Neural Network Use in the MPPT of Photovoltaic Pumping System

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Abstract – This *study can be summed up as follows: The embodiment of the recent outcomes in the approach of the rudimentary theory of the neural network and its application in the field of the photovoltaic system of pumping water with centrifugal pump. And this can be done by means of elevations in the level of execution and control of the quantity of water that floods from the required head, for the close relation between the head and the quantity of the solar radiation that is fallen on the photovoltaic generator, under systematic conditions in its temperature. The followed strategy in relying on the intelligence of the technique of the back propagation for the error of neural network has proved its success in the level of learning and was esteemed by 100%.*

Résumé – *Cette étude peut se résumer comme suit: L'incorporation des résultats récents dans l'approche de la théorie rudimentaire du réseau neurone artificiel et son application dans le domaine du système de pompage photovoltaïque d'eau avec une pompe centrifuge. Le contrôle de la quantité d'eau est exécuté selon une boucle des relations entre la hauteur, la quantité d'eau et l'éclairement solaire incident sur le générateur photovoltaïque, dans des conditions systématiques du température. La stratégie suivie en comptant sur l'intelligence de la technique de retro-propagation pour calculer l'erreur du réseau neurone a prouvé son succès au niveau de l'étude, et a été estimée de 100%.*

Key Words: Maximum power point tracking (MPPT) – Neural network – Photovoltaic system of pumping water – Solar energy.

1. INTRODUCTION

After the human discovery of the electric energy, the human life has changed. Then, There was the exploitation of the vanishing natural resources, such as: coal, oil, uranium...etc, in order to produce energy with different ways. Through time, our green planet was endangered by the radiation of the nuclear stations, the sea and land pollution, the rising of temperature because of the intoxicated gases in the air that come from electric power stations that use oil and its derivatives and which will diminish in the future, human being will be obliged to use a renewable source of energy. Since the world is convinced by this, especially developed countries which tried to adopt intensive planning and program in order to encourage researchers to find out methods to get this energy with less expensive costs.

The sun is the first resource of the unrenewable energies that were accumulated through millions of years like, oil, coal and natural gas. It is also a source for other renewable energies. Like, winds, waterfalls, biomass, sea waves, and temperature of oceans and so on. Thus, the sun is the important source of energy through which we produce the electric energy through its solar radiation. That is abundant, free, enduring and unpolluted.

Since the ancient ages, the human being benefited directly from solar radiation energy in different applications. And till now, solar energy offers good solution to supply desert and isolated regions with DC and AC electricity. It is also used in lighting roads, buildings, different means of communication, loading batteries, pumping water and so on. Solar energy is used by transferring the solar radiation to electrical energy through solar cells. These latter consist of semi-conductor substances like CELISIUM and GERMANIUM and so forth. They are characterized by not having moving pieces. It has high fiability with less maintenance. But its efficiency is only about 14%. The studies are continuing to rise this percentage and to decrease its cost of production. Its relatively high price is considered temporary. And it is also the basic obstacle to spread the use of photovoltaic system. Specially for the countries that miss its technological fabrication. The fast development of solar cells production and the important recorded historical discoveries are signs of the new incline in the use of solar energy.

As Algeria is characterized by its good geographical situation, it receives important quantity of solar radiation during the years and the seasons[1]. By exploiting this energy, we can be on the top in the use of solar energy systems. Among them, we have photovoltaic pumping system by which we store water in basins, and by this way, the global cost of the system decreases. By applying the technique of Maximum Point Power Tracking (MPPT), the efficiency of the system rises whatever is the solar radiation value and the temperature of the environment. And which not like the use of direct link. The technique of MPPT was applied by different ways and means[2]. In this study, we execute this technique with the use of artificial neural network

2. PHOTOVOLTAIC PUMPING SYSTEM

It is a way to bring out and pump water to a limited standard. Where it can be stored or used directly. And this needs the use of suitable pumps that are frequently used because they can pump water to an acceptable head, even in slow speed.

2.1. Centrifugal pumps

The use of centrifugal pump needs a preliminary study of the most important charts that characterize it. These charts sum up the relation between the whole variables that control the pumped water quantity to a desirable head(Q-H). In addition, they are related to dimensions, kinds and rotation speed of the pump [3].

The chart of the water quantity-head(Q-H) explains the different variations in the head of pumping, according to water quantity which forms bent charts. These latter are calculated by the following equations:

$$H = C1\,\omega^2 - C2\,\omega Q - C3Q^2 \quad (1)$$

$$H = H_g + \Delta H \quad (2)$$

The variation of the pump's rotation speed can give us numerous charts. The more speed rises, the more pumped water quantity with the head rises [4]. But all charts are limited to the geometric head H, shown in figure 2.

2.2. Permanent magnet bruchless direct current motor

The needed rotation speed to make a pump can be provided by the (BLDC). This latter can be used in PV pumping system because it has a good efficiency about 80%, It is small in size, but with a large scale of speed variations and it is flexible in function. Furthermore, it is similar to the DC motor. Based on DC motor equations which are given as follow:

$$U_{ch} = 2R\,Ich + 2ke\omega \quad (3)$$

$$Ich = (A_c/ke)\,\omega^2 \quad (4)$$

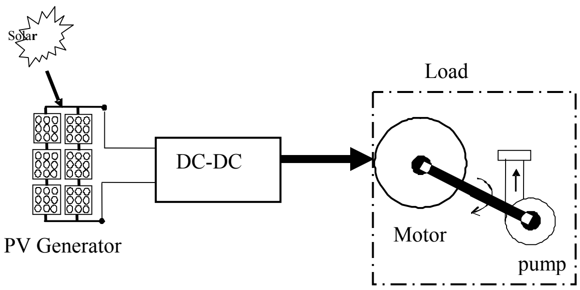

Fig.1: Schematics of a photovoltaic pumping system

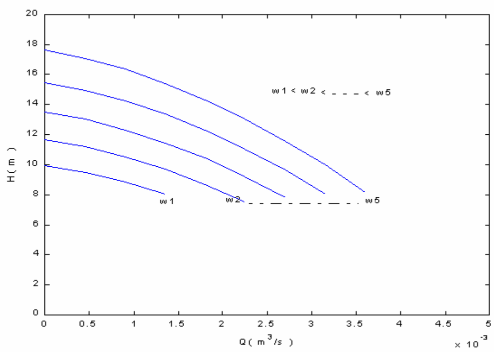

Fig.2: H-Q Characteristics centrifugal pumps with various speeds w

2.3. Photovoltaic generator

In the PV pumping system, the group of pump-motor is considered as the load that must be supplied by a nominal power from the photovoltaic generator. In this PV generator, 36 solar cells are assembled to form a photovoltaic module which can store a battery of voltage 12 V through the ascendant solar radiation. The link between these modules in series helps us to rise the required direct voltage value. And its link in parallel helps us to rise direct current value. Thus, the photovoltaic generator is a group of linked photovoltaic modules according to the values of both the current and the voltage that are required (i.e. according to necessary power to supply the load), shown in figure 3.Two main parameters can directly affect the power of generator which are both the temperature and solar radiation. The presented characteristics in figure 4 explain them clearly. Yet, figure 5 explains non- linear relation between the current and voltage of the photovoltaic generator [5], and according to the equations (5) and (6).

$$I = I_g - I_{sat}\left[\exp\left(q(V+R_s I)/(AKT)\right)-1\right] \quad (5)$$

$$I_g = \left[I_{sc} + K_I(T_c - 25)\right](\lambda/100) \quad (6)$$

2.4. Solar radiation

The earth receives solar energy as electro-magnetic waves which we define as "solar parameters" as the average quantity of the radiation that is incident on the earth level. The value of this parameter is between 0 and 1000(w/m^2). The quantity of solar energy, which is ascendant somewhere, (i.e. solar radiation values)relies on many factors: The geographical situation, the time during the day and the season, the purity of the air, the determination of the variation in humidity and temperature, and the wind speed. All these factors were taken into account during the determination of solar radiation direction in the chart. Most of the researches tended to simplify and generalize solar radiation that is mentioned in sinusoidal function (9). It is limited in 12 hours a day where it reaches the peak during the mid-day, like in figure 6.

$$E(t) = E_m \sin\left(15(t-6)\right) \quad (7)$$

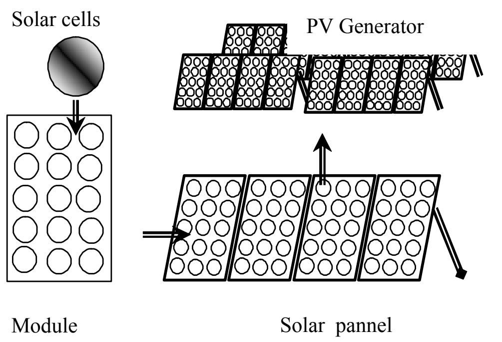

Fig. 3. Photovoltaic generator hierargy

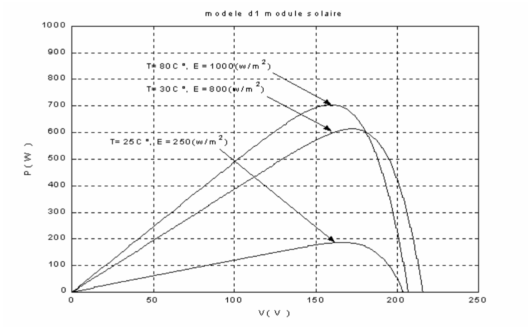

Fig.4. Effect of solar radiation and temperature on PV generator power

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Fig.5: Non-linear charts of PV generator voltage and current

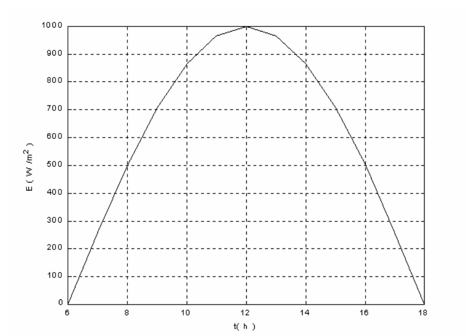


Fig.6: Model of solar radiation during a day

3. EXPERIMENTS AND RESULTS

The increasing demand for a developed technology in the different systems, characteristics and efficiency led to an important development in the new techniques and its introduction in the numerical control systems. For instance, neural network technique [6] which is characterized by its capacity to adopt in order to identify the parameters of non-linear system [7-8] and improve its work. Like the case in the proposed system which acts under a random variation of the natural factors like, temperature, solar radiation and wind speed. This variation imposes a study on the system's function with the neural network techniques.

3.1. Neural network architecture

Neural network architecture is specified in finding the appropriate solution for the non-linear and complex systems or the random variable ones. Among its types, there is the back propagation network which is more widespread, important and useful. The function and results of artificial neural network are determined by its architecture that has different kinds. And the simpler architecture contains three layers as shown in figure 7. The input layer receives the extern data. The second layer, hidden layer, contains several hidden neurons which receive data from the input layer and send them to the third layer, output layer. This latter responds to the system.

We can conclude unlimited neural network architectures. The more several hidden layers and neurons in each layer are added; the more complex they become. The realization of the back propagation network is based on two main points: learning and knowledge. This research was applied by the use of sigmoid function as an activation function in order to calculate the hidden layer output and the linear function to calculate the output[9]. X_i is applied to the input vector which consists of n variable. The outputs are calculated by the following equations:

$$Y_j^h = f\left(\sum_{i=1}^{n} W_{ji} x_i + \theta_j^h\right) \tag{8}$$

$$Y_k^o = f\left(\sum_{j=1}^{Nh} W_{kj} Y_j^h + \theta_k^o\right) \tag{9}$$

Algorithm architecture of the back propagation implies the following steps:

- Step one: It is the initial state in which the synaptic weights are given in random values.
- Step two: It is to apply input vector X_i with this desired output and the example given one by one, then, the calculation of present output vector by (8) and (9) equations.
- Step three : It is to compare the present output with the desired one and the calculated error.
- Step four : It is to regulate an adaptation of the synaptic weights anew.
- Step five: It is to repeat the second Step to the fourth one by using another example.

3.2. Maximum point power tracking

The direct motor supply from the PV generator occurs in special cases, i.e. when the load is adopted to PV generator. The used power is often weak when compared with the extracted power which weakens clearly the efficiency of the system. For the purpose of raising the power and as a result the efficiency of its system, the DC.DC chopper take an intermediate position between the generator and the motor in order to regulate its supply with a maximum power by regulating its gain. The MPPT and neural network have been interconnected in order to control over the chopper gain. This can be done by considering both the open-circuit voltage and short circuit current as two inputs, and the optimal voltage as the output for the neural network [10]. We can also consider both the open-circuit voltage and the time corresponding to the solar radiation value as inputs [11]. The detailed study of MPPT technique in the PV pumping system has confirmed that its efficiency is about 99%, thus it can obtain a considerable pumped water quantity, and this is based on the data and results [12].

Fig. 8 explains the increase of Q by the increase of E, and its decrease by the increase of temperature in the environment. At 25 C° the water flood from centrifugal pump is optimal. In another hand, there is a direct relation that is proved between the standards of pumped water head H and the solar radiation E, see [13]. According to special mathematical models that are applied on various pumping systems, the use of H and E to control over pumping operation is a possible method. Then, we chose to change the application of neural network by choosing Q and E as its output and input respectively, and tracking the error of algorithm back propagation in applying the learning program. The proposed question here is, what is the less complex network, that must be structured and which has a high possible competence?

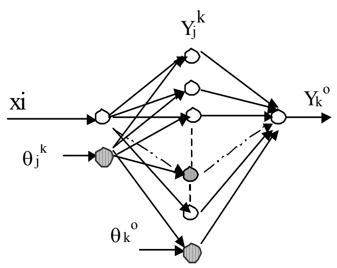


Fig.7: Diagramme of neural network hierarchy

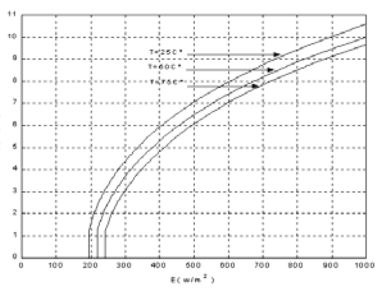


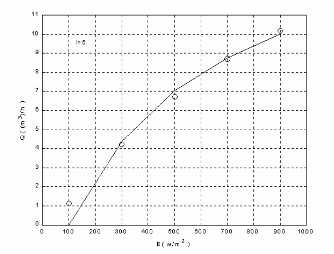
Fig.8: Charts of pumping water quantity during a half day with changeable temperature

4. DISCUSSION

The maximum execution of the used pump is at 25 C°, this is shown in figure 8. Since the water quantity has a direct relation with solar radiation, both of the variables can be exploited to execute the neural network. This exploitation was engaged in the study of the effect of learning examples on network learning and effect of network architecture on learning.

4.1. Effect of learning examples on network learning

There are many factors and stimuli that play important roles in correctness of the concluded solutions of the synaptic weights for the executed program. Among these factors, there is a number of proposed learning examples on the network. Figure 9 shows its effect or the fast convergence of the program. The increase of the number of learning examples improves the synaptic weights values. In addition, it can decrease the difference between the example and that follows it. This can diminish any far expectation about the points between them. Figure 10 was found out according to a fixed number about 50 iterations. It draws the calculated outputs on the desired charts, Thus, the observed increase of examples to 50 make us track the output function precisely. The learning error starts from 1 and decreases to 10^{-2} , taking 20 iteration, for 5 learning examples. We can improve this by the increase of the number of examples. At 50 examples, the error starts from 10^{-1} and converges fast to 10^{-4} taking 15 iterations.



(a)

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(b)

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(c)

Fig.9: Output function and calculate examples charts

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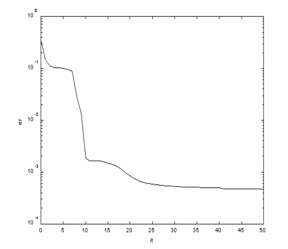
(a)



(b)

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(c)

Fig.10: Learning error with learning examples in 50 iteration

4.2. Effect of network architecture on learning

In our study of the effect of network architecture on learning, we took 900 points as a number of learning examples. The single input is solar radiation and the single output is the required pumped water quantity. We have changed the number of hidden layers and neurons in each layer. This architecture is summarized in the second column of the table-1. Third column represents the bias. Concerning the fourth column, there are synaptic weights. The fifth column contains the first group, which concerns a network with a single hidden layer, learning error can be improved by increasing the number of neurons. By 8 neurons, the error decreases to 10^{-6}.

The second group concerns a network with two hidden layers. In the case 4, the program was diverged and the error became great. Whereas, the cases 5 and 6 gave considerable outcomes where the error is 10^{-10}. The more we arise the number of layers and neurons, the more we improve the learning program by an error of 10^{-12}, like in the case 12. But this increase can complicate and make the network bigger in size. We can have the same size of network whatever is the number of its layers and neurons, this is shown clearly in the case 2 which has the same size with case 4, case 3 with 10 and the case 8 with 11.The last column sums up the number of iterations. A fixed learning error is that about 10^{-6}.

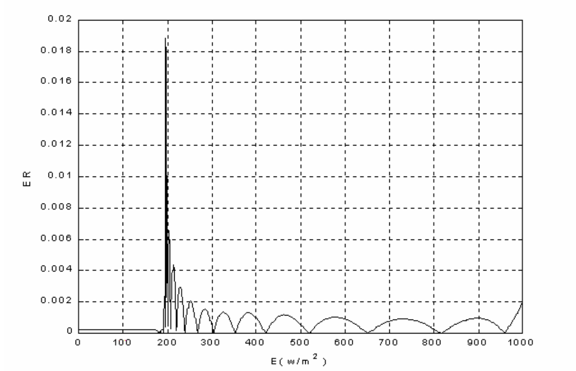

Fig.11: Chart of error between calculated and desired outputs during a half day

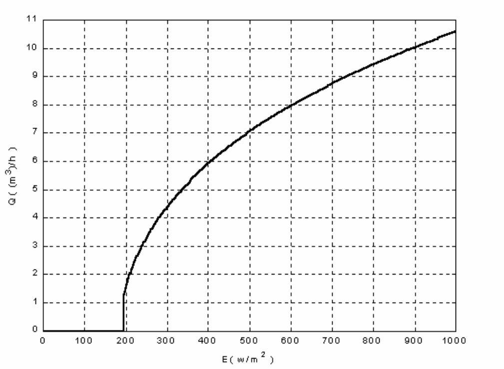

Fig.12: Two Charts of pumping water quantity by neural network application

The difference between the neural network architectures affects clearly the convergence speed of learning program and as a result the time of execution. We have chosen the case 6 i.e. the neural network with two hidden layers, with 4 neurons for each and 1802 learning examples to draw the fig. 11. This figure shows the error of calculated output and desired output by the solar radiation function. The error arises in low values of (E= 200(w/m^2)). This leads to the loss of 1.9% in the water quantity. These losses are neglected values. This is proved in fig. 12 for the two charts compatibility i.e calculated output and desired output for water quantity by the solar radiation function during a half day.

Table.1: Effect of network architecture on learning

Cases	$[x_i\ Y_j^k\ Y_k^o]$	θ	W	Error it=500	it
1	[1 2 1]	3	4	$3.3*10^{-4}$	-
2	[1 4 1]	5	8	$8.7*10^{-5}$	-
3	[1 8 1]	9	16	$4.5*10^{-6}$	-
4	[1 2 2 1]	5	8	$2.6*10^{-4}$	-
5	[1 2 4 1]	7	14	$1.3*10^{-7}$	824
6	[1 4 4 1]	9	24	$2.3*10^{-10}$	146
7	[1 2 2 2 1]	7	12	$6.9*10^{-12}$	1310
8	[1 2 4 2 1]	9	20	$9.9*10^{-8}$	1902
9	[1 3 4 3 1]	11	30	$7.5*10^{-12}$	180
10	[1 2 2 2 2 1]	9	16	$8.3*10^{-9}$	3116
11	[1 2 2 3 2 1]	10	20	$4.9*10^{-9}$	916
12	[1 3 3 3 3 1]	13	33	$8.9*10^{-12}$	311

5. CONCLUSION

The obtained outcomes demonstrate the error of the back propagation technique for the neural network. This technique guarantees first the rising in the efficiency of PV pumping system by improving the control of system functioning, through a linked loop that relates three elements to each other. And the control of the water head that concerns the pumped water quantity that is related to the absorbed solar radiation quantity from photovoltaic generator. The appropriate choice of single output and input for the neural network (i.e the pumped water quantity and solar radiation quantity respectively), the execution of learning program with a great deal of examples and the chose of the suitable mathematic equations help us to apply it with a distinctive, simple and highly competent structure.

The application of the practical chosen neural network with cheap available electronic instruments rests an objective for generalizing and spreading the use of photovoltaic pumping system.

APPENDIX

PV generator	Short circuit current (A)	4.81
	Open-circuit voltage (v)	224
	Resistance Series (Ω)	2.25
Motor	Nominal power (w)	690
	Nominal speed (tr/min)	3000
	Supply voltage (v)	200-220
	Nominal current (A)	4.8

NOMENCLATURE

A_c : Constant of resistive torque $w/((rd/s)^3)$
E: Solar radiation (w/m^2)
H: Head (m)
H_g : Geometric head (m)
I_{ch}: PV generator current (A)
I_{sat} : solar saturation current (A)
I_{sc}: Short circuit current of PV generator (A)
ke: Constante of e.m.f (v/(rd/s))
Q : Water quantity (m^3/s)
R : Motor resistance (Ω)
R_s : Resistance Series of PV generator (Ω)
t : Time (hour)
T: Temperature (C°)
V : PV generator load (V)
U_{ch} : Load voltage (V)
ω : Rotation speed (rd/s)

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