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DETERMINATION OF THE OPTIMAL CAPACITY OF ELECTRIC HYBRID RENEWABLE ENERGY SYSTEMS USING A SMART OPTIMIZATION ALGORITHM

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ABSTRACT

Due to the abundance environmental concerns, since decades using renewable energies such as wind, solar, and fuel cells has drawn much attention as resources of electricity generation. To enhance the reliability of energy supply Hybrid Renewable Energy Systems (HRES) are increasingly used particularly in remote areas, where various energy resources are available. Hybrid Renewable Energy system (HRES) consists of two or more renewable resources that are used together for increasing the efficiency and achieving an optimum level of availability in energy supply. The combination of resources examined as HRES in literatures depends on various factors such as the geographic location of consumption, the availability and cost of energy in various renewable sectors as well as the price and availability of energy which could be delivered by the electric utility and diesel generators. Examples of such combination include solar arrays-wind turbines, biomass-fuel cells, etc. In this case study the combination of wind turbine-electrolyzer-fuel cells-biomass systems has been considered and as one option a compressor unit is added to check the effect of this addition on hydrogen storage tank capacity. The IEEE standard demand load curve with 500kW peak load assume in this case study. In this case study Particle Swarm Optimization (PSO) is used for getting the optimum size of each element of hybrid system to supply the above mentioned demand load. During the running PSO, various constraints has been considered such as amount of hydrogen tank capacity in begin and end of period of study. Finally optimum sizes of each element and total cost of mentioned system will be counted.

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KEY WORDS

biomass, determine the optimal capacity, fuel cell, Hybrid renewable energy systems, wind energy, optimization, solar arrays, wind power plant

INTRODUCTION

Fossil fuels are a major source of greenhouse gas emissions and the main reason for global warming that account for 95 percent of Iran's electricity generation sources. Ecology is not only an environment for human life but also it is important for the economy and creates high economic value-added in many manufacturers and significantly contributes in human well-being. The ecological revolution that started in the 1970s in the industrialized world still did not have a significant impact on large parts of the developing world. Expansion of globalization process and the transfer of polluting industries to developing countries, increasing rates of urbanization, industrial development and the increasing need to energy, have caused significant environmental damage. In addition, electricity is a very useful energy in the process of developing a significant role in promoting economic growth. But the production of electricity depends on other energy sources, especially fossil fuels so that in 2011 about 67% of world electricity, 15 Percent of hydropower and 4% of other renewable energy sources are directly produced from these sources [33]. Generators used in power generation and renewable hybrid systems include: Wind turbines, Fuel Cell, Electrolyzer, and Reformer.

MATERIALS AND METHODS

Modeling of hybrid systems

Two hybrid systems discussed in this article are listed in Figure 3 and 4.

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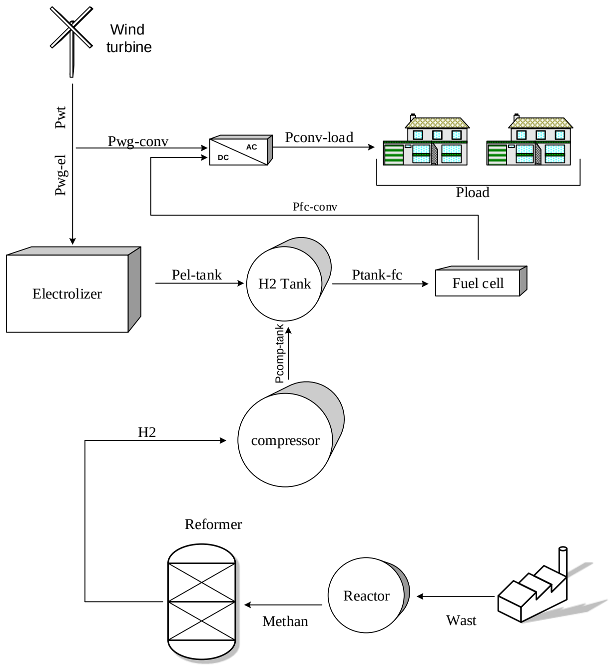

Fig: 1. Hybrid system (1)

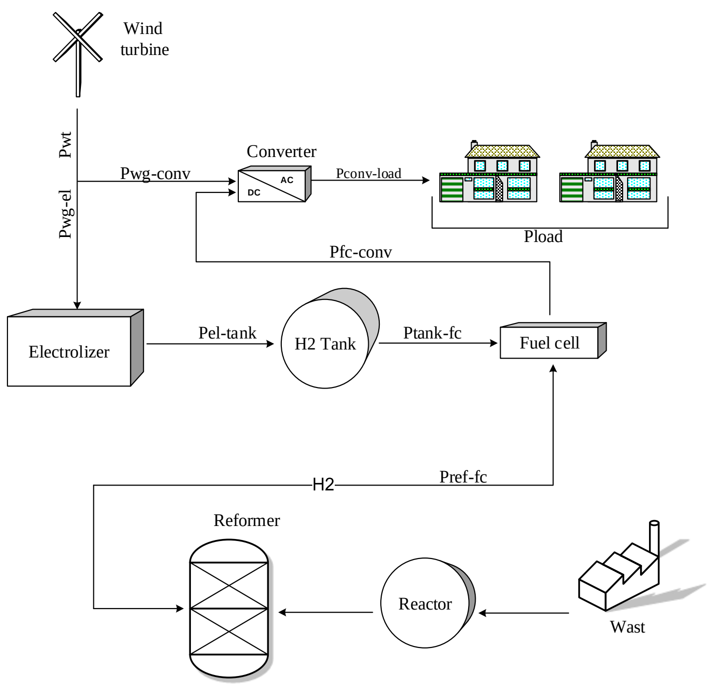

Fig: 2. Hybrid system (2)

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Hybrid system model 1

In the system, the power produced by the wind turbine system is delivered to the load by converters and hydrogen is stored in tank by a reformer. If the power produced by the wind turbine is higher than load demand, excess power is fed into the electrolyzer and the hydrogen is produced. The hydrogen is stored in hydrogen tank. When the wind turbine can provide the load, the fuel cell is fed with hydrogen stored in tanks and helps provide wind turbine load.

The system has three modes:

(A) Power produced by the wind turbine is equal to load power

In this case, the total power produced by the wind turbine is delivered to the load and the excess power of the wind turbine is given to the electrolyzer and the produced hydrogen is stored in hydrogen tank. The equations are expressed as follows:

$P_{wg\_conv} = P_{wt}$

$P_{wg\_el}=0$

$P_{fc\_conv}=0$

$P_{el\_tank}=0$

$P_{tank\_fc}=0$

$E_{tank(i)}=E_{tank(i-1)}+P_{comp\_tank(i)}$

(B) Power produced by the wind turbine is greater than load power:

In this case, the power produced by the wind turbine is greater than the required power for load and excess power is delivered to the electrolyzer and the hydrogen is stored in hydrogen tanks. The system' equations are as follows:

$P_{wg\_conv}=P_{load}/\eta_{conv}$

$P_{wg\_el}=P_{wt}-P_{wg\_conv}$

$P_{el\_tank}=\eta_{el}\times P_{wg\_el}$

$P_{tank\_fc}=0$

$P_{fc\_conv}=0$

$E_{tank(i)}=E_{tank(i-1)}+P_{comp\_tank(i)}+P_{el\_tank(i)}$

(C) Power produced by the wind turbine is less than the load power:

The system equation is as follows:

$P_{wg\_conv}=P_{wt}$

$P_{wg\_el}=0$

$P_{el\_tank}=0$

$P_{fc\_conv}=P_{load}/\eta_{conv}-P_{wg\_conv}$

$P_{tank\_fc}=P_{fc\_conv}/\eta_{fc}$

$E_{tank(i)}=E_{tank(i-1)}+P_{comp\_tank(i)}-P_{tank\_fc(i)}$

In all three modes, the hydrogen produced by the reformer is compressed by the compressor and is stored in hydrogen tank.

Hybrid system model 2

In this system the hydrogen produced by the reformer goes directly to the fuel cell. While the power produced by the wind turbine plus the power produced by the fuel cell (fed by reformer) is more than the load power, excess power of wind turbine goes to the electrolyzer and as the power produced by the wind turbine plus the power produced by the fuel cell (fed by reformer) is less than the load power, more fuel cells are used and the cells are fed into the stored hydrogen in tanks.

The system has three modes:

(A) Power produced by the wind turbine plus power produced by the fuel cell is equal to load power:

The system equation is as follows:

$P_{wg\_conv}=P_{wt}$

$P_{wg\_el}=0$

$P_{fc\_conv}=\eta_{fc}\times P_{ref\_fc}$

$P_{el-tank}=0$

$P_{tank-fc}=0$

$E_{tank(i)}=E_{tank(i-1)}$

Here the electrolyzer does not produce anything and the system equations are as follows:

(B) Power produced by the wind turbine plus power produced by the fuel cell is greater than the load power:

In this case, the extra power generated by the wind turbine is given and the produced hydrogen is stored in tanks. The equations are as follows:

$P_{wg\_el}=P_{wt}-P_{wg\_conv}$

$P_{el\_tank}=\eta_{el}\times P_{wg\_el}$

$P_{tank\_fc}=0$

$P_{fc\_conv}=\eta_{fc}\times P_{ref\_fc}$

$E_{tank(i)}=E_{tank(i-1)}+P_{el\_tank(i)}$

(C) Power produced by the wind turbine plus power produced by the fuel cell is less than the load power:

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In this case, the fuel cell is fed through the hydrogen tank in order to provide load power. The equations are as follows:

$P_{wg\_conv}=P_{wt}$

$P_{wg\_el}=0$

$P_{el\_tank}=0$

$P_{fc\_conv}=P_{load}/\eta_{conv}-P_{wg\_conv}$

$P_{tank\_fc}=P_{fc\_conv}/\eta_{fc}-P_{ref\_fc}$

$E_{tank(i)}=E_{tank(i-1)}-P_{tank\_fc(i)}$

In any case hydrogen produced by reformer is delivered to fuel cell and cell fuel generates power.

Global Best algorithm (Global Best)

This algorithm corresponds to the star topology and one of PSO algorithms. In this algorithm, each particle motion is carried out by his experience and knowledge of all other particles. It is therefore clear that there is a lot of social interdependence and connectivity is established between the particles.

Steps of this algorithm are given in Figure 7.

Comparison of the optimal size of the hybrid systems

The nominal power of each wind turbine is 5.7 kW, each electrolyzer and fuel cell power is 1 kW, the capacity of each hydrogen tank is 1 kg and lifecycle of each project is 20 years.

Hybrid systems input

Input data in are given in Tables 1 and 2.

Table: 1. Wind speed inputs and wind turbine power

	Low disconnection speed	Nominal speed)(m/s)	(high disconnection speed) m/s	Nominal power (kW)
Wind turbine (7.5 K.W)	3	11	25	7.5

Table: 2. Inputs related to costs, efficiency and lifecycle of components

	Life cycle (yr)	h (%)	Maintenance and repair costs $/yr	Replacement cost ($)	Initial investment cost ($)
Fuel cell (unit 1 kW)	5	50	175	2500	3000
Wind turbine (5.7 kW unit)	20	-	75	15000	19400
Electrolyzer (Unit 1 kW)	20	90	20	1500	2000
Reactor and reformer (per kg waste)	20	-	100	130	1450
The hydrogen tank (capacity 1 kg)	20	100	15	1200	1300
Compressors (Unit 1 kW)	15	90	9	10	10
Converters (Unit 1 kW)	15	90	10	750	800

Table: 3. Demographic information and waste and load peak

Peak load (kW)	Hydrogen energy value(kWh)	The amount of hydrogen produced per kg of waste	The amount of waste produced per person	Population
500	37.8	0.0454(Kg)	600(g)	800

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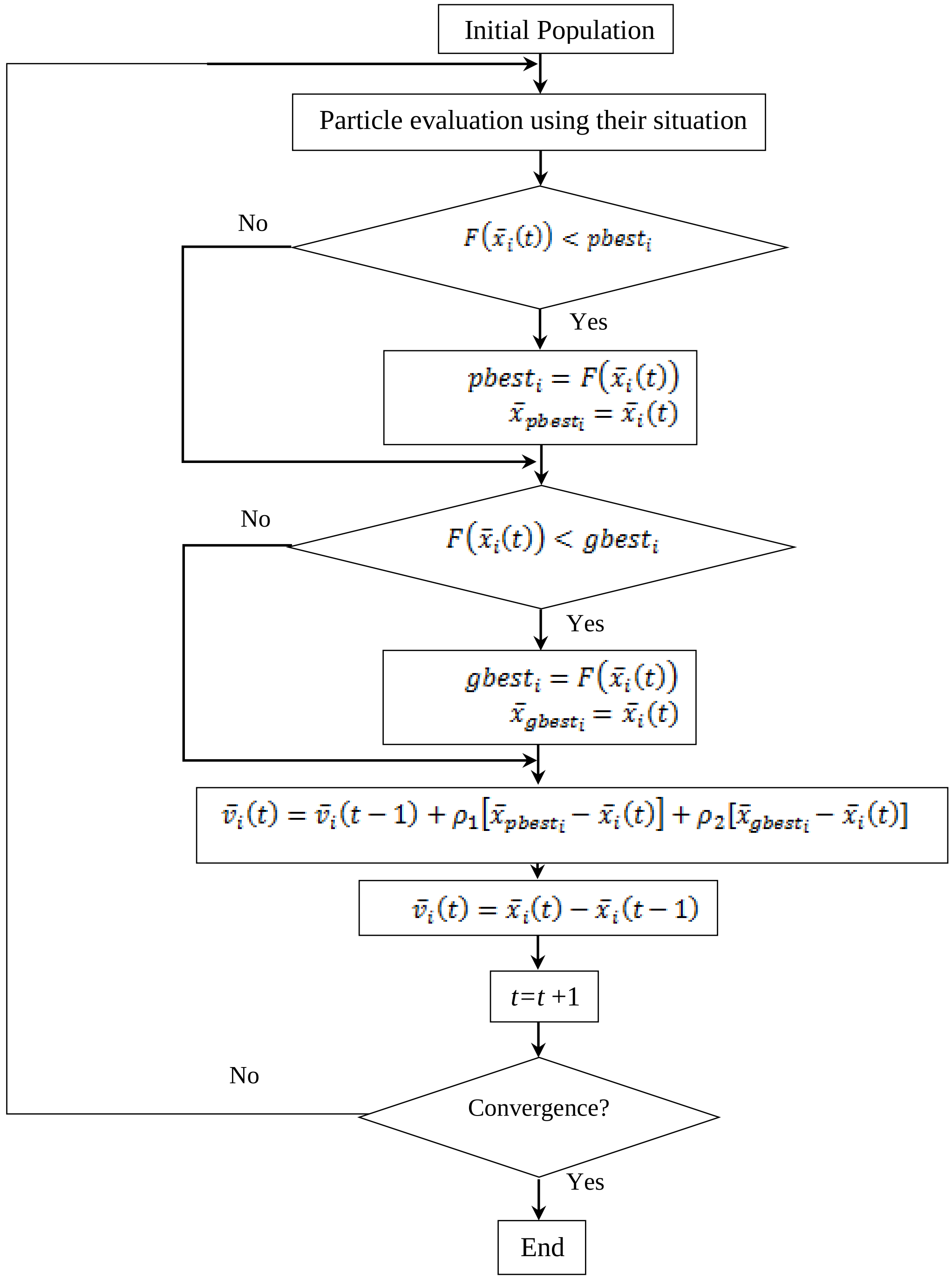

Fig: 3. Flowchart of particle swarm optimization

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Table: 4. PSO Parameters

Population	Number of repetition	C1	C2	(Inertia) w
30	300	2	2	0.7

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Load curve is considered based on the IEEE standard [39], this curve is based on per-unit. In this project it is assumed that a load peak equals to 500 kW, thus, the load curve of the IEEE standard curve is obtained by multiplying the peak times.

This curve is moved for six months to comply with the residential areas load curve in Iran. This study is consisted of 800 people and it is assumed that per person produces 600 grams of waste per day, and this waste is delivered daily to the anaerobic reactor and this reactor produced a fixed amount of methane during the day, the methane is converted into hydrogen by a reformer. Given to the amount of waste produced during day, the anaerobic reactor and the reformer size will be constant. The amount of hydrogen produced per kg of waste is equal to 0.0415525 kg, then the value of total hydrogen produced during the day will be about 20 kg 37.8 kw/h. which is equivalent to 756 kwh energy. It is noteworthy that the size of the reactor is determined according to the generated solid waste. The amount of waste is 480 kg of per day in the region. Reformer size is determined based on the amount of hydrogen from garbage in a given day which is equal to 20 kilograms per day (480*0.0415525). Amount of energy generated per kilogram of hydrogen is equal to 37.8 kw/h. As a result, compressor size is equal to 31.5 kW.

RESULTS

The results of the optimization program for the system (1)

The optimum number of system units 1 and the cost is given in Table 5.

Table: 5. the optimum number of system units and its cost of (1)

Number of wind turbine	Number of fuel cell	Number of hydrogen tanks	Number of electrolyzer	Cost ($)
609	3248	4374	522	$3.08638*10^7$

Note: In this article the estimated cost is calculated from the basic expenses in [7] and certainly with the advancement of technology these costs will be significantly reduced.

The results of the optimization program for the system (2)

The performance of the system 2 is similar to No. 1, with the difference that the in system 2 fuel cell always be generated, because the hydrogen produced by reformer moves directly to the fuel cell. Optimum size of system units (2) and their cost are shown in Table 6.

Table: 6. the optimum number of system units and its cost of (2)

Number of wind turbine	Number of fuel cell	Number of hydrogen tanks	Number of electrolyzer	Cost ($)
756	1551	6059	520	$3.249*10^7$

Note: In this article the estimated cost is calculated from the basic expenses in [7] and certainly with the advancement of technology these costs will be significantly reduced.

Comparison of the results of two hybrid system

The difference between the two systems is that the hydrogen produced by the reformer in the system is stored in the tank (1) and if needed is consumed by the fuel cell, but in system 2 the hydrogen produced by the reformer moves directly to the fuel cell. These differences gives rise to differences in the optimum size of system components which results in an increase in costs compared with the system system1. As compared to the second strategy, system 1 has better performance for the hydrogen produced by the reformer is stored in tanks and is used according to the load requirement.

CONCLUSION

In this study the optimal size and mode of operation of the hybrid system were studied. The system includes wind turbine, fuel cell, electrolyzer, hydrogen tank, anaerobic reactor, reformer, heat exchangers and compressors (for system 1), respectively. Wind and regional waste have been used as primary sources of energy production. The difference between the two systems is that the hydrogen produced by the reformer is stored in the hydrogen tank system 1 and if necessary is used by the fuel cell. While hydrogen produced by the reformer in system 2 is directly connected to the fuel cell. These differences give rise to differences in the optimum size of system components which results in an increase in costs in system 2 compared with system. System1 has better performance as compared to the second strategy because the hydrogen produced by the reformer is stored in tanks and used according to the load requirement. With increasing system reliability, system costs are increased as the result of increased hydrogen size. For the following reasons combined wind-fuel cell system is suitable for the area:

1. Suitable wind speed and steady approach during the years

2. Use of zone wastes

3. Lack of environmental pollution

In both systems fuel cell is as a supporter of wind turbines, so both systems are high reliability in power supply. Combine power systems are the best option to cover electrical energy in remote areas of the network. While these systems have an acceptable efficiency and less environmental pollution and their technology is faced with the enormous progress. Another advantage of these systems is reduced investment costs to develop the transmission grid, improved power quality, increased reliability in energy supply, reducing the purchase of electricity from neighboring countries and lack of construction of high-capacity plants

CONFLICT OF INTEREST
Authors declare no conflict of interest.

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FINANCIAL DISCLOSURE
None declared.

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