FACTA UNIVERSITATIS
Series: **Working and Living Environmental Protection** Vol. 13, N° 3, 2016, pp. 165 - 176
DOI: 10.22190/FUWLEP1603165M

PARTICLE SWARM OPTIMIZATION OF A HEAT PUMP PHOTOVOLTAIC ENERGY SYSTEM

UDC 621.577:620.9

Marko Mančić[1], Emina Petrović[1], Vlastimir Nikolić[1], Milena Jovanović[2]

[1]Faculty of Mechanical Engineering, University of Niš, Serbia
[2]Faculty of Occupational Safety in Niš, University of Niš, Serbia

Abstract. *This paper presents cost optimization of a heat pump photovoltaic-thermal energy supply system designed to meet heating, cooling and electricity loads of an energy efficient detached family house. Particle Swarm Optimization algorithm (PSO) was applied and discussed in the paper, where geometrical and mathematical algorithm explanation was given. Convergence analysis is done via eigenvaluess in order to avoid cyclical and quasi-cyclic or divergent behavior of the presented. The performance of described optimization method was numerically tested for optimization of an efficient house model with decentralized energy production and compared to the results obtained by generic algorithm optimization. The model assumes bivalent heat pump operation with a gas boiler, and application of roof integrated and façade integrated photovoltaic thermal collectors. Nominal heat pump power and photovoltaic array surface area are set as optimization variables, optimized according to the value of net present value fitness function. The optimal solution showed that 35% of the design load should be covered by the heat pump, and total available south roof area and east façade area should include photovoltaic integration.*

Key words: *Heat pump, Photovoltaic, energy system optimization, Particle swarm optimization, convergence*

1. INTRODUCTION

In recent years, with the "liberalized" electricity market in Serbia and rising energy prices, decentralized electricity production (DE) and renewable power generation are gaining interests [1]. Models and approaches for decentralized energy planning can differ worldwide, since development strategies are area-based, shaped to meet energy needs and develop renewable energy potentials with least cost to the economy and environment [2].

Received January 13, 2017 / Accepted January 16, 2017
Corresponding author: Marko Mančić
University of Niš, Faculty of Mechanical Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia
E-mail: markomancic@yahoo.com

A model of an energy efficient house model with DE production was presented in [3], where a water-water heat pump (HP) was used with both roof and wall façade integrated photovoltaic water cooled solar collectors (PV). The proposed model adopts simple geometry, and shows the limits of meeting heating, cooling and electricity demands, including the consumption of home appliances, by the analyzed hybrid heat pump photo voltaic (HP-PV) system. Although the ratio of energy demands met by on-site HP-PV system were determined, cost analysis was omitted from the study.

The aim of this paper is twofold: to perform cost optimization of the dwelling model presented in [3], and to test the convergence and performance of the Particle Swarm Optimization algorithm (PSO). Optimization of such energy systems is challenging, because they are highly non-linear, multivariable and involve non-convex functions and the conventional equation-solving and local optimization gradient-based algorithms are not well suited for finding global solutions, due to presence of trivial solutions, local optima, or divergences that occur after a significant amount of iterations [4]. Various stochastic optimization methods for solving such problems have been reported in the literature such as genetic algorithm (GA), Particle Swarm Optimization (PSO) and simulated annealing (SA) [5]. In [4], a hybrid particle swarm optimization algorithm which includes two alternative gradient-based methods for handling constraints has been discussed to solve process synthesis and design problems which involve continuous and binary variables and equality and inequality constraints. Bornaticoet all [6] investigated a solar comb system for a mid-sized single-family house in Zurich, Switzerland. They investigated optimization problem of finding the optimal size of the main components for a solar thermal system. The Particle Swarm Optimization algorithm was used for solving this problem, and a detailed analysis has been carried out on the performance of proposed algorithm.

In this paper, results of annual TRNSYS performance simulation of the HP-PV system, coupled to the model of an energy efficient household [3], are used to determine mean specific performance properties of the system. The mean specific annual values of performance of the HP-PV system are used for calculating cash flows of the HP-PV system operating in bivalent regime with a gas boiler. The optimization variables are nominal HP power P_{hp}, south roof integrated photovoltaic area A_{sr}, south façade integrated photovoltaic area A_{sw}, and east façade photovoltaic integrated area.

2. Particle Swarm Optimization

Particle swarm optimization is a population based stochastic search algorithm that is the most recent developments in the category combinatorial meta-heuristic optimization. It was first introduced by Kennedy and Eberhart in 1995 [7]. It was inspired by the social behavior exhibited by flocks of birds flying across an area looking for food. PSO algorithms have been developed to solve constrained problems, multi-objective optimization problems and problems with dynamically changing landscapes. PSO algorithm is a derivative-free algorithm.

The problem is to find minimum or maximum for a given function $f : S \rightarrow R$, where $S \subseteq R^D$, i.e., to find a point x^* such that

$$\min(\max)_{x \in S} f(\boldsymbol{x}) = f(\boldsymbol{x}^*) \tag{1}$$

In the basic particle swarm optimization, particle swarm consists of *n*particles, and the coordinates of each particle represent a possible solution [2]. At each iteration, each particle moves towards an optimum solution, through its present velocity, personal best solution obtained by themselves so far and global best solution obtained by all particles.

The position of *i*th particle of the swarm in m^{th} iteration $x_i^{(m)}$ can be represented by a *D*-dimensional vector

$$\boldsymbol{x}_i^{(m)} = (\boldsymbol{x}_{i1}^{(m)}, \boldsymbol{x}_{i2}^{(m)}, \ldots, \boldsymbol{x}_{iD}^{(m)}) \quad (i = 1, 2, \ldots, n) \tag{2}$$

The best position previously visited by the *i*th particle is denoted as

$$\boldsymbol{b}_i^{(m)} \in \{\boldsymbol{x}_i^{(1)}, \boldsymbol{x}_i^{(2)}, \ldots, \boldsymbol{x}_i^{(m)}\}, \quad f(\boldsymbol{b}_i^{(m)}) = \min(\max)\{f(\boldsymbol{x}_i^{(1)}), f(\boldsymbol{x}_i^{(2)}), \ldots, f(\boldsymbol{x}_i^{(m)})\} \tag{3}$$

Or, recursively,

$$f(\boldsymbol{b}_i^{(m)}) = \min(\max)\{f(\boldsymbol{b}_i^{(m-1)}), f(\boldsymbol{x}_i^{(m)})\}, \tag{4}$$

and

$$\boldsymbol{b}_i^{(m)} = \begin{cases} \boldsymbol{b}_i^{(m-1)}, \ if \quad f(\boldsymbol{b}_i^{(m-1)}) \le (\ge) f(\boldsymbol{x}_i^{(m)}), \\ \boldsymbol{x}_i^{(m)}, \ if \quad f(\boldsymbol{b}_i^{(m-1)}) > (<) f(\boldsymbol{x}_i^{(m)}). \end{cases} \tag{5}$$

If the topology is defined such that all particles are assumed to be neighbors and g is the index of the particle visited the best position in the swarm, then $\boldsymbol{p}_g$ becomes the best solution found so far

$$\begin{gathered} \boldsymbol{p}_g^{(m)} \in \{\boldsymbol{b}_1^{(m)}, \boldsymbol{b}_2^{(m)}, \ldots, \boldsymbol{b}_n^{(m)}\}, \\ f(\boldsymbol{p}_g^{(m)}) = \min(\max)\{f(\boldsymbol{b}_1^{(m)}), f(\boldsymbol{b}_2^{(m)}), \ldots., f(\boldsymbol{b}_n^{(m)})\}. \end{gathered} \tag{6}$$

The velocity (position change per generation) of the particle $\boldsymbol{x}_i$ can be represented by another *D*-dimensional vector

$$\boldsymbol{v}_i^{(m)} = (\boldsymbol{v}_{i1}^{(m)}, \boldsymbol{v}_{i2}^{(m)}, \ldots, \boldsymbol{v}_{iD}^{(m)}) \qquad (i = 1, 2, \ldots, n) \tag{7}$$

The velocity of a particle and its new position will be determined according to the following two equations:

$$\begin{gathered} \boldsymbol{v}_i^{(m+1)} = w\boldsymbol{v}_i^{(m)} + c_1 r_{1i}(\boldsymbol{b}_i^{(m)} - \boldsymbol{x}_i^{(m)}) + c_2 r_{2i}(\boldsymbol{p}_g^{(m)} - \boldsymbol{x}_i^{(m)}) \\ \boldsymbol{x}_i^{(m+1)} = \boldsymbol{x}_i^{(m)} + \boldsymbol{v}_i^{(m+1)} \end{gathered} \tag{8}$$

Where r_1 and r_2 are random variables in the range [0,1]; c_1 and c_2 are acceleration coefficients regulating the relative velocity toward global and local best.

The particle velocity is the step size of the swarm. All particles proceed by adjusting the velocity that each particle moves. There are two characteristics: exploration and exploitation. Exploration is the ability to explore different area of the search space for locating a good optimum, while exploitation is the ability to concentrate the search around a searching area for refining a hopeful solution. The inertia weight, denoted by w, is considered to replace by adjusting the influence of the previous velocities in the process.

The stochastic influence of the cognitive and social components is maintained in the acceleration coefficients c_1 and $c_2$and the random values r_1 and r_2.

Wrong initialization of c_1 and c_2 may result in divergent or cyclic behavior of algorithm. Denote by

$$\varphi_1 = c_1 \cdot r_1, \quad \varphi_2 = c_2 \cdot r_2, \quad \varphi = \varphi_1 + \varphi_2, \ (r_1, r_2 \in \text{RandomReal}[0,1])$$

3. Convergence Analysis via Eigenvalues

The present analyses of the particle swarm done by Clerc [7] lead to a generalized model of the algorithm, containing a set of coefficients to control the system's convergence tendencies. Simplification of the system was done by stripping the algorithm down to the simplest form.

The initial investigation was simplified by looking at the behavior of a particle whose velocity is adjusted by only one term

$$\boldsymbol{v}_i^{(m+1)} = \boldsymbol{v}_i^{(m)} + \varphi_1(\boldsymbol{b}_i^{(m)} - \boldsymbol{x}_i^{(m)}) + \varphi_2(\boldsymbol{p}_g^{(m)} - \boldsymbol{x}_i^{(m)}) \ (i = 1,\ldots,D; m = 0,1,\ldots) \tag{10}$$

i.e.,

$$\boldsymbol{v}_i^{(m+1)} = \boldsymbol{v}_i^{(m)} + \varphi\left(\frac{\varphi_1}{\varphi}(\boldsymbol{b}_i^{(m)} - \boldsymbol{x}_i^{(m)}) + \frac{\varphi_2}{\varphi}(\boldsymbol{p}_g^{(m)} - \boldsymbol{x}_i^{(m)})\right). \tag{11}$$

The formula can be shortened redefining as follows:

$$\boldsymbol{v}_i^{(m+1)} = \boldsymbol{v}_i^{(m)} + \varphi\left(\frac{\varphi_1 \boldsymbol{b}_i^{(m)} + \varphi_2 \boldsymbol{p}_g^{(m)}}{\varphi} - \boldsymbol{x}_i^{(m)}\right). \tag{12}$$

Denoting by

$$\mathbf{P}_i^{(m)} = \frac{\varphi_1 \boldsymbol{b}_i^{(m)} + \varphi_2 \boldsymbol{p}_g^{(m)}}{\varphi}, \tag{13}$$

We can write

$$\boldsymbol{v}_i^{(m+1)} = \boldsymbol{v}_i^{(m)} + \varphi(\mathbf{P}_i^{(m)} - \boldsymbol{x}_i^{(m)}). \tag{14}$$

The system can be simplified even further by considering a one-dimensional problem space and again further by reducing the population to one particle.

When the particle swarm operates on an optimization problem, the value of $\mathbf{P}i^{(m)}$ and φ are constantly updated, as the system evolves toward an optimum. In order to further simplify the system and make it understandable, Clerc set them to two constant values in the following analysis:

$$\mathbf{P}_i^{(m)} \equiv \mathbf{P} \qquad (\forall i, m), \qquad \varphi(c_1, r_1, c_2, r_2) = \varphi = const.$$

Since φ is defined as a random number between zero and a constant upper limit, he removed the stochastic component initially and reintroduced it in later sections. The effect of φ on the system is very important and much of the present paper is involved in analyzing its effect on the trajectory of a particle.

According to this it is possible to consider the following reduced system

$$v_i^{(m+1)} = v_i^{(m)} + \varphi(P - x_i^{(m)}),$$
$$x_i^{(m+1)} = x_i^{(m)} + v_i^{(m+1)} \tag{15}$$

Denote by $y_i^{(m)} = P - x_i^{(m)}$. Hence $v_i^{(m+1)} = v_i^{(m)} + \varphi y_i^{(m)}$. Since $y_i^{(m)} = P - x_i^{(m)} x_i^{(m)} = P - y_i^{(m)}$, we can write $v_i^{(m+1)} = v_i^{(m)} + \varphi y_i^{(m)}$. In the form $P - y_i^{(m+1)} = P - y_i^{(m)} +$ $[v_i^{(m)} + \varphi y_i^{(m)}]$, i.e. $y_i^{(m+1)} = -v_i^{(m)} + (1-\varphi) y_i^{(m)}$.

Omitting the index i , the basic simplified dynamic system is defined by:

$$v^{(m+1)} = v^{(m)} + \varphi y^{(m)},\ \ y^{(m+1)} = -v^{(m)} + (1-\varphi) y^{(m)} \tag{16}$$

The trajectory of the points $(v^{(m)}, y^{(m)})$ is a conic $v^2 + \varphi v y + \varphi y^2 = C,$ where C depends only of starting point. Let $C = (v^{(1)})^2 + \varphi v^{(1)} y^{(1)} + \varphi (y^{(1)})^2$. Suppose that it is valid for arbitrary m. Then $(v^{(m+1)})^2 + \varphi v^{(m+1)} y^{(m+1)} + \varphi (y^{(m+1)})^2 =$ $(v^{(m)} + \varphi y^{(m)})^2 +$ $\varphi (v^{(m)} + \varphi y^{(m)})(-v^{(m)} + (1-\varphi) y^{(m)}) + (-v^{(m)} + (1-\varphi) y^{(m)})^2$
wherefrom:

$$(v^{(m+1)})^2 + \varphi v^{(m+1)} y^{(m+1)} + \varphi (y^{(m+1)})^2 = (v^{(m)})^2 + \varphi v^{(m)} y^{(m)} + \varphi (y^{(m)})^2 .$$

4. Optimization of the Hybrid HP-PV System for Energy Demands of the House Model

An energy efficient house model with DE production presented in [3] where performance of a water-water heat pump was used with both roof and façade integrated photovoltaic water cooled solar collectors (PV) annual performance was simulated using TRNSYS software, was used as basis for optimization in this paper. Annual system performance showed that the PV system could not meet the entire electricity demand of the household, which included the simulated electricity consumption of the electric appliances. The model assumes that the entire south wall façade area and east wall façade area were covered by PV panels, in addition to the south roof PV panels. Adequate technical approach implies economic PV production for maximum electricity generation by mounting the panels only on the south roof surface of the house [8]. However, the optimal surface area of PV was not determined for each of the facades nor the roof, which is performed in this paper.

The analysis in this paper adopts specific mean annual performance data obtained from the annual simulated performance results [3]. The economic analysis, used to define optimization criteria, envisages identical system performance during the economic project lifetime: (1) total annual heating and cooling loads are equal to the simulation total annual heating and cooling loads, (2) coefficient of performance (COP) of the HP depends on the heat source and heat sink temperatures and not on HP capacity, hence average simulation annual HP COP can be considered the same for a range of HPs with different heating and cooling nominal capacities, (3) average annual electricity production of a unit of PV surface are the same for the PV integrated with the same dwelling construction element, hence integrated façade and roof surface area of PV can be scaled for optimization purposes.

Based on the heat pump market in Serbia, specific initial investment of large scale heat pump I_{hp}[€]can be approximated as a function of installed heat pump power $P_{hp}[kW]$:

$$I_{hp} = (-0.116 P_{hp} + 218.325) \cdot P_{hp} \tag{22}$$

The feed-in tariff used in the estimation for rooftop mounted solar collectors is a linear function of total installed (peak) PV array power [31].Investment cost of a PV system I_{PV} is estimated based on specific cost of 1.2 €/kW$_e$ per kW of installed PV system power P_{PV} which accounts for and installation costs as well as module and AC/DC equipment purchase cost. The nominal power of the PV system is proportional to the power of a unit of surface area of the PV system, with a factor of 0.123 kW/m^2.

$$I_{PV} = 1.23 \cdot P_{PV}$$

Total initial capital investment can be calculated as:

$$I_O = I_{PV} + I_{HP}$$

Net annual balance is defined as the difference between the profit obtained by export of electricity obtained by using the PV system, cost of electricity needed to run the heat pump [9]. In contrast to the household balance performed in [3], electricity load of the household appliances was omitted from the annual balance. The annual cash flow balance for the first year includes the initial capital investment cost, a function of Installed PV system nominal power rating and nominal HP capacity. Annual energy costs and profits are determined with respect to fuel and electricity cost rates. An average electricity cost rate of 0.065 €/kWh, is adopted, and an average natural gas cost rate of 0.047 €/kWh is adopted for the initial analysis. A constant annual cost change rate *a* of 3% is adopted for electricity and fuel costs, as well as for profits achieved by electricity export. A feed in tariff 20.26 c€/kWh [9]. Annual energy demands heat demands of the household E_{hp_y} are based on simulated annual heating and cooling demands [3].

Annual PV system production can be estimated as:

$$E_{y\_pv\_y} = C_{sr} \cdot A_{sr} + C_{sw} \cdot A_{sw} + C_{ew} \cdot c$$

Where C_{sr} =146.02 kWh/m^2, C_{sw}=120.17 kWh/m^2 and C_{ew} = 51.14 kWh/m^2, represent specific simulated PV electricity production per unity surface area of the PV system for the south roof PV, south façade PV, and east façade PV, respectfully. The A_{sr}, A_{sw} and A_{sw} represent installed surface area of the PV system on the south roof, south façade and east façade respectfully.

It is assumed that the HP operates in a bivalent regime with a gas boiler, where the boiler is engaged for peak loads when, larger than the HP maximum rated heating capacity, and that a typical air conditioning unit (i.e. air to air heat pump) could be engaged for cooling loads larger than the maximum heat pump capacity.

Average monthly load values are used to evaluate the performance of the bivalent system:

$$B_{thp} = \sum_{1}^{12} \left(\frac{Q_{(mheatHP,i)}}{COP} \cdot m_i C_e + \frac{Q_{(mcoolhp,i)}}{COP} \cdot m_i C_e + \frac{Q_{(mheatB,i)}}{\eta} \cdot m_i C_g + \frac{Q_{(mcoolAc,i)}}{COP_{AC}} m_i C_e \right)$$

Where $Q_{mheatHP,i}$ is the average heating load in the month met by the heat pump, and $Q_{mcoolHP,i}$ is the average cooling load in the month met by the heat pump, COP is the average value of COP of the HP; $Q_{mheatB,i}$ is the heating load met by the gas boiler, η is the average boiler efficiency, $Q_{mcoolAC,i}$ is the cooling load met by the air conditioning unit, with a coefficient of performance of COP_{AC}, the m_i is the number of equipment operating hours during a year. Engagement of the gas boiler in bivalent regime with the HP is determined by:

$$Q_{mcoolAc,i} = \begin{cases} 0,\ for P_{HP} \geq Q_{mcool,i} \\ Q_{mcool,i},\ for P_{HP} \leq Q_{mcool,i} \end{cases}$$

$$Q_{mheatB,i} = \begin{cases} 0,\ for P_{HP} \geq Q_{mheat,i} \\ Q_{mheat,i} - P_{HP},\ for P_{HP} \leq Q_{mheat,i} \end{cases}$$

Where $Q_{mheat,i}$ is the average monthly heating load and $Q_{mcool,i}$ is average monthly cooling load, based on simulation results [7].

Annual base case cost is determined for the scenario of heating load completely met by the gas boiler and cooling load completely met by the air conditioning unit:

$$B_{tb} = \sum_{1}^{12} \left(\frac{Q_{mheat,i}}{\eta} m_i C_g + \frac{Q_{mcool,i}}{COP_{AC}} m_i C_e \right)$$

Annual energy costs B_t are determined by the costs for electricity used to power the heat pump and air conditioning unit, cost of gas burned in the boiler and profit achieved of electricity export.

Profit from electricity export is calculated as:

$$B_{ePV} = E_{y\_pv\_y} \cdot C_{\_fe}$$

Where $C_{\_fe}$ is the fid in tariff for electricity export.

Annual energy costs B_t is determined as cost saving achievable by application of HP PV system compared to the conventional system consisting of a gas boiler and air conditioning unit.

$$B_t = B_{tb} - B_{thp} + B_{ePV}$$

The following parameters were calculated to investigate financial and economic feasibility of the project [10]:

Net annual balance:

$$B = \sum B_t P_e - \Delta C_e \tag{23}$$

Where: B – total annual balance in €; B_t – energy savings for one year (t=1...n); ΔC_e - exploitation cost change.

Net present value NPV:

$$NPV = \sum_{0}^{n} B_t / (1 + d^t) - Io \tag{24}$$

Where I_o is the total initial capital investment of the Heat pump PV system, equal to the sum of PV (I_{pv}) system investment and heat pump investment (Ihp). A discount rate (d) of 5% was assumed, and a fuel price change rate (a) of 3%.

Bounds of parameters which are optimized are: $0<A_{sr}<27.98, 0<A_{sw}<13.38, 0<A_{ew}<13.38, 0<Php<10$, which are determined based on maximum available façade and rooftop area for PV integration.

5. Optimization Results

5.1. Particle Swarm Optimization results

Particle swarm optimization is used to determine the optimal set of parameters of the describe HP-PV system. The maximization of the fitness function by means of the PSO algorithm, each generation consists of 30 particles is shown in Fig.1. Parameters of PSO used for simulation are $c_1=c_2=2.1$ and $w = w_{max} - (w_{max} - w_{min}) \cdot \text{iteration/maxiteration}$, $w_{max}=0.9$, $w_{min}=0.3$. By means of a global best value (gbest) for each generation and by considering the values of residual particles in swarm pbest), it is possible to visually judge the convergence of the algorithm. From the Figure we can see that PSO find optimum solution after 15 iterations.

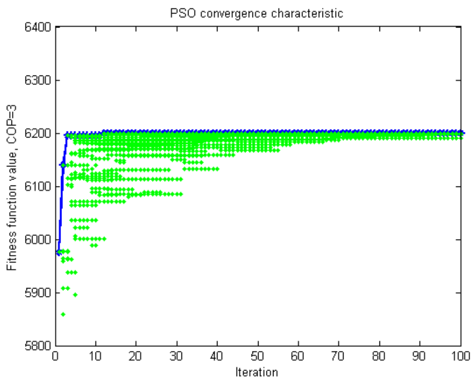


Fig. 5 PSO convergence of fitness function towards 6199.8 €

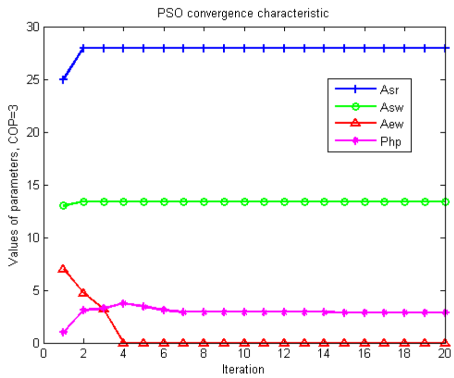
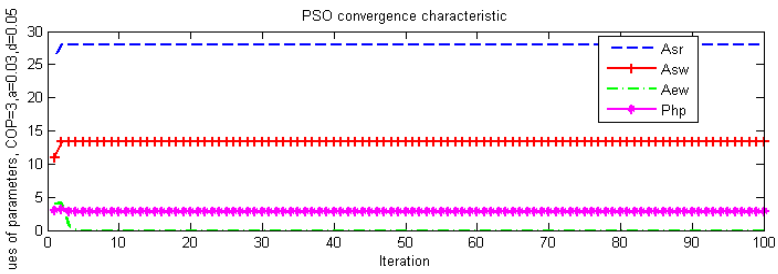
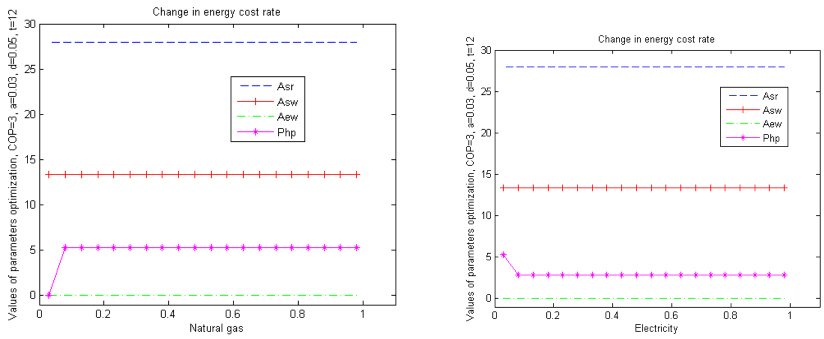


Fig. 6 PSO convergence for all parameters considered in this study

The obtained numerical values of parameters are: A_{sr}=27.9800, A_{sw}=13.3800, A_{ew}=0, P_{hp}=2.8600. The value of fitness function obtained by PSO is:6199.8.





(a) b)

Fig. 7 Sensitivity of the optimal solution to the change of energy costs: a) natural gas, b) electricity

Figure 6 showed that the optimal capacity of heat pump changes for the values of natural gas below 0.05 €/kWh, and does not change with the further change of this cost. Hence, with the present tendency of rising fossil fuel costs, the optimal system configuration remains the same. Figure 7 b) shows that the optimal heat pump capacity drops to 3kW for electricity for the raised electricity cost after 0.1 €/kWh, but remains unchanged with further raise of electricity cost.

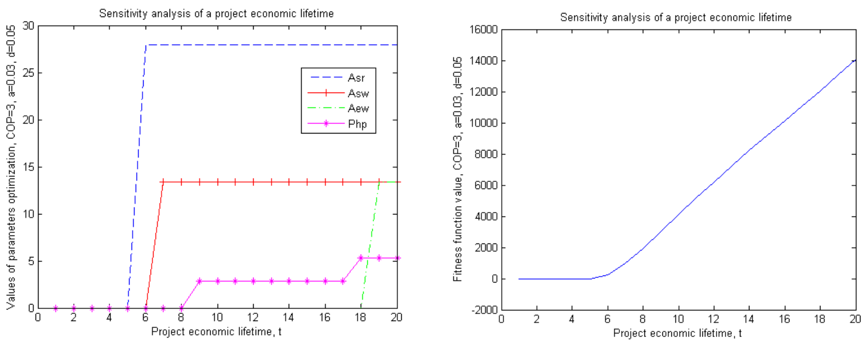


Fig. 8 Sensitivity analysis of the economic project lifetime to the optimal solution

Figure 8 shows that profitability of the HP-PV system installation: South roof collector system shows positive profitability for the entire south roof surface area 5 years after implementation, and the south façade PV system shows profitability 6 years after implementation. Further increase of the economic lifetime does not affect the optimal PV surface area. Application of 3kW heat pump is profitable after 9 years, and 5kW heat pump after 18 years, with the current electricity prices. However, analysis of impact of increased electricity price (fig 7), which can be expected in the future, shows better profitability of the 5kW heat pump. The east façade integrated PV system shows profitability only after year 19. The entire HP-PV system, can be considered profitable in the year 6 after implementation (Fig. 8 b.).

5.2 Genetic optimization

The Genetic Algorithm (GA) stochastic method for solving complex and difficult engineering problems which cannot be solved conventional optimization methods. GA keeps and manipulates a population of solutions and implements a survival of the fittest strategy in their search for better solutions. The fittest individuals of any population tend to reproduce and survive to the next generation thus improving successive generations. In this research a standard GA has been applied and the same set boundaries was used for solving problem of funding the maximum value for the same fitness function. Population of 30 individuals was used.

After 81 generations (Figure 9), the following parameters were calculated: Asr=27.9770, Asw=13.3750, Aew=0.025, Php=2.8760., and the fitness value was 6195.84.

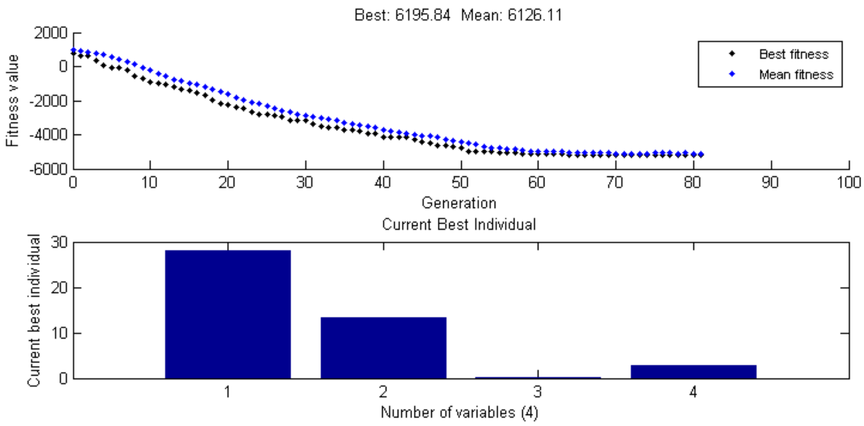


Fig. 9 Change of fitness value during genetic optimization

6. CONCLUSION

The PSO algorithm is able to solve an optimization problem of finding the optimal hybrid energy system sizing. In this paper, it was applied to a hybrid heat pump system operating in bivalent regime with a gas boiler, and optimization of optimal area of façade and rooftop integrated photovoltaics. The optimal capacity for heating of the HP-PV system corresponds to the 35% of the heating load, and meets the complete cooling load. The optimal PV area corresponds to the entire available south roof surface area, and south façade area available for PV integration. Integration of PV to the east façade is not profitable, as the optimization showed the optimal area of 0m^2 for this façade PV system.

PSO is easy to implement and it is does not require gradient information of the objective function. Also it is able to avoid local optima and is very well suited to non-linear problems. The results obtained by PSO algorithm are compared to those obtained with the more common Genetic Algorithm. When the implementation efforts are considered, the PSO is a better algorithm for solving the presented problem, especially since the PSO converges to the optimal solution faster the GA.

Acknowledgement: *This work was supported by grant No III 42006, from the Ministry of Education, Science and Technological Development of the Republic of Serbia.*

REFERENCES

1. Schneider et all. "Mapping the potential for decentralized energyGeneration based on res in Western Balkans,"Thermal Science11, 037 (2007).
2. Hiremath, S. Shikha and N. Ravindranath, "Decentralized energy planning; modeling andapplication—a review, "Renewable and Sustainable Reviews11, 729 (2007).
3. Goran Jovanovic, Dragoljub Zivkovic, Marko Mancic, Vladana Stankovic, Danica Stankovic, Velimir Stefanović and Petar Mitkovic, A model of a Serbian energy efficient house for decentralized electricity production, J. Renewable Sustainable Energy 5, 041810 (2013);
4. Ruben Ruiz-Femenia and Jose A. Caballero, A particle swarm optimization for solving NLP/MINLP process synthesis problems,20th European Symposium on Computer Aided Process Engineering – ESCAPE20.
5. Erdinc, O.; Uzunoglu, M. Optimum design of hybrid renewable energy systems: Overview of different approaches. Renew. Sustain. Energy Rev. 2012, 16, 1412–1425.
6. R. Bornatico, M. Pfeiffer A.Witzig and L. Guzzella ,Particle Swarm Optimization for the Optimal Sizing of a Solar Thermal Building Installation, Proceedings of the "23rd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems" (ECOS 2010), Lausanne, Switzerland, June 14-17, 2010.
7. M. Clerc, J. Kennedy, The particle swarm−explosion, stability, and convergence in a multidimensional complex space. IEEE Trans. on Evolutionary Computation, (2002), (1):58-73.
8. Structure optimization of energy supply systems in tertiary sector buildings. Miguel A. Lozano, Jose´ C. Ramos, Monica Carvalho, Luis M. Serra. 2009, Energy and Buildings, T. 41, str. 1063–1075.
9. Official Gazette of Rebublic Serbia84, 04 (Ministry of Minings and Energy, Government of the Republic of Serbia, Belgrade, 2004)].
10. Vladan Karamarkovic, Maja Matejic, Ljiljana Brdarevic, Mirjana Stamenic, Biljana Ramic, Handbook for preparing energy efficiency projects in municipalities, Belgrade, 2008, Ministry for mining and energy of Republic of Serbia
11. Woodward, M.: Epidemiology: Study Design and Data Analysis. 2nd Ed. Chapman & Hall/CRC; London: pp. 1-849, 2005.
12. Yu, Y., Su, F-C., Callaghan, B.C., Goutman, S.A., Batterman, S.A. and Feldman, E.L.: Environmental Risk Factors and Amyotrophic Lateral Sclerosis (ALS): A Case-Control Study of ALS in Michigan. 2014. PLoS ONE 9(6): e101186. doi:10.1371/journal.pone.0101186
13. Zhang Q.G., Zhang, J., Yu, P. and Shen, H.: Environmental and genetic factors associated with congenital microtia: A case-control study in Jiangsu, China, 2004 to 2007. Plast. Reconstr. Surg., Vol. 124, pp.1157–1164, 2009.

OPTIMIZACIJA SISTEMA TOPLOTNE PUMPE I FOTONAPONSKIH SOLARNIH KOLEKTORA PRIMENOM PSO ALGORITMA

Ovaj rad predstavlja optimizaciju troškova sistema toplotne pumpe i fotonaponskih solarnih kolektora zaduženog da zadovolji potrebe grejanja, hlađenja i električne energije jedne energetski efikasne samostojeće porodične kuće. Optimizaciona metoda rojeva čestica (Particle swarm algorytm - PSO) je primenjen u radu i predstavljena je njegova matematička reprezentacija. Urađena je analiza konvergencije ove metode. Rezultati optimizacije primenom navedenog algoritma su numerički testirani za optimizaciju modela energetski efikasne kuće sa proizvodnjom decentralizovane energije i upoređivani su sa rezultatima dobijenih optimizacijom metodom genetskog algoritma. Model energetskog sistema podrazumeva rad toplotne pumpe u bivalentnom režimu sa gasnim kotlom, i primenom sa fotonaponskih - toplotnih kolektora integrisanih u krov i fasadu objekta. Nominalna snaga toplotne pumpe i niza fotonaponske površine su postavljene kao optimizacione promenljive i optimizovani prema funkciji cilja određenoj neto sadašnjom vrednošću. Optimalno rešenje je pokazalo da 35% dizajniranog opterećenja treba da bude pokriveno toplotnom pumpom, a ukupna dostupna južna površina krova i istočna površina fasade treba da bude pokrivena fotonaponskim kolektorima.

Ključne reči: *toplotna pumpa, fotonaponski kolektori, sistem optimizacije energije, optimizacija roja čestica, konvergencija*