# Design and Analysis of Hybrid Solar, Wind, Osmotic for Green Plants Systems Using an Ant Colony Optimization Algorithm

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## Abstract

*Nature has always proven that it is able to overcome its problems. However, human manipulation has led to environmental degradations. The dryness of a thousand-year Urmia Lake (a brine water lake in Iran) is an example of environmental degradation that happened due to successive droughts and construction of dams on the basin of this lake. This study examines methods for the revival of Urmia Lake by making use of the water gathered behind the dam of Urmia Lake for agricultural purposes. This examination will be carried out by constructing several green plants around this lake over 20 years. The cost and amount of this construction project is analyzed with MATLAB software and by using an Ant Colony Algorithm.*

**Keywords:** Optimal design system, solar energy, wind energy, osmotic power, ACO algorithm

## 1- Introduction

Using renewable energy can reduce the dependence on fossil fuels, the emissions of polluting gases from manufacturing sectors, the consumption of energy resources, and the emission of greenhouse gases which result in global warming. The structure of renewable energy is different from that of the conventional energy generation technologies, because the development process of renewable energy demands high initial investment costs, while its maintenance costs are low. However, in the methods of energy generation from conventional resources, the initial investment costs are low. For independent and remote systems, including radio communication systems, satellite ground stations, and so, that are away from a power system, hybrid energy systems are preferred. These systems are usually supported and equipped by a backup system to meet the peak load over short periods, when energy is less accessible.

## 2- Methodology

Intelligent algorithm for design and economic analysis, as well as environmental considerations of power systems and desalination of seawater using osmosis in remote areas were reviewed. The combination of available equipment was chosen for full coverage of the load for a period of 20 years and with the lowest possible cost. Costs include the cost of investment and maintenance. Sazmane

Energihaie Noe Iran (SUNA) [Renewable Energy Organization of Iran] power distribution organization, government offices, and banks can benefit from the results.

Therefore, the main objectives of the thesis are: 1. optimizing the wind-solar-osmosis hybrid system to reduce generation costs and 2. choosing the appropriate benchmark systems for optimizing the design of the proposed hybrid power plant using Ant Colony Algorithm (ACO).

## 3- Advantages of this Method

1. A global network is not required;

2. No fuel is required;

3. It is environmentally friendly, and does not cause environmental pollution;

4. It can preserve ecosystem and natural drying lakes;

5. It results in dispersal and diversification of energy generation in the country;

6. It has the capability to generate reliable electrical energy with stable prices;

7. It is able to help electricity providers to diversify the required resources to produce electricity;

8. It can expand power generation with minimal environmental pollution;

9. It can help countries to achieve the development goals of applying renewable energy;

10. It does not produce noise pollution.

## 4- History

Osmotic pressure is formulated by Jacobus Henricusvan"t Hoff in 1887, as follows.

$$\pi V = nRT \tag{1}$$

$$\pi = \frac{n}{V} RT \tag{2}$$

$$\pi = MRT \tag{3}$$

Where $\pi$ represents osmotic pressure, R is the ideal gas constant (0.0821L.atm / K.mol), M is the molarity of solution in moles per liter, and T is the temperature in Kelvin. Power generation using Pressure-Retarded Osmosis (PRO) is a reliable method for future. In this method, water penetrates from a feed (low flow salt or clean water flow) through a semipermeable membrane to a concentrated solution or a high-pressure concentrated stream, such as sea water causing a further increase of discharge and pressure. Then this high-pressure flow passes a water turbine and turns a generator connected to it and generates electric power. In this study, in addition to examining a power plant performance based on PRO and checking if it is appropriate for the working condition of Iran, a PRO model is examined to predict water flow and power density under the terms of the theory.

## 5- Solar Systems

Photovoltaic systems are applied for public consumption and agriculture as plants independent of global networks or systems connected to global networks with a fixed or mobile structure installed in small units with low-power to supply electrical energy required for a wide range of machines from small calculators to large plant systems.

In the case of mobile systems, it is important to note that it allows for the tracing of the sun and an increase in the electric energy from the sun during the day. Despite this, because the failure of mechanical system is likely and probable, it is not recommended to depend on electric energy to move the structure for small and scattered uses. Only a few solar power (photovoltaic) plants make use of this type of structure in the whole world.

## 6- Efficiency of Solar Cells

Efficiency of solar cells is defined as the percentage of energy which is transformed into electricity (as a result of the conversion of absorbed radiant energy into electric energy).

When an electrical circuit is connected to a solar cell, the efficiency of solar cell is calculated as follows:

$$\eta = \frac{P_m}{E \times A_c} \tag{4}$$

Where Pm represents maximum power, E indicates input light intensity under standard terms, and Ac manifests the area of the surface of solar cell.

Sufficiency is another important factor in explaining the behavior of solar cells which is calculated as follows:

$$FF = \frac{P_m}{V_{dc} \times I_{sc}} = \frac{\eta \times A_c \times E}{V_{dc} \times I_{sc}} \tag{5}$$

Where Pm indicates maximum power, $V_{de}$ manifests voltage and open circuit, and $I_{sc}$ represents short circuit current [1].

## 7- Wind Power

Nominal power of wind can be calculated using the following equation.

P = work / time

$p = \frac{1}{2} mv^2/t = \frac{1}{2} (\rho Ad) v^2/t = \frac{1}{2} pAv^2$

d/t = v

$P = \frac{1}{2} \rho Av^3$

P= wind power (watts);

$\rho$= air density;

A= circular surface swept by router blades

V= relative velocity of wind which is the resultant of both actual velocity in the environment and the velocity of router.

7.1- Active seawater battery system

Due to the low energy generated by osmotic system, swab system or seawater battery system can also be used along osmosis system. In swab method, seawater is used as a catalyst for the reaction of magnesium in the water leading to the generation of electricity. Chemical formula and the way of generating power are shown in figure 1 [18].

$$Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2 + 98Wh \tag{6}$$
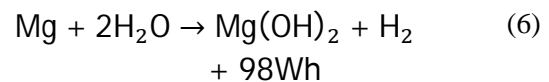
[NaCl catalyst]

Chemical formula for the generation of power from Mg

## 8- Theory of Osmotic Processes

Osmosis is the process of transforming water through a permeable (semipermeable) membrane of a solution such as pure water to a concentrated solution such as water and salt.

The process allows water to pass through a permeable membrane using the difference in the molar concentration of solutions; this permeable membrane does not allow most of solutions and ions such as salt to pass. If some hydraulic pressure or working pressure ($\Delta P$) is applied on concentrated solution, water molecules are not transferred through the membrane. In this case, the difference in osmotic pressure ($\Delta \pi$) equals the difference in hydraulic pressure.
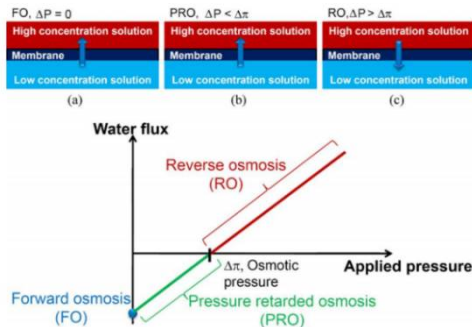


**Fig.1.** Flow direction of solvent (water) in (a) Forward Osmosis (FO), (b) Retarded-Pressure Osmosis (PRO), (c) Reverse Osmosis (RO) and (d) water flux vs. working pressure in osmotic processes [10].

## 9- Power Generation Using PRO

PRO systems are divided into two groups: open cycle and closed cycle. Figure 2 shows a schematic of these cycles [10].

In open cycle, solar energy causes the evaporation of seawater; the evaporated water is condensed into rain and creates fresh rivers. The rivers are flowing back into the sea. In order to make commercial uses of osmotic power, various projects were evaluated regarding flexibility and compatibility of open cycle power plants in real situations and the efficiency and energy generation of plants

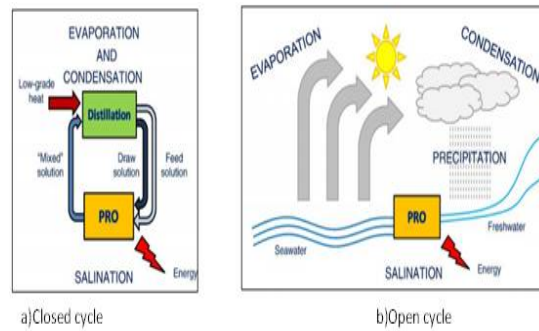according to the location and mounting position of plants [10 and 11] .



**Fig.2.** Schematic representations of open and closed cycles of power generation using PRO [10]

The plants can be constructed at sea level, below sea level, or slightly lower than sea level. If the plants are constructed several meters below sea level, the number of required pumps reduces to minimum and 81% of efficiency is possible. So in this case, overall efficiency is not only significantly higher than when the position plant is at sea level, but due to the problems of construction, installation condition is better when the plant is constructed below sea level [4].

Figure 2 shows a schematic representation of an open cycle power plant PRO on the sea surface that has been implemented by Stat Kraft Company in Norway. In this plant, fresh water or water with low salt content enters membrane chamber as feed water after purification. Through membrane, 80-90% of water with low concentration of salt is transferred to high-pressure and seawater with high concentration of salt membrane using osmotic process. Osmotic process causes an increase in the discharge of high-pressure water; and this increase is the basis of energy transfer in the process of power generation.

This process requires appropriate membranes, and it particularly requires high rate of water flow transfer and proper impermeability of salt. First, brine seawater is filtered and enters into membrane chamber after passing through pressure transducers which results in an increase in pressure. In membrane chamber, clean water penetrates through the other side of membrane; this penetrated clean water dilutes the seawater and then causes an increase in its pressure. Volumetric flow rate of brine water is about twice more than that of fresh water.
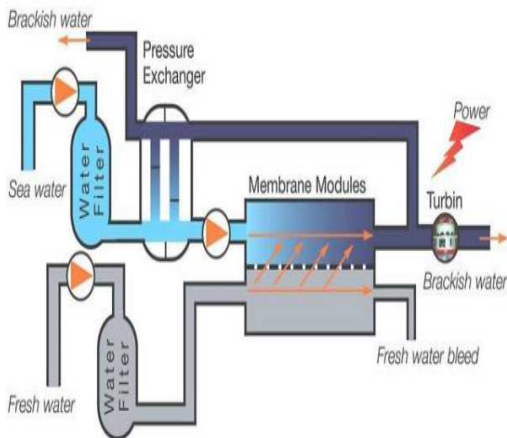


**Fig.3.** Representation of the osmotic system

Then, diluted seawater is divided into two parts: one-third of the capacity of seawater enters water turbines for power generation and the remaining two-third returns to a low-pressure sewer to evaluate energy and increase the pressure of the salt water inlet of system. The optimal operating pressure range is between 11 and 15 times of the equivalent water with the range of height from 100 to 145 meters in a hydropower plant, which is capable of generating 1 MN over $m^3/s$ of clean water; clean water works at ambient pressure.

## 10- Ruling Equations

The general equation of water flow passing through the membrane using PRO, RO, and FO is obtained from equation (3).

$$J_w = A(\Delta\pi - \Delta\rho) \tag{7}$$

Where, JW represents water flow, and A indicates water permeability coefficient of the membrane. For RO, $\Delta P > \Delta\pi$, and for PRO, $\Delta P < \Delta\pi$. Figure 1 shows the direction of influx for the three mentioned states. For FO, dense layer (active layer) is located in asymmetric membrane in the side of concentrated solution of water and salt, and RO and PRO of dense layer is in contact with clean solution.

In PRO, generation capacity per unit of membrane surface (i.e., power density) equals the product of the water mass flow and the difference in hydraulic pressure:

$$W = J_w\Delta\rho = A(\Delta\pi - \Delta\rho)\Delta\rho$$

By differentiation of $\Delta P$ it can be shown that the highest possible power density (special power) is obtained in $\Delta P = \Delta\pi/2$ by placing $\Delta P$ in equation (4) we have:

$$W_{max} = \frac{A(\Delta\pi)^2}{4} \tag{8}$$

In figure 4, JW is shown as a function of $\Delta P$ for the ideal and the real terms. FO point, and RO, PRO areas are shown in figure. Reversal point of flow direction occurs in $\Delta P = \Delta\pi$
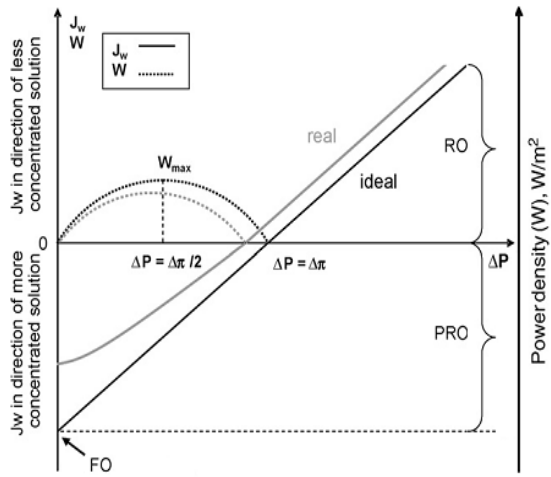
Figure 4 also shows W and $W_{max}$ in PRO area.

**Fig.4.** Size and direction of the water passing through the membrane (JW) and the size of special power (W) in FO, PRO, RO [10]

## 10.1- Permeability of salt

A little salt penetrates the membrane because of the difference in concentration on both sides of membrane; this is called reverse penetration of salt. Membranes used in osmotic process are sensitive to reverse penetration of salt. Reverse penetrate causes in the reduction of effective osmotic pressure through membrane. Salt permeability coefficient (B) from a semipermeable membrane is obtained from the experimental results for RO placed in the following equation:

$$B = \frac{A(1 - R)(\Delta\rho - \Delta\pi)}{R} \qquad (9)$$

Where, R is salt rejection and is defined as follows:

$$R = 1 - \frac{C_p}{C_f} \qquad (10)$$

Where, CP represents salt concentration in the side of clean solution (influx) and CF indicates the concentration of salt in the feed side (seawater).

## 11- Summary

Curves of PRO for water flow and power density (special power) are shown as a function of hydraulic pressure for three kinds of concentrated solutions with different concentrations compared with experimental results [4]. Most of difference in hydraulic pressure is obtainable in experimental conditions 970 KPa and more pressure causes membrane perforation. Concentrated solutions that are simulated as seawater are assumed to have 35 g/l and 60 g/l of salt (NaCl). The amount of water flow and special power, is shown in (a) and second axes of y, respectively.

In both cases, an increase in the hydraulic pressure reduces the flow of water passing through membrane to reach zero and then reverses the flow. Maximum power density occurs when hydraulic pressure is almost half the osmotic pressure. For example, in a solution with a concentration of 35 g/l salt Figure.5a, and feed of 25 g/l salt, the reverse flow point and maximum power density occur in the pressure of 2450 kpa and 1280 kpa, respectively. When there is an increase in the concentration of feed, passing flow and power density decrease.

This is due to the decrease of osmotic pressure $(\Delta\pi)$, the increase of concentration polarization, and the increase of passing salt. Comparing figures 5a and 5b, it is observed that the more the concentration of salt in a concentrated solution like seawater, or the more concentration differences on both sides of membrane, the more the power density and passing flow.
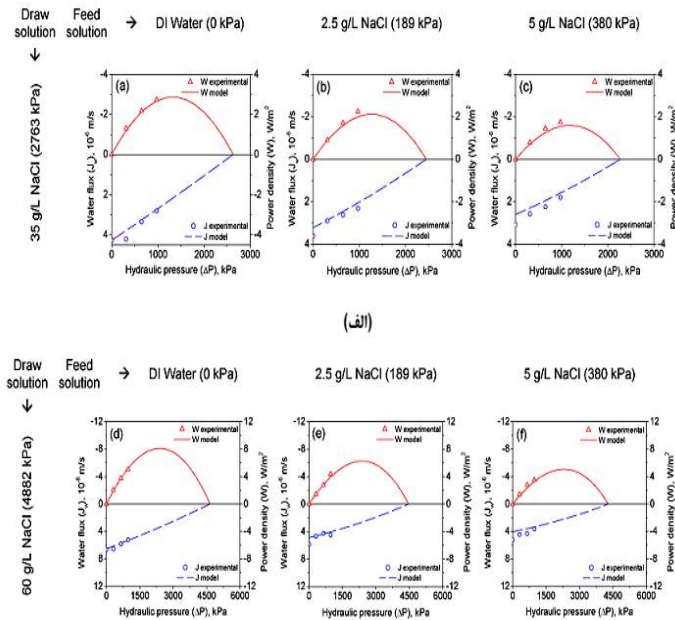
**Fig.5.** Comparing the results of the model with experimental results for water flow passing through membrane (JW) and special power (W) as a function of working hydraulic pressure ΔP of flows of brine concentration in figure (a) 35g/lnacl (2763 kpa) and figure (b) 60g/lnacl (4882 kpa) [10]

That is due to increased thrust. Maximum of special power is between $1.6 w/m^2$ to 2.9 for a concentration of 35 g/l and between 5.1 to 1.8 $w/m^2$ for a concentration of 60 g/l. comparing these results with the results of the models [1, 8] and the difference of $4 w/m^2$ show that the development of this model is more successful than previous methods. Moreover, the effect of external and internal concentration polarization and passage of salt on water flow passing through membrane and the especial power are shown in figure 10. In ideal conditions, when reducing factors of power are not available (and when external and internal concentration polarization does not take place and salt does not pass through membrane), maximum power and maximum water flow passing through the membrane are obtained. An increase in each effect such as external concentration polarization (Wk), internal concentration polarization (Wk), concurrent impact of internal concentration polarization and passage of salt K, WB (B is assumed to be $10-7 \times 1.11$), and eventually the impact of all cases result in a more reduction of power and water flow passing through membrane. Furthermore, it was mentioned that an increase in the concentration of thick fluid salt (seawater), results in a decrease and an increase in special power and passing water flow, respectively.
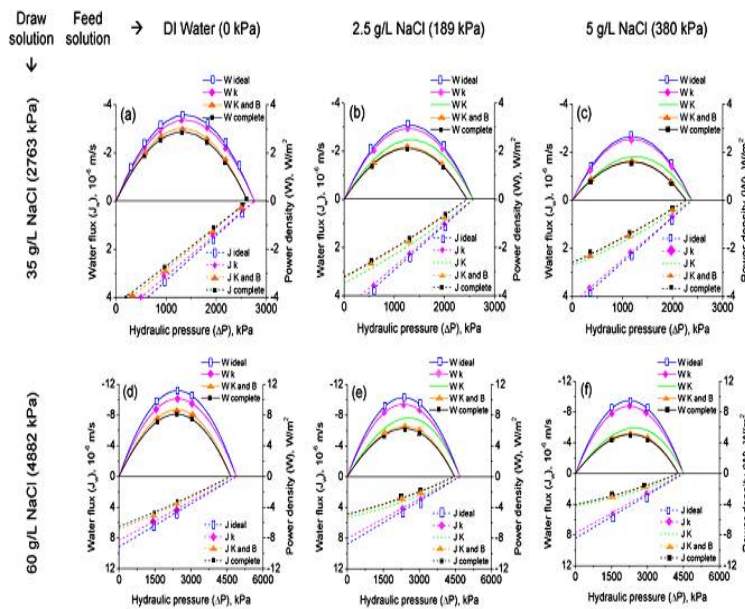
**Fig.6.** Results of model for water flow passing through the membrane (JW) and special power (W) as a function of working hydraulic pressure ΔP for different concentrations of feed flow and brine [1].

Several projects were considered for PRO plants. The operation will be performed as follows: fresh water is taken from a river near the plant and enters the plant after filtration and then is conducted to "hollow fiber or spiral arrangement" membrane section. Seawater with double volume than that of fresh water enters the plant through underground pipes. In the membrane, about 80-90 percent of fresh water enters the area which is pressurized by brine water through passing membrane. Then, this diluted brine water, is divided into two parts, that is one-third of it enters turbine to generate electricity and the other two-third of it is returned to pressurized area to keep incoming feed water at high pressure. Optimal operating pressure of the plant is between 11-15 bars. Used diluted water is pumped to river so that the river discharge is maintained. Sometimes, water requires some pretreatment operations before being purified, although experiences obtained in refineries of Norway indicate that mechanical filtration to 50 microns along standard maintenance cycles causes in 7-10 years of membrane performance. However, a similar life time is also considered for osmotic power plants. In Iran, regarding high concentration of salt in Urmia Lake (salt concentration of 280 grams per liter in the summer and salt concentration of 260 grams per liter in the winter) and given that many of rivers flow to this lake are fresh water rivers, this lake contains huge potential of energy. Therefore, Urmia Lake is an ideal place for osmotic power generation. Moreover, Persian Gulf and Oman Sea have salt concentration of about 48 grams per liter and 37 grams per liter, respectively. Regarding the availability of fresh water in Persian Gulf and Oman Sea, there is a good potential for the use of this method in the south of country with developed technology of producing membranes.

Caspian Sea having salt concentration of about 13 grams per liter is not a suitable sea for applying this method.

## 12- The Model of Photovoltaic Panels

Power generated by any radiated solar array is obtained as follows:

$$P_{PV} = \frac{G}{1000} \times P_{PV,rated} \times \eta \qquad (11)$$

G: perpendicular radiation to the plane of the array W/ m$^2$

$P_{pv}$: nominal power of any array obtained for G = 1000W / m$^2$.

$\eta_{pv}$ = efficiency of DC / DC converter installed between each array and DC bus bar and is considered about 95 percent [25].

## 13- Wind Turbine Model

Wind velocity at reference height $h_r$, is applied as daily average to determine the velocity of wind turbine in proposed model in the following.

$$v = v_{hr} \cdot \left(\frac{h}{h_r}\right)^{\gamma} \qquad (12)$$

Where wind velocity is at height h. Vr represents wind velocity at height $h_r$ and $\gamma$ is legal symbol of power and its value is from 1.7 to 1.4.

The following equation is used to calculate the power output of the turbine and $P_{WT}$ (t) as follows:

$$P_{WT} = \begin{cases} a.v^3 - b.P_R ; v_{ci} < v < v_r \\ P_R \qquad ; v_r < v < v_{co} \\ 0 \qquad\qquad otherwise \end{cases} \qquad (13)$$

Where, $a = \frac{P_R}{v_r^3 - v_{ci}^3}$ , $b = \frac{v_{ci}^3}{v_r^3 - v_{ci}^3}$ are allowed power, $V_{ci}$ , $V_r$ , $V_{co}$ are low cutting speed, nominal velocity and high cut-out speed of wind turbine, respectively [13].

## 14- Battery Model

State of charge and discharge of battery bank SOC can be calculated from the following equation [6]:

$$SOC(t + \Delta t) = SOC(t) + \eta_{bat}\left(\frac{P_B(t)}{V_{bus}}\right)\Delta t \qquad (14)$$

Where $\eta_{ba}$ equals 80% of efficiency for charge state and 100% of efficiency for discharge state.

$V_{bus}$: is the busbar voltage of DC and $\Delta t$ is the time step and equals one day.

SOC$_{min}$ is calculated as follows:

$$SOC_{min} = (1 - DOD).SOC_{max} \qquad (15)$$

Where, DOD represents the maximum depth of discharge and SOC $_{min}$ indicates the lower limit of SOC battery at the time of discharge [13].

## 15- Osmotic System Model

Osmosis is defined as movement and spontaneous movement of solvent molecules among part of impermeable membrane within the area of higher concentration of solutes in a way that solutes tend to balance on both sides. Osmosis is probably used to describe a physical process in which each solvent moves in semipermeable membrane flow (membrane is permeable to solvent but is not permeable to solutes); Osmosis can be applied to separate two solvents with different concentrations [17].

Regarding that the study area of Urmia Lake is located near a dam, required fuel for osmotic system of this study can be provided. Therefore, the model used for osmosis system is selected according to [10] and is capable of generating 1MW per $m^3/s$ of clean water, clean water flow performs at ambient pressure based on the fallowing equations:

A = Water permeability of the membrane

$\Delta\pi$ = Osmotic pressure

$\Delta P$= Hydraulic pressure

Jw= power

The general equation of water flow through the membrane ,

$$J_w = A(\Delta\pi - \Delta P) \tag{16}$$

Power density or power especially in PRO,

$$W = A\left[\pi d, b\, e^{\left(\frac{-Jw}{K}\right)} \frac{1 - \frac{\pi f,b}{\pi d,m} e^{(JwK)} e^{\left(\frac{Iw}{K}\right)}}{1 + \frac{B}{Jw}[e^{JwK} - 1]} - \Delta P\right]\Delta P \tag{17}$$

To administer algorithm, following parameters are taken into consideration as parameters of Ant Colony Algorithm

Table .1. Ant Algorithm parameters

| Pheromone evaporation factor | $\wp$ | 0.8 |
|---|---|---|
| Constant chosen by the user | $\alpha$ | 1 |
| Parameter to set the best route charm | $\zeta$ | 40 |
| The initial population of ants | m | 30 |
| The number of repetitions | | 50 |

Figures 7, 8, and 9.show generating power by hybrid solar-wind (renewable) system, generating power by osmosis system and required power of loading for various combinations of given system, respectively. As it is shown in below figures osmosis system has less efficiency compared with 10 kw wind-solar system. And although its overall cost is higher than other compounds, we are not disappointed from using it since the main purpose of osmotic system is not merely electricity generation and it should be used for environmental costs because it can prevent any change in the ecosystem of the region and any irreparable damage. Figure 10.shows input/output power of battery bank for a given system, and determines their state of charge and discharge during the year. Pb> 0 indicates battery charge and input power to the battery and Pb<0 represents battery discharge and output power of the battery. Convergence chart of the given system in ant algorithm for different combinations is shown in figure 11. figure 12.shows the operation of osmosis systems over the year. Regarding the volume of water in the river filled with the most water flowing to Urmia Lake and its basin, salt concentration of the water of area and maximum power with which membrane can be exploited are calculated.

Table.2.The result of optimum design of system in ant colony algorithm

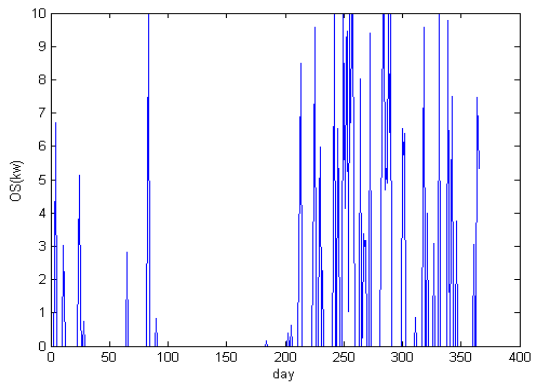| Solar And wind3 kw And osmotic | Type of system / Optimal values |
|---|---|
| 11 | Size photovoltaic (kW) |
| 5 | The number of wind turbines |
| 6 | Number of Batteries |
| 10 | Osmotic size(kW) |
| 20 | Size Exchanger(kW) |
| 139370 | Gross national expenditure($) |

**Fig.7.** Generating power of osmosis system
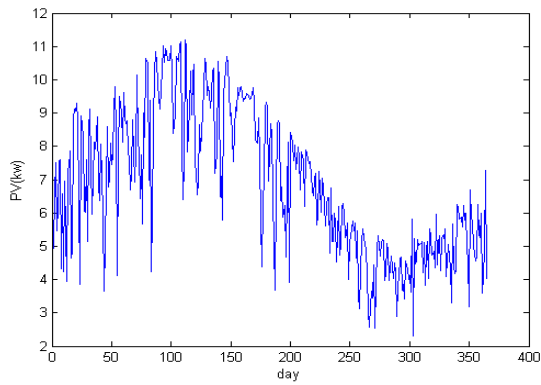


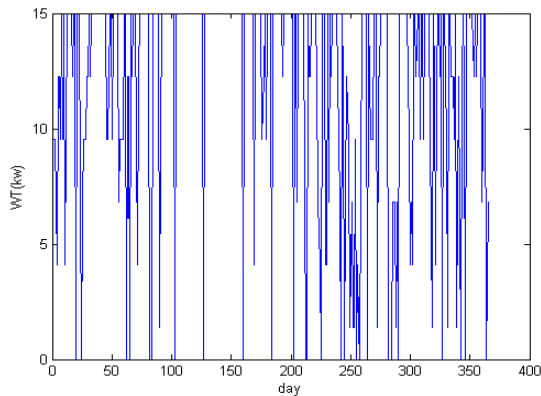**Fig.8.** Generating power of solar system



**Fig.9.** Generating power of wind system
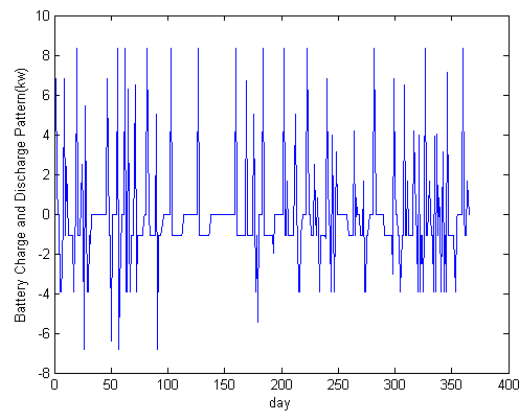


**Fig.10.** Charge and discharge of the battery
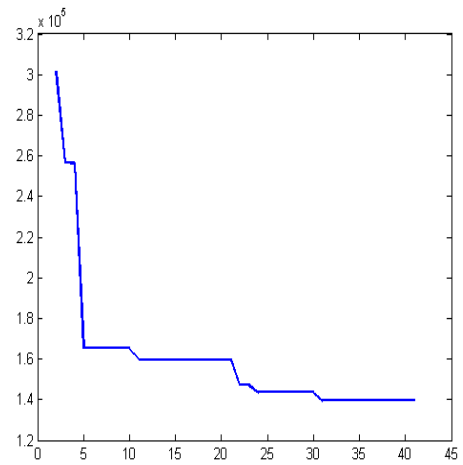


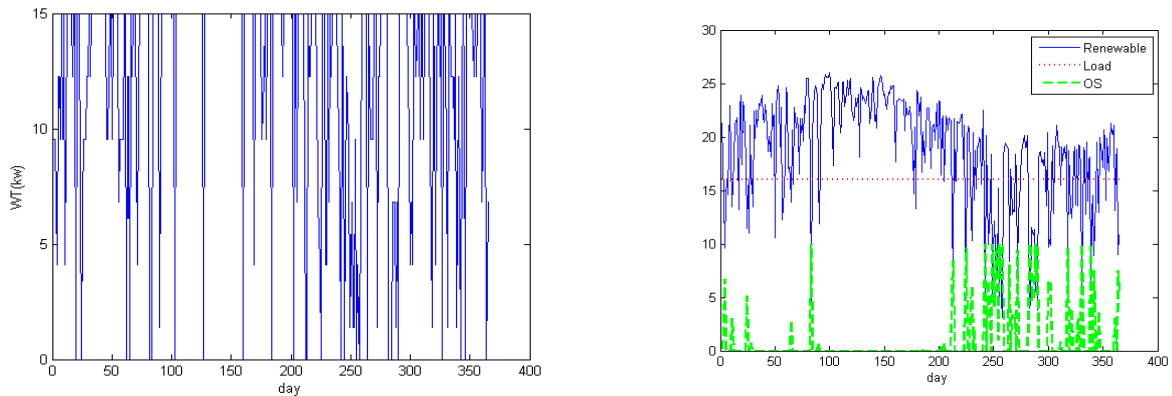**Fig.11.** Convergence chart of given system for 3kw wind turbine



**Fig.12**. Overall chart showing how to supply the given load of system

## 16- Conclusion

In this study, the optimal design of solar-wind-osmosis hybrid system is proposed for the area around Urmia Lake. This method of energy generation is so influential due to high potential of this method in energy generation due to the high concentration of the lake and its (fresh water) basin in the area. It is believed that this method can be beneficial for environmental structures and supplies the required water for Urmia Lake so that it will be revived. Costs for solar-wind-osmosis hybrid are estimated. The main objective of this thesis is to present a new way of hybrid energy generation to supply electricity power and above all to restore drying Urmia Lake using new methods of energy generation. In addition to power generation, the brine water can be used whenever necessary after it is purified to fresh water by proposed plant for agricultural purposes. Performing this method is examined thoroughly in the third chapter. Using this plant, it is not necessary to store water using dams which results in a disturbance in environment and its aftermath. The main aim of this thesis is to reduce the cost of generation and exploitation using algorithm according to the type of ecosystem and also new design of the osmotic power plant construction. In this design, plants are constructed under the ground near the dam of freshwater and brine lake. Using this method, it is no longer necessary to build water pump and compressor chambers. Therefore, osmosis plant construction requires lower amount and is more beneficial to exploit. So it can be said that the construction of such power plants will be affordable. Regarding that so far energy generation has been the number one cause of environmental pollution, which ranges from global warming to the pollution of fresh water and the entrance of industrial chemicals and radio-actives to seawater and ocean water which result in different genetic disorders in organisms, this type of plant promises a better future for our environment.

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