solid wastes to yield a mixture of H₂ and CO, accompanied by water-gas shift conversion to produce H₂ and CO₂, are well-proved processes. Also, the use of animal manure, like that of any other biomass, can contribute to sustainable development in rural areas [5, 6].

Pyrolysis has been applied for thousands of years for charcoal production but it is only on the last 30 years that fast pyrolysis at moderate temperatures of around 500 °C and very short reaction times of up to 2 s has become of considerable interest. This is because the process directly gives high yields of liquids of up to 75 wt% which can be used directly in a variety of applications or used as an efficient energy carrier [7]. Chemically, bio-oils consist of hundreds of organic compounds, including many valuable chemicals. However, most of the chemicals are in low contents, making their recovery not only technically difficult but also economically unattractive at present [8].

In the future, biomass combustion will play an important role in energy production to obtain electricity or heating. But the variability in properties of biomass fuels is great and may significantly influence the efficiency and environmental impacts associated with their utilization [9-10]. In the field of biomass power plants, it's very important to optimize the plant size and location. This optimization process is done via different optimization algorithms.

Authors as Lopez and et al have compared meta-heuristic techniques of determining optimal location and size of biomass power plants. They have used four meta-heuristic techniques to find optimal location, size and supply area of a typical biomass fueled power plant inside a region of 32000 km² covered with natural forest vegetations [11].

Lopez and et al have also proposed individual particle swarm optimization to find optimal location, supply area and plant size in a region of 1024 square kilometers covered with natural forest vegetations [12].

In a different work, Jurado and Cano have studied on optimal placement of biomass fueled gas turbine. As opposed to previous works, beside economic constraints, loss reduction plays more important role to find the optimum placement and plant size [13]. In particular, Taleghan is an Iran Town in Alborz province. The agricultural economy mainly works with cattle ranching. This region is divided in 72 parcels of different surface S_i . The extension is 1400 km² approximately.

In this work, we will investigate the region and determine the optimal location, supply area and size of a typical biomass fueled power plant using two metaheuristic techniques, GA and BPSO. Animal manures are used as the plant input feedstock and gasification being the major conversion process.

II. OPTIMIZATION PROBLEM

A. Problem Description

The problem to be solved consists of determining the optimum location, size and supply area of a biomass-fueled power plant based on animal manures. For such goal, 2 metaheuristic techniques are applied and compared. Here, we have employed two population-based methods (GA and BPSO). The size of the generation system depends on:

1. Biomass quantity that can be collected,
2. Selection of parcels where to collect the biomass,
3. Technology used to convert biomass to electrical energy.

Placement of power plant (parcel p) mainly depends on the characteristics of the parcels. In this work, K parcels of different area have been considered, all of them characterized by a predominant biomass type (animal manure). These parcels also present other relevant characteristics, such as accessibility.

The values of the variables involved in the problem are obtained from databases or Geographic Information Systems (GIS). These are the following:

- S_i : Area of parcel i (km²),
- U_i : Usability coefficient of parcel i . It is applied to only take the usable surface into account,
- D_i : Net density of dry biomass yield from parcel i (ton/km².yr),
- LHV_i : Lower heat value of biomass in parcel i (MW h/ton),
- L_p : Length of the electric line that connects the power plant to the grid (km),
- $Dis(p; i)$: Distance between parcel i and the power plant, which is located in parcel p (km),
- C^{cu} : Biomass collection unit cost in parcel i (\$/ton).

Therefore, assuming the total mean efficiency of the gas turbine η , the electricity produced, E_g (MWh/yr), equals to:

$$E_g = \eta \cdot \sum_{i=1}^k S_i \cdot U_i \cdot D_i \cdot LHV_i \quad (1)$$

Assuming a plant operating time of T (h/yr), the installed power, P_e (MW), is:

$$P_e = E_g / T \quad (2)$$

B. Objective Fitness Function

The objective fitness function takes costs and benefits into account. Particularly, initial investment and collection, transportation, maintenance and operation (M&O) costs are intended, against to benefits from the sale of electrical energy. Thus, the profitability index is selected as the objective function. In this section some interesting parameters to evaluate the profitability index of the project are reviewed. The initial investment, the present value of cash inflows (benefits) and cash outflows (costs) and the net present value are studied and adapted to the particularities of this work.

The initial investment (INV) consisting of design, construction and equipment of the biomass power plant is expressed as:

$$INV = INV_f + I_s \cdot P_e + C_L \cdot L_p \quad (3)$$

where INV_f is the fixed investment (\$), I_s is the specific investment (\$/mw) and C_L is the electric line cost (\$/km). The present value of cash inflows (PV_{in}) is gained from the sold electric energy during the useful lifetime, V_u . It can be written as:

$$PV_{in} = P_g \cdot E_g \cdot \frac{K_g \cdot (1 - K_g^{V_u})}{1 - K_g} \quad (4)$$

where P_g is the selling price of electric energy injected to the network (\$/MWh), E_g is the sold and produced electric energy (MWh/yr), r_g is being the annual increase rate of the sold energy price, d is the nominal discount rate and K_g is the constant and expressed as follows:

$$K_g = \frac{1 + r_g}{1 + d} \quad (5)$$

The present value of cash outflows (PV_{out}) is the sum of the following costs during the useful lifetime of the plant: Annual collection cost, C_c , annual transport cost, C_t , and annual M&O costs, C_{mo} . The annual cost of biomass collection is:

$$C_c = \sum_{i=1}^k (C_{cu_i} \cdot U_i \cdot S_i \cdot D_i) \quad (6)$$

The annual cost of biomass transport is:

$$C_t = \sum_{i=1}^k (C_{tu_i} \cdot U_i \cdot S_i \cdot D_i \cdot dist(p, i)) \quad (7)$$

The annual M&O cost is:

$$C_{mo} = C_{mof} + m \cdot E_g \quad (8)$$

Finally, the present value of cash outflow is:

$$PV_{out} = C_c \cdot \frac{K_c \cdot (1 - K_c^{V_u})}{1 - K_c} + C_t \cdot \frac{K_t \cdot (1 - K_t^{V_u})}{1 - K_t} + C_{mo} \cdot \frac{K_{mo} \cdot (1 - K_{mo}^{V_u})}{1 - K_{mo}} \quad (9)$$

where

$$K_c = \frac{1 + r_c}{1 + d}, \quad K_t = \frac{1 + r_t}{1 + d}, \quad K_{mo} = \frac{1 + r_{mo}}{1 + d} \quad (10)$$

The net present value (*NPV*) of an investment is defined as:

$$NPV = PV - INV \quad (11)$$

$PV = PV_{in} - PV_{out}$ is the present value. An investment is profitable when $NPV > 0$. The Profitability Index (*PI*) is chosen in this work as objective fitness function. It is defined as follows:

$$PI = \frac{NPV}{INV} = \frac{PV}{INV} - 1 \quad (12)$$

We can also say that an investment is profitable when $PI > 0$.

III. META-HEURISTICS

A. Binary Particle Swarm Optimization

The common version of the particle swarm optimization proposed via Kennedy and Eberhart, operates in a continuous search space. In order to solve optimization problems in discontinues and discrete search spaces, several binary discrete PSO algorithms have been introduced. In a discrete binary search space the position of a particle is depicted by an *N*-length bit string and the movement of the particle consists of flipping some of these bits.

In this work, we have presented an improved version of the binary PSO algorithm proposed in [14, 15], which incorporates an inertia weight factor, like the classical continuous approach. Now, particle position (x_i) and particle velocity (v_i) are *N*-length binary vectors. The algorithm uses the Hamming distance, and the logical AND ('-'), OR ('+') and XOR ('⊕') operators. Particle position is updated by using the XOR operator instead of the sum-operator, as in [16, 17].

$$x_{ij}^t = x_{ij}^{t-1} \oplus v_{ij}^{t-1}, \quad i = 1, \dots, p, \quad j = 1, \dots, p \quad (13)$$

where *t* represents the number of variables of the function to be optimized and *p* the number of particles in the swarm. In this algorithm, the velocity vector can be interpreted as a change vector. Thus, if $v_{ij}^t = "1"$, then $x_{ij}^t = \bar{x}_{ij}^{t-1}$ being the logical negation of x_{ij}^{t-1} . However, if $v_{ij}^t = "0"$, then $x_{ij}^t = x_{ij}^{t-1}$ (no change happens). The velocity vector (change vector) is updated by applying the following equation [17, 18]:

$$v_{ij}^t = \bar{\omega}_{ij} + \omega_{ij} \cdot (C1_{ij} \cdot (pbest \oplus x_{ij}^{t-1}) + C2_{ij} \cdot (gbest^{t-1} \oplus x_{ij}^{t-1})) \quad (14)$$

where, $C1_i = [C1_{i,1}, \dots, C1_{i,n}]$ and $C2_i = [C2_{i,1}, \dots, C2_{i,n}]$ are random *N*-length binary strings, whose components have the same probability.

- $pbest_i^{t-1} = [pbest_{i,1}^{t-1}, \dots, pbest_{i,n}^{t-1}]$, $gbest_i^{t-1} = [gbest_1^{t-1}, \dots, gbest_n^{t-1}]$ are also *N*-length binary strings.
- $\omega_i = [\omega_{i,1}, \dots, \omega_{i,n}]$ is the inertial vector of the *i*th particle. It is a random *N*-length binary vector, whose components are '0' with probability P_ω .
- $\bar{\omega}_i = [\bar{\omega}_{i,1}, \dots, \bar{\omega}_{i,n}]$ is the one's complement of inertial vector ω_i .

The inertial probability, P_ω is a very important parameter in BPSO. As just mentioned, the bits in ω_i are '0' with probability P_ω . Inertial probability decreases with

the number of iterations, in such a way that at the initial iterations (high P_x values) the algorithm explores the search space and at the last iterations (low P_x values) the algorithm exploits the search space. It must be noted that if $x_{i,j} = '0'$, then $v_{i,j} = '1'$, and so position of the *i*th particle is changed. However, if $x_{i,j} = '1'$, the movement of the *i*th particle at the *t*th iteration is conducted by $pbest_{i,t-1}$ and $gbest_{i,t-1}$ solutions, with a partially stochastic behavior due to the random learning vectors $C1_i$ and $C2_i$. The idea is to allow particle swarm to perform a random exploration over the space search at the initial iterations. Later, when the swarm has acquired enough knowledge about the problem, the movement of each particle is mainly conducted by $pbest$ and $gbest$ solutions [19-22].

B. Genetic Algorithm

The genetic algorithm is a search heuristic that mimics the process of natural evolution. Physics, Biology, Economy or Sociology often have to deal with the classical problem of optimization. Purely analytical methods widely proved their efficiency. They nevertheless suffer from a insurmountable weakness: Reality rarely obeys to those wonderful differentiable functions your professors used to show you. They are general purpose search algorithms that use principles inspired by natural genetics to evolve solutions to problems.

A GA starts off with a population of randomly generated chromosomes, and advances toward better chromosomes by applying genetic operators. During successive iterations, called generations, chromosomes in the population are rated for their adaptation as solutions. On the basis of these evaluations, a new population of chromosomes is formed using a selection mechanism and specific genetic operators, such as crossover and mutation. An evaluation or fitness function must be devised for each problem to be solved.

Given a particular chromosome (a possible solution), the fitness function returns a single numerical value, which is supposed to be proportional to the utility or adaptation of the solution represented by that chromosome [23]. Although there are many possible variants GA, the underlying mechanism operates on a population of chromosomes or individual, and consists of three operations:

- Evaluation of individual fitness. For each problem to be solved, a suitable fitness function is required.
- Formation of a gene pool through selection mechanisms. Here, the so-called elitist strategy has been used in order to include into the gene pool the best found solutions.
- Recombination through crossover and mutation operators. In this work, single point crossover performed, and an exponentially decreasing function is used for the mutation probability.

GA is especially well-fitted to difficult environments where the space is usually large, discontinuous, complex and poorly understood. It is generally accepted that application of GA must take into account the following components:

- A genetic representation of solutions to the problem.
- A way to create an initial population of solutions.
- An evaluation function, which gives the fitness of each chromosome.
- Genetic operators, which modify the genetic composition of offspring during reproduction.
- Values for the parameters of the GA (population size, probabilities of applying genetic operators, etc.).

IV. EXPERIMENTAL RESULTS

The region under study is consisting of 72 parcels with different surfaces. Each parcel contains animal manures residues that can be used as a useful biomass feedstock. All parcels are connected to overhead electrical network so that no electrical line cost is needed to connect the plant to the grid.

The theoretical biomass potential, which is defined from the net density of dry biomass that can be obtained at any parcel, D_i ($t/(km^2 \cdot yr)$), and provides a measure of the primary biomass resource and also the available biomass potential. It has been created taking the following parameters into account: D_i ($t/(km^2 \cdot yr)$), U_i , S_i (km^2) and LHV_i (MWh/t). Multiplying the four variables for all parcels that comprise the entire region, it results

the available biomass potential, expressed in (MWh/yr). Simulation results for Genetic algorithm consisting of optimal location, supply area, installed power and profitability index is compared with BPSO algorithm.

As is shown in Figure 1, the search space consists of 72 individual parcels. To start simulation, two technical constraints are applied. The first simulation will start with the following technical constraints:

1. The electric power generated by the plant is limited to 2 MW.
2. The plant must be supplied via optimized parcels.

In Iran electric energy price for a plant $P_e \leq 2$ MW is 1.3 \$/KWh. Since the plant is supplied via discreet biomass centers, supply area is consisting of several parcels inside an optimum area. The optimum location and supply area of the best found profitability index for GA and BPSO for $P_e = 2$ MW is shown in Figures 2 and 3, respectively. The Average profitability index evolution for GA and BPSO is shown in Figure 4.

Figure 4 shows that GA is rapidly converged while BPSO has higher profitability index than GA. The optimum location is the same for both algorithms. The supply centers inside the optimum area are 47 for GA and 52 for BPSO.

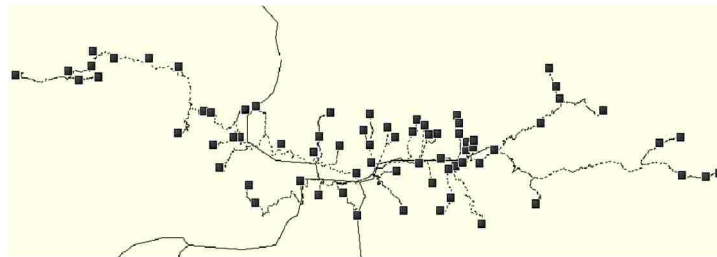


Figure 1. The geographical position of parcels in the region under study

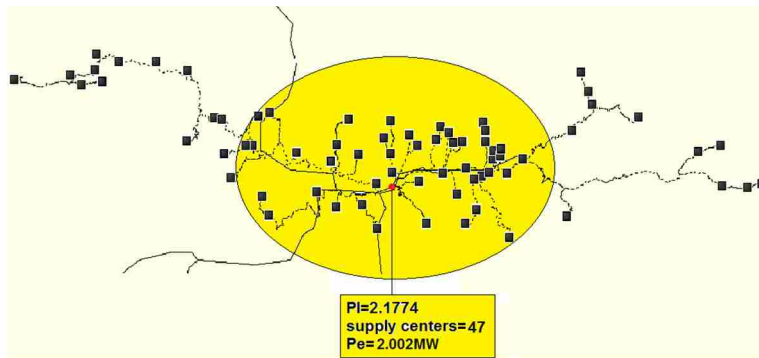


Figure 2. Optimal location and supply area of biomass power plant for Genetic algorithm ($P_e = 2$ MW)

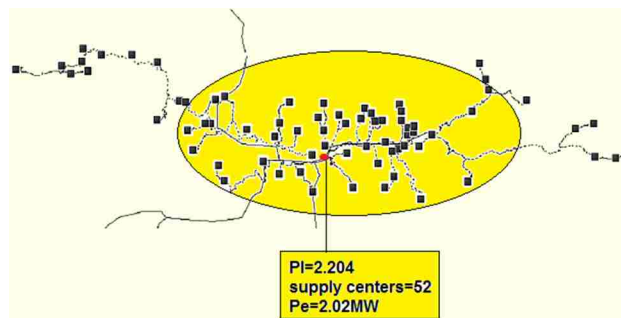


Figure 3. Optimal location and supply area of biomass power plant for Binary particle swarm optimization ($P_e = 2$ MW)

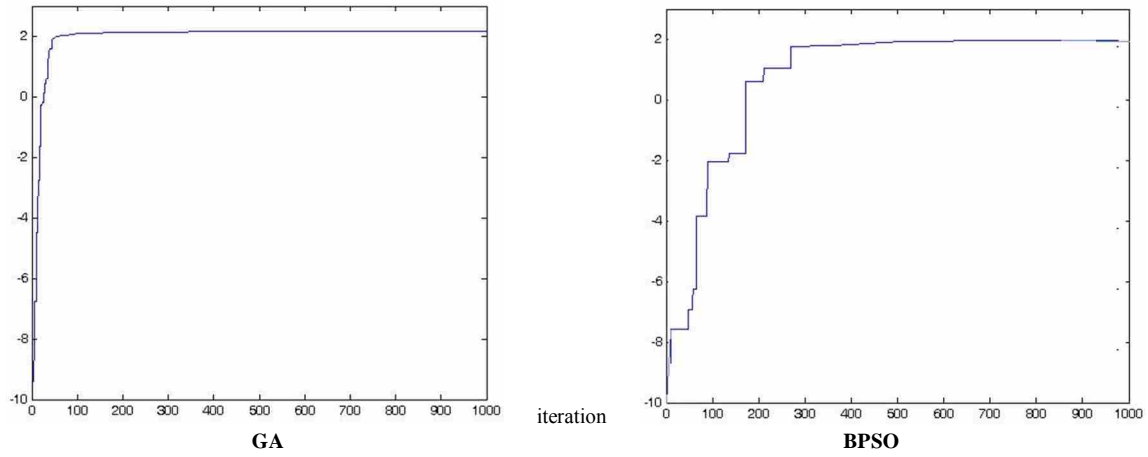


Figure 4. Average profitability index versus iteration for GA and BPSO ($P_e = 2$ MW)

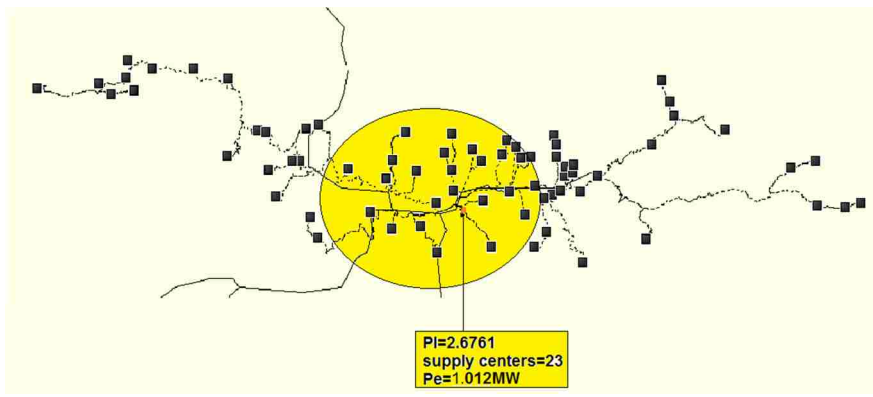


Figure 5. Optimal location and supply area of biomass power plant for GA and BPSO ($P_e = 1$ MW)

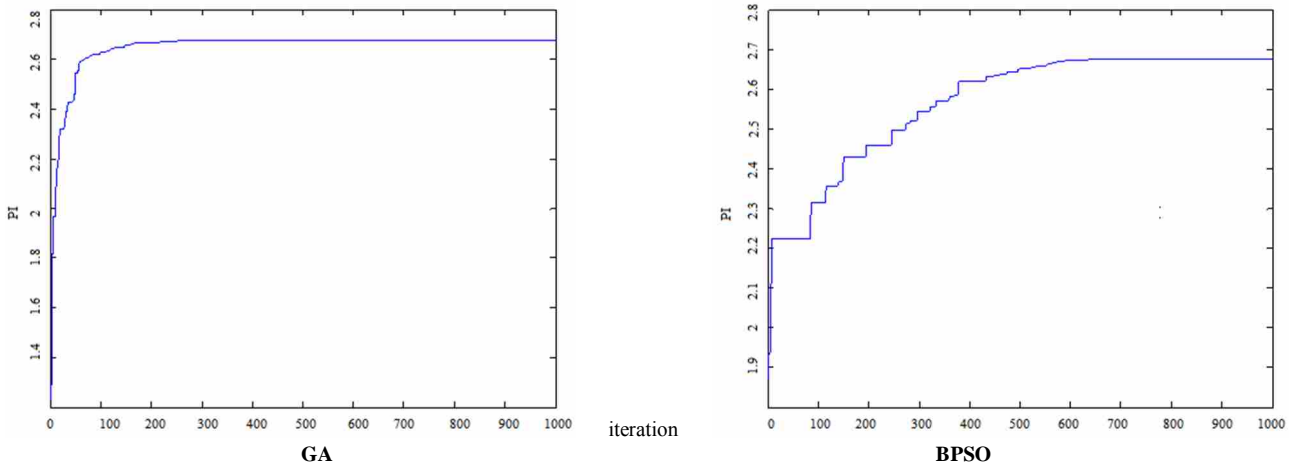


Figure 6. Average profitability index versus iteration for GA and BPSO ($P_e = 1$ MW)

Table 1. GA versus BPSO simulation results

Algorithm	P_e (MW)	PI	Location Coordinate	Supply Centers
GA	2	2.177	$L_x = 478962$ $L_y = 4003802$	47
BPSO	2	2.204	$L_x = 478962$ $L_y = 4003802$	52
GA and BPSO	1	2.6761	$L_x = 481499$ $L_y = 4002736$	23

The second simulation will start with the following technical constraints:

1. The electric power generated by the plant is limited to 1 MW.
2. The plant must be supplied via optimized parcels.

The optimal location and supply area of the best found profitability index for GA and BPSO for $P_e = 1$ MW are the same for both algorithms and are shown in Figure 5. Average profitability index evolution for GA and BPSO is shown in Figure 6. The second simulation ($P_e = 1$ MW) has the same results for the both algorithms. The only difference here is that the GA is more rapidly converged and has lower simulation time than BPSO. The profitability index in this case is higher than first simulation. The comparison of simulation results for $P_e = 1$ MW and $P_e = 2$ MW are shown in Table 1.

V. CONCLUSIONS

The aim of this paper is to find optimal location, size and supply area of a typical biomass fueled power plant in a typical region in Iran. The region under study is approximately 1400 km² and is consisting of 72 parcels with different surfaces S_i . Each parcel is covered with tame animal manure that can be converted into electrical energy. There are several options to convert biomass into electrical energy. Gasification, pyrolysis and combustion are the most popular of them.

All of our experiments show that the optimal plant size according to profitability index is 1.012 MW ($PI = 2.6761$). The best locations corresponds to coordinate $X = 481499$ and $Y = 4002736$ (Figure 6). The simulation results for 2MW case show that the profitability index in this case is lower than 1 MW. The plant won't be profitable if $P_e \leq 0.4$ MW. The profitability versus installed power characteristics is shown in Figure 7. As is shown in this figure, maximum profitability index is achieved in $P_e = 1$ MW. Here, GA and BPSO are the meta-heuristics techniques applied to optimization problem. As experiments show, due to discreet search space, GA is rapidly converged and has lower simulation time than BPSO (Figures 5 and 7).

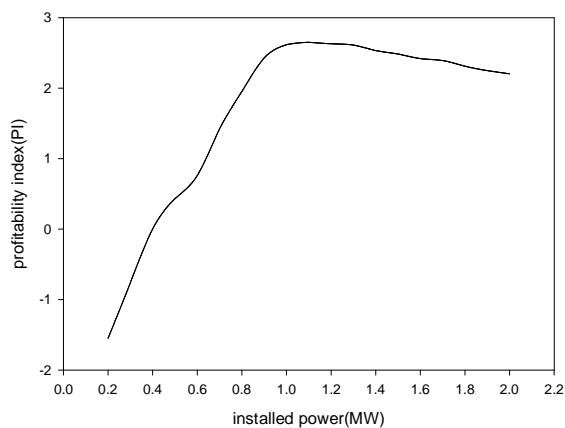


Figure 7. Profitability versus installed power

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BIOGRAPHIES



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