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Genetik Algoritma Kullanılarak Hibrit Yenilenebilir Enerji Kaynaklarının Maliyet Minimizasyonu

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ÖZET: *Bu yazıda güneş panelelleri, rüzgâr jeneratörü ve batarya içeren bir hibrit yenilenebilir enerji sistemi önerilmiştir. Bütün sistemin maliyet fonksiyonları belirlenmiştir. Her yenilenebilir enerji modülü (fotovoltaik, rüzgâr jeneratörü, akü) için güç-maliyet ilişkileri gösterilmiştir. Önerilen yenilenebilir enerji sisteminin toplam maliyetini en aza indirmek için genetik algoritma kullanılır. Genetik algoritma için hesaplamaları basitleştirmek için maliyet katsayısı tanımları yapılmıştır. Geleneksel hesaplama algoritmalarının yanı sıra, hesaplama zamanı ve hesaplama çabasını azaltmak için genetik algoritmanın olasılık yaklaşımı kullanılmıştır. Sonuç olarak; genetik algoritma, yenilenebilir enerji maliyet optimizasyonu problemlerinde hesaplama çabasını azalttığından, geleneksel hesaplama algoritmalarından daha uygun olduğu gösterilmiştir.*
Anahtar Kelimeler: Hibrit yenilenebilir enerji sistemi, yenilenebilir enerji, genetik algoritma, maliyet minimizasyonu, optimizasyon.

Cost Minimization of Hybrid Renewable Energy Systems Using Genetic Algorithm

ABSTRACT: *In this paper, a hybrid renewable energy system is proposed which includes PV, wind generator and batteries. Cost functions of whole system is determined. Power-cost relations for each renewable energy module (PV, wind generator, battery) are inspected. Genetic algorithm is used to minimize the total cost of proposed renewable energy system. For genetic algorithm, cost coefficient definitions are made for simplifying calculations. Beside conventional search algorithms, genetic algorithm's probabilistic approach is used for reducing calculation time and computation effort. In results, it is shown that genetic algorithm is more suitable than conventional search algorithms for reducing computation effort for renewable energy cost optimization problems.*
Keywords: Hybrid renewable energy system, renewable energy, genetic algorithm, cost minimization, optimization, HRES.

INTRODUCTION

Hybrid PV systems are best suited to reduce dependence on fossil fuel by using available solar radiation. Hybrid PV system includes the PV generator, diesel generator and/or battery system. Battery storage increases the flexibility of system control and adds to overall system availability. These energy systems have good prospects and many opportunities in hot climates and are considered as one of the cost effective solutions to meet energy requirements of remote areas (Shaahid and Elhadidy, 2003).

The conventional methodology (empirical, analytical, numerical, hybrid, etc.) for sizing PV systems have been used generally for a location where the required weather data (irradiation, temperature, humidity, clearness index, wind speed, etc.) and the information concerning the site where the PV system will be implement are available. In this case, these methods present a good solution for sizing PV systems, particularly the hybrid method. However, these techniques could not be used for sizing PV systems in remote areas, where the required data are not available. Moreover, the majority of the above methods need long-term meteorological data such as total solar irradiation, air temperature, wind speed, etc. for its operation. So, when the relevant meteorological data are not available, these methods cannot be used, especially in isolated areas (Mellit et al., 2008).

Wind energy is also a good solution for reducing dependency to fossil fuel. Nowadays, wind energy conversion systems (WEC) are used together with PV systems for maximizing total energy generation for different weather conditions. However, hybrid PV-Wind systems are not capable for energy storage. So, they need to supply with batteries.

In recent studies, different algorithms and technics were used for sizing problems of hybrid renewable energy systems. Billionnet et al. used a constraint generation algorithm where each sub-problem (the recourse problem) can be reformulated by a mixed-integer linear program and hence solved by a standard solver (Billionnet et al., 2016).

Chang provided a quantile-based simulation optimization model, followed by the development of an efficient solution methodology, to enable the control of the upside risk and, as a result, to enhance the decision quality regarding the sizing of hybrid renewable energy systems (Melanie, 1998).

Khare et al. proposed a novel hybrid many optimizing liaisons (MOL) and teaching-learning based optimization (TLBO) i.e. MOL-TLBO based optimization of integrated hybrid renewable energy sources (IHRES) for techno-economic-socio analysis (Chang, 2016).

Berrada et al. proposed methods for determining the optimal operation and sizing of energy storage systems. The main purpose of the operation strategy is to maximize the revenues of the renewable farm. The sizing model, on the other hand, has a purpose to minimize the cost of the hybrid system while meeting the service requirement. Both methods were formulated as non-linear programming optimization models (Khare and Kumar, 2016).

Colmenar-Santos et al. examined smart grids and new information and communications technologies, microgeneration and storage technologies, Active Management Network, multiobjetive planning as an optimization tool for sizing and selection of sites distributed generators. They classified optimization technics for sizing of distributed generator sites (Colmenar-Santos et al., 2016).

Ferrari et al. carried out a time-dependent hierarchical thermo-economic analysis to evaluate both the optimal size and the management approach related to the system, considering a fixed size of 1 MW for the photovoltaic panels (Ferrari et al., 2016).

Brka et al. compared the operational impacts of both predictive and reactive Power Management Strategies (P-PMS and R-PMS). They woked on a stand-alone hybrid system based on wind turbines (WG), batteries (BAT) and hydrogen technology. The P-PMS uses real-time Neural Network (NN) predictions of wind speed and load demand to adjust the control set points affecting the switching of devices. In their study, they also analyses the effects of using another intelligent technique, Particle Swarm Optimisation (PSO), for real-time optimisation of fuel cell operation (Brka et al., 2016).

Atia et al. presented a novel model based on mixed integer linear programming for the optimization of a hybrid renewable energy system with a battery energy storage system in residential microgrids in which the demand response of available controllable appliances is coherently considered in the proposed optimization problem with reduced calculation burdens (Atia and Yamada, 2016).

Singh et al. presented an optimal sizing methodology for a stand-alone and grid connected PV-biomass hybrid energy system that serves the electricity demand of a typical village. An artificial bee colony (ABC) algorithm is used to detect out the optimum hybrid system configuration with the least levelised cost of energy while minimising annualised cost of the system (Singh and Kaushik, 2016).

Siddaiah et al. offered a comprehensive review of the research work carried out in planning, configurations, and modeling and optimization techniques of hybrid renewable energy systems for off grid applications (Siddaiah and Saini, 2016).

Hosseinalizadeh et al. designed techno-economically optimized systems by simulating behavior of various combinations of renewable energy systems with different sizing, including wind turbine (WT), photovoltaic (PV), fuel cell (FC), and battery banks based on the solar radiation and average wind speed maps. According to the results obtained by a computer program, it is concluded that the hybrid systems including WT and PV with battery backup are less costly compared to the other systems (Hosseinalizadeh et al., 2016).

Eltamaly et al. presented an optimization model to design hybrid renewable energy systems consisting of wind turbines, photovoltaic modules, batteries, controllers and inverters. A new computer program has been designed to simulate the optimization model. The main function of the new proposed computer program is to determine the optimum size of each component of the hybrid energy system for the lowest price of kWh generated and the best loss of load probability. To use this model, a data bank is required where detailed specifications and cost of the equipment must be available. It must also include the wind speed, solar radiation data for the desired site, and hourly load power with several numbers of wind turbine and PV module types to get the optimum size of each component and the minimum cost of kWh generated at highest reliability. The proposed computer program changes the penetration ratio of wind/PV with certain increments and calculates the required size of all components and the optimum battery size to get the predefined lowest acceptable probability. This computer program has been designed in flexible fashion that is not available in market available software like HOMER and RETScreen (Eltamaly and Mohamed, 2016).

Mohamed et al. introduces a new proposed design and optimization simulation program for the techno-economic sizing of a stand-alone hybrid photovoltaic/wind/diesel/battery energy system using the iterative optimization. The main function of the new proposed simulation program is to determine the optimum size of each component of a hybrid renewable energy system for the lowest price of generated energy and the lowest value of dummy energy at highest reliability (Mohamed et al., 2015).

Sharafi et al. developed a simulation-based meta-heuristic approach that determines the optimal size of a hybrid renewable energy system for residential buildings. This multi-objective optimization problem requires the advancement of a dynamic multi-objective particle swarm optimization algorithm that maximizes the renewable energy ratio of buildings and minimizes total net present cost and CO2 emission for required system changes. Three proven performance metrics evaluate the quality of the Pareto front generated by the proposed approach (Sharafi et al., 2015).

In this paper, a hybrid renewable energy system is proposed which includes PV, WEC and batteries. Instead of conventional sizing solutions, genetic algorithm approach is used to determine size-amount of PV, WEC and batteries. Matlab software is used for genetic algorithm application (www.mathworks.com). For genetic algorithm, each part of renewable energy system is modelled as cost weight coefficients. This coefficients creates a cost equation for each part of the system. Then, each renewable energy part equations create a general cost matrix together. Genetic Algorithm (GA) is used for finding global minimum of this proposed cost matrix. Instead of conventional methods, GA solution took less time and better result.

METHODOLOGY

In this study, optimum hybrid energy system configuration is tried to obtain for a hybrid energy system consists of PV, WECS and battery banks. In this chapter, genetic algorithm methodology is handled superficially. Then, a general cost function is defined by simple equations. After, every part of general cost function is detailed. Then, constraints for the cost minimization problem are determined. After, determined general cost function and constraint factors used as input data for genetic algorithm.

There are few studies on hybrid renewable energy system sizing application using genetic algorithm. Ogunjuyigbe et al. (Ogunjuyigbe et al., 2016), studied on a Genetic Algorithm which is utilized to implement a tri-objective design of a grid independent PV/Wind/Split-diesel/Battery hybrid energy system for a typical residential building with the objective of minimizing the Life Cycle Cost (LCC), CO2 emissions and dump energy. To achieve some of these objectives, small split Diesel generators are used in place of single big Diesel generator and are aggregable based on certain set of rules depending on available renewable energy resources and state of charge of the battery. The algorithm was utilized to study five scenarios (PV/Battery, Wind/Battery, Single big Diesel generator, aggregable 3-split Diesel generators, PV/Wind/Split-diesel/Battery) for a typical load profile of a residential house using typical wind and solar radiation data.

Upadhyay et al. (Upadhyay and Sharma, 2016), studied on sizing of hybrid energy system using genetic algorithm, particle swarm optimization and biogeography based optimization techniques by keeping energy index ratio at 1. The model also incorporates net present cost, cost of energy, renewable fraction and emissions of carbon di-oxide from diesel generator.

Gonzalez et al. (Gonzalez et al., 2015), used GA and Partical Swarm Optimization (PSO) on the optimal sizing of hybrid grid-connected photovoltaic-wind power systems from real hourly wind and solar irradiation data and electricity demand from a certain location. The proposed methodology is capable of finding the sizing that leads to a minimum life cycle cost of the system while matching the electricity supply with the local demand.

Ko et al. (Ko et al., 2015) presents a methodology to optimize a HES consisting of three types of NRESs and six types of FFESs while simultaneously minimizing life cycle cost (LCC), maximizing penetration of renewable energy and minimizing annual greenhouse gas (GHG) emissions. An elitist non-dominated sorting genetic algorithm is utilized for multi-objective optimization.

Genetic Algorithm

Genetic Algorithm (GA) is arose as an evolutionary problem solving technic. It depends on in nature, best fitting genotypes to the environment can still alive principle. In genetic algorithm methodology, GA tries to minimize or maximize an objective function called "fitness function". For optimization of fitness function, chromosome data is produced some different ways. In this process; selection, crossover, mutation and different functions can be used. Then, best fitness function result is chosen by some probabilistic methods. For this probabilistic methodology, computation time of fitness function reduces then conventional search algorithms.

Given a clearly defined problem to be solved and a bit string representation for candidate solutions, a simple GA works as follows (Billionnet et al., 2016):

1. Start with a randomly generated population of n l−bit chromosomes (candidate solutions to a problem).
2. Calculate the fitness $f(x)$ of each chromosome x in the population.
3. Repeat the following steps until n offspring have been created:

a. Select a pair of parent chromosomes from the current population, the probability of selection being an increasing function of fitness. Selection is done "with replacement," meaning that the same chromosome can be selected more than once to become a parent.

b. With probability pc (the "crossover probability" or "crossover rate"), cross over the pair at a randomly chosen point (chosen with uniform probability) to form two offspring. If no crossover takes place, form two offspring that are exact copies of their respective parents. (Note that here the crossover rate is defined to be the probability that two parents will cross over in a single point. There are also "multi−point crossover" versions of the GA in which the crossover rate for a pair of parents is the number of points at which a crossover takes place.)

c. Mutate the two offspring at each locus with probability pm (the mutation probability or mutation rate), and place the resulting chromosomes in the new population. If n is odd, one new population member can be discarded at random.

4. Replace the current population with the new population.
5. Go to step 2.

In next sections of the paper, mathematical model definitions for HRES are made. Then, a general cost function created using new weight coefficient methodology.

Definition of cost function for hybrid system

Proposed hybrid renewable energy system is consists of PV panels, wind turbine, and batteries. Total cost of system can be given as equation 2.1.

$$C_{total}=C_{bat}+C_{pv}+C_{wind} \tag{2.1}$$

C_{total}: Total cost of hybrid system
C_{bat} : Cost of battery modules
C_{pv} : Cost of photovoltaic panels
C_{wind} : Cost of wind turbine

When calculating total cost of the system, cost of all subsystems have to be summed part by part. So, it is needed to analyze costs of all subsystems (PV, Wind. Battery).

PV Cost

PV subsystem is mainly consists of PV panels, inverters and cables. Additionally, installation costs should be added to total cost of PV subsystem. Equation 2.2 determines total cost of PV subsystem.

$$C_{pv}=C_{panel}+C_{inst}+C_{cable}+C_{inverter} \quad (2.2)$$

$$C_{inst}=\sim\%2 \text{ of } C_{pv}, \quad (2.3)$$

$$C_{cable}=\sim\%1 \text{ of } C_{pv}, \quad (2.4)$$

$$Cinverter=\sim\%20 \text{ of } Cpv \quad (2.5)$$

Cpv : PV system cost

C_{panel} : PV panel cost

C_{inst} : Installation cost

C_{cable} : Cable cost

$C_{inverter}$: Solar inverter cost

In this work; installation, cable and inverter costs proposed as equation 2.3, 2.4 and 2.5 in order to ease of calculations.

Battery Cost

Batteries in proposed system are consist of accumulators, charging units and cables. Equation 2.6, 2.7 and 2.8 show cost function for total cost of battery subsystem.

$$C_{bat} = C_{acumulator}+C_{cable}+C_{charjing\_unit} \quad (2.6)$$

$$C_{cable} = \sim\%1 \text{ of } C_{acumulator}, \quad (2.7)$$

$$C_{charjing\_unit} =\sim\%3 \text{ of } C_{acumulator} \quad (2.8)$$

$C_{acumulator}$: Accumulator cost for battery system

$C_{charjing\_unit}$: Charging unit cost for battery system

Wind Turbine Cost

According to recent market conditions, wind turbine cost is approximately 5 € / Watt including installation costs. In this study, wind turbine costs are directly calculated as how many watts are going to produce by wind turbine for proposed renewable energy system multiplied by 1 watt cost.

Constraint Factors

Hybrid system design is affected by average wind speed, average solar insulation, temperature, humidity and number of cloudy days in a month. Considering these factors, size-amount of modules (PV, WEC and Battery) can change.

In this work, for specific geographical locations, sum of these constraint factors are proposed as weight coefficients named A1, A2 and A3. (Equation. 3.1) These coefficients makes calculations easier and takes away massive mathematical equations for preparation of GA fitness function.

$$\begin{bmatrix} A_1 & A_2 & A_3 \end{bmatrix} \begin{bmatrix} P_{bat} \\ P_{PV} \\ P_{wind} \end{bmatrix} = [P_{Load}] \quad (3.1)$$

A1: Weight coefficient of battery

A2: Weight coefficient of PV panels

A3: Weight coefficient of wind turbine

Power-Cost Relations

Cost of hybrid energy system is proportional with installed capacity of system. However, cost of each equipment is proportional with its power capacity. Equations 4.1 to 4.4 represent relations between cost, power capacity and number of batteries.

$$P_{bat} = P_{1bat} n_{bat} \quad (4.1)$$

$$C_{bat} = n_{bat} C_{1bat} \quad (4.2)$$

$$C_{bat} = \frac{P_{bat}}{P_{1bat}} C_{1bat} \quad (4.3)$$

$$P_{bat} = C_{bat} \frac{P_{1bat}}{C_{1bat}} \quad (4.4)$$

P_{bat}: Battery power

P_{1bat}: Power for 1 battery

n_{bat}: Number of batteries

C_{1bat}: Cost of 1 battery

C_{bat}: Battery total cost

Equations 4.5 and 4.6 show expression of cable and charger cost for proposed system.

$$C_{cable} = 0.01C_{bat} \quad (4.5)$$

$$C_{charger} = 0.03C_{bat} \quad (4.6)$$

Equation 4.7 shows total battery cost function.

$$C_{bat} = \frac{P_{bat}}{P_{1bat}} C_{1bat}(1 + 0.01 + 0.03) \quad (4.7)$$

Equations 4.8 to 4.11 shows power-cost relations for PV subsystem.

$$P_{PV} = P_{panel} n_{panel} \quad (4.8)$$

$$C_{PV} = n_{PV} C_{panel} \quad (4.9)$$

$$C_{PV} = \frac{P_{PV}}{P_{panel}} C_{panel}$$

(4.10)

$$P_{PV} = C_{PV} \frac{P_{panel}}{C_{panel}} \quad (4.11)$$

P_{PV}: Photovoltaic power

P_{panel}: Power for 1 PV panel

n_{panel}: Number of PV panels

C_{panel}:Cost of 1 PV panel

C_{PV}: PV total cost

Equations 4.12-14 determine cable, inverter and installation cost relations.

$$C_{cablepv} = 0.01C_{PV} \quad (4.12)$$

$$C_{inverter} = 0.2C_{PV} \quad (4.13)$$

$$C_{installation} = 0.02C_{PV} \quad (4.14)$$

Equation 4.15 shows total PV cost function.

$$C_{PV} = \frac{P_{PV}}{P_{panel}} C_{panel}(1 + 0.01 + 0.2 + 0.02) \quad (4.15)$$

For wind there are no additional cost function proposed for this work. Equation 4.16 shows wind power-cost relation.

$$C_{wind} = P_{wind}\ C_{1watt} \quad (4.16)$$

C_{wind}:Wind turbine cost

P_{wind}: Wind turbine power

C_{1watt}:approx. cost of 1 Watt wind turbine

General constraint of the problem

Summing up all these constraints, a total constraint function can be written as equation 5.1, and it can use in main cost function system as Equation 5.2.

$$A_{eq} = \begin{bmatrix} \mathrm{A_1 P_{1bat}/(C_{1bat}\ (1 + n1 + n2))} \\ \mathrm{A_2 P_{panel}/(C_{panel} * (1 + k1 + k2 + k3))} \\ \mathrm{A_3/C_{1watt}} \end{bmatrix} \quad (5.1)$$

$$[A_{eq}] \begin{bmatrix} C_{bat} \\ C_{pv} \\ C_{wind} \end{bmatrix} = [P_{load}] \quad (5.2)$$

This constraint function at Equation 5.2. is used as general constraint function in GA.

Examples of GA solution for Cost Minimization Problems

In this section, solutions for a few specific HRES sizing problem are given using GA and new coefficient factors methodology. Weight factors are obtained from different environmental conditions (solar irradiance, wind speed, etc.) for different problems.

In the first problem, a 1kW system for a house tried to optimize for a hybrid system consists of PV panels, WECS and batteries. Paraneters of the system is shown below:

A1=0.4, A2=1, A3=0.8, C1watt=4 €, P1bat = 40 Watt C1bat=150 €, n1=0.03, n2=0.01, Ppanel=80 Watt Cpanel=350 €, k1=0.2, k2=0.01, k3=0.02, Pload = 1000 Watt

In second problem, HRES design for a rural area is calculated. The parameters of the second problem is shown below:

A1=0.3, A2=1, A3=0.7, C1watt=4 €, P1bat = 100 Watt C1bat=400 €, n1=0.03, n2=0.01, Ppanel=250 Watt, Cpanel=350 €, k1=0.2, k2=0.01, k3=0.02, Pload = 8 MW

In third problem, another rural area which is more suitable for WECS is calculated for cost minimization of a HRES installation. Parameters for the third problem is given below:

A1=0.3, A2=1, A3=0.7, C1watt=4 €, P1bat = 100 Watt, C1bat=400 €, n1=0.03, n2=0.01, Ppanel=250 Watt, Cpanel=350 €, k1=0.2, k2=0.01, k3=0.02, Pload = 8 MW

Regarding the problems, general cost function can be express as fitness function for GA in Matlab software as:

```
function [ y ] = cost(x)
```

y=x(1)+x(2)+x(3);

end

x(1):Batery cost (€)

x(2):PV cost (€)

x(3):Wind turbine cost (€)

Genetic algorithm, tries to find minimum value of function y. However, default Matlab GA options are used for calculations.

RESULTS

In this section, GA solutions for specified problems are given. For the first problem was for calculation of electricity need for a house. The planning power capacity was 1kW. GA decided that 61% of the total power is better to produce by wind energy, 37% PV and system needs batteries for 2% of total power. Results are shown on Fig. 1. Total cost of the system is calculated as 2810€.

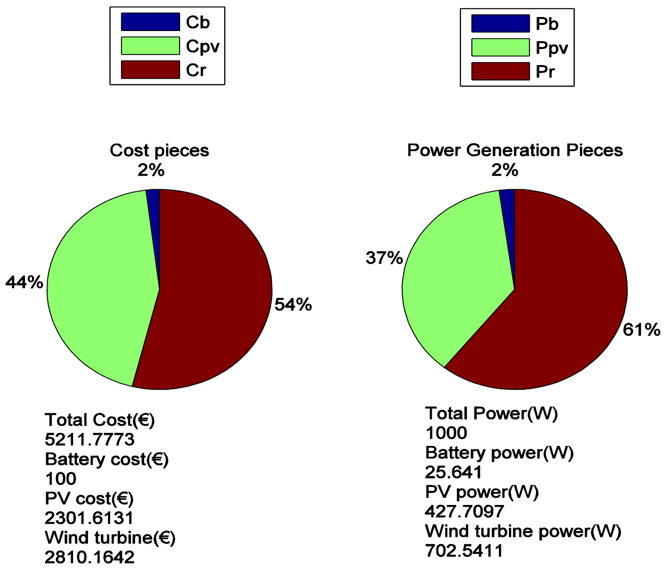

Fig. 1. Cost pie diagram and power pie diagram for proposed hybrid system for the first problem. (Total cost has minimized by genetic algorithm)

For the second problem, a HRES installation planning is made for 8MW installation capacity. GA decided that 89% power generation by PV panels and 11% by WECS. Battery need for this system is calculated less than 1%. Total cost of the system is calculated as 3.8 million €. Cost and power pie diagrams are shown in Fig. 2.

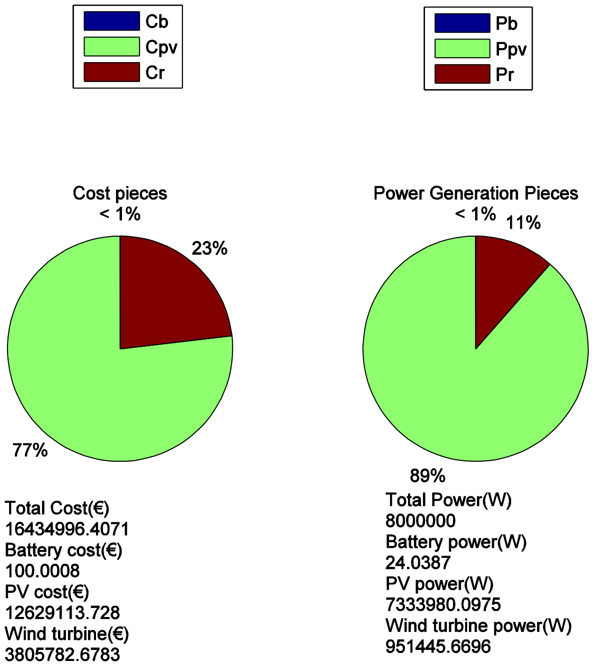

Fig. 2. Cost pie diagram and power pie diagram for proposed hybrid system for the second problem. (Total cost has minimized by genetic algorithm)

For the third problem, for another rural area, a HRES installation planning is made for 8MW installation capacity. GA decided that 55% power generation by PV panels and 45% by WECS. Battery need for this system is calculated less than 1%. Total cost of the system is calculated as 28 million €. Cost and power pie diagrams are shown in Fig. 3.

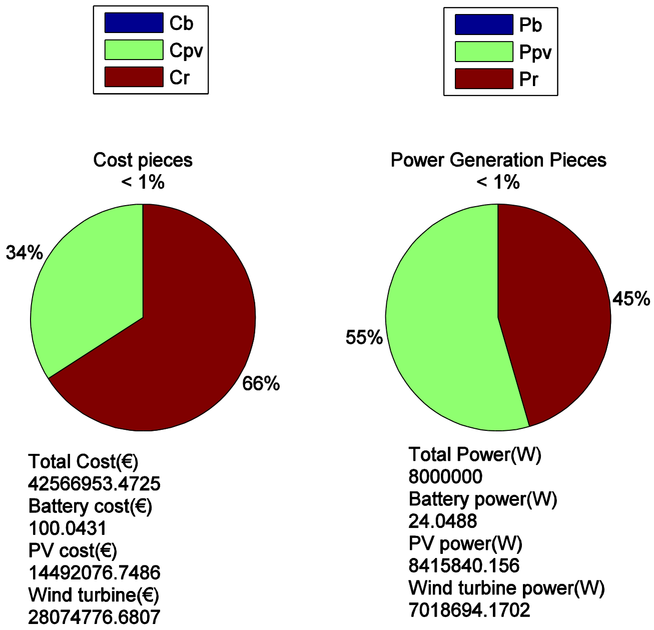

Fig. 3. Cost pie diagram and power pie diagram for proposed hybrid system for the third problem. (Total cost has minimized by genetic algorithm)

CONCLUSION

Finding cost of a hybrid renewable system is commonly an important problem for investors. When planning a hybrid system, it is important to decide how much power can be generated by each module of system. Commonly wind-PV systems are preferred to achieve maximum efficiency for different weather conditions. However, they are hard to control without storage systems like batteries. So, generally the best configuration for HRES is WECS, PV systems and batteries.

There are many technics for sizing of HRES. However, conventional technics takes long time to find optimal solution. Also, they boost computation effort. Tough, they are many artificial intelligence technics like artificial neural network prediction, particle swarm optimization, bee colony optimization etc. mentioned in previous studies. But this technics needs massive mathematical solutions.

In this study, parts of HRES are presented as basic coefficient factors. A general cost function (fitness function) created with coefficient factors. General cost function is tried to minimize using GA. It’s seen that proposed mathematical model with GA reduce calculation time and computation effort for these types of problems.

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