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Chapter 4 DESIGN OF WES INTERCONNECTED WITH EU

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Chapter 4

DESIGN OF WES INTERCONNECTED WITH EU

4-1 INTRODUCTION

Depletion of fossil fuels and the concomitant climate change have compelled nations to seek new, nonpolluting ways to produce energy. Consequently, renewable energies like wind, solar, biomass, and geothermal energies have been viewed as attractive solutions [112]. The total installed wind generation capacity worldwide is expected to rise from 14,000 MW in 2002 to 47,000 MW in the year 2004. The wind generation in Europe alone is projected to reach approximately 33,600 MW by the year 2004 [113]. Egypt targets to increase the installed capacity to reach 1750 MW by the end of 2017, more than 750 MW will be undertaken by private sector [46]. Wind energy is transformed into mechanical energy by means of a wind turbine that has several blades. It usually includes a gearbox, G.B., which matches the turbine low speed to the higher speed of the generator. Some turbines include a blade pitch angle control for controlling the amount of power to be transformed. The electrical generator transforms mechanical into electrical energy. The electrical generator can be synchronous or asynchronous [18].

This chapter introduces a proposed computer program for optimal design of WES to be interconnected with EU. A proposed computer program has been designed to determine the optimum number of WTG's based on MPPs by using neural network for the system under study. Many WTG types have been introduced to the computer program to choose the best type of WTG. By using the proposed computer program the WES components can be completely designed to be interconnected with EU. This program has a subroutine which by using it the optimum operation of WES can be determined hour by hour through the year. Then, the monthly surplus energy, monthly deficit energy and yearly purchase from EU or selling energy to EU can be estimated. The decision from the computer program is based on minimum price of the generated kWh from the WES. Control system is needed for the WTG to track the MPPs. This control system has been designed by neural network approach.

4-2 DESIGN METHODOLOGY OF WES AT MPPs

The design of WES has been summarized as follows:-

4-2-1 Modification of Average Wind Speed to Hub Height

Usually weather stations measure wind speed at 10-m or 20-m. If these heights do not match the hub height of a wind turbine it is necessary to extrapolate the wind speeds to hub height of the turbine [114]. This process can be done by the following equation:

$$u_h = u_{ho}(h/h_o)^{\alpha} \qquad [114] \qquad (4\text{-}1)$$

Where;

u_h : The wind speed at height h-m, m/s.

u_{ho} : The wind speed at height h_o-m, m/s, (h_o is usually 10-m)

h : The height from ground, m.

α : The Exponent is usually 1/7.

4-2-2 Estimation of Weibull Parameters, C and K

There are several methods available for determining the Weibull parameters C and K. One of them is based on least-squares approximation to straight line. In this method the wind speed (u) is distributed as the Weibull distribution if its probability density function is as follows [114]:-

$$f(u) = \frac{K}{C}\left(\frac{u}{C}\right)^{K-1} \mathrm{Exp}\left[-\left(\frac{u}{C}\right)^{K}\right] \qquad (K > 0,\ u > 0,\ C > 1) \qquad [114]\ (4\text{-}2)$$

Where;

C : The scale parameter, m/s.

K : The shape parameter.

u : The wind speed, m/s.

We perform the necessary mathematical operations on Eqn. (4-2) to linearize it and then determine (C) and (K). The first step of linearization is to integrate the following Equation:

$$f(u) = \frac{dF(u)}{du} \qquad [114]\ (4\text{-}3)$$

Where;

F(u) : The cumulative distribution function.

Substituting from Eqn. (4-2) into Eqn.(4-3) and integration it for F(u), with taking F(0)=0 and F(∞) =1. The following equation can be obtained:

$$F(u) = 1 - \mathrm{Exp}\left[-\left(\frac{u}{C}\right)^{K}\right] \qquad [114]\ (4\text{-}4)$$

It can be seen that the F(u) contains an exponential and that in general, exponentials are linearized by taking the logarithm twice [114].

$$\mathrm{Lin}\left[-\mathrm{Lin}\left(1 - F(u)\right)\right] = K\ \mathrm{Lin}(u) - K\ \mathrm{Lin}(C) \qquad (4\text{-}5)$$

This is in the form of an equation for a straight line.

$$y = ax + b \qquad (4\text{-}6)$$

where x and y are variables, a is the slope, and b is the intercept of the line on the y axis. In particular,

$$\begin{aligned} y &= \mathrm{Lin}[-\mathrm{Lin}(1-F(u))] \\ a &= k \\ x &= \mathrm{Lin}(u) \\ b &= -K\ \mathrm{Lin}(C) \end{aligned} \qquad [114]\ (4\text{-}7)$$

Data will be expressed in the form of pairs of values of u_i and $F(u_i)$. When given values for $u=u_i$ and $F(u)=F(u_i)$, we can find values for $x = x_i$ and $y = y_i$ in Equ. (4-7). From x_i and y_i the proper values for a and b are as follows [114]:-

$$a = \frac{\sum_{i=1}^{w} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{w} (x_i - \bar{x})^2} \qquad (4\text{-}8)$$

$$b = \frac{1}{w} \sum_{i=1}^{w} y_i - \frac{a}{w} \sum_{i=1}^{w} x_i \qquad (4\text{-}9)$$

Where;

$\bar{x}$ and $\bar{y}$: The mean values of x_i and y_i.

w : The total number of pairs of values available.

The final results for the Weibull parameters are as follows:-

$$\begin{aligned} K &= a \\ C &= \exp(-b/K) \end{aligned} \qquad (4\text{-}10)$$

4-2-3 Calculation of Capacity Factor, CF and ANWTG

The capacity factor, CF, has calculated by using the following Equation:

$$CF = \frac{\mathrm{Exp}\left[-(U_c/C)^K\right] - \mathrm{Exp}\left[-(U_r/C)^K\right]}{(U_r/C)^K - (U_c/C)^K} - \mathrm{Exp}\left[-(U_f/C)^K\right] \qquad [114]\ (4\text{-}11)$$

Where;

U_c : The cut-in speed of the WTG, m/s.

U_r : The rated wind speed of the WTG, m/s.

U_f : The cut-off speed of the WTG, m/s.

The average electric power output form WTG, $P_{e,ave}$ can calculated by using the following Equation:-

$$P_{e,ave.} = P_{rated}\ CF \qquad [114] \qquad (4\text{-}12)$$

Where;

CF : The capacity factor.

P_{rated} : The rated electrical power output from the WTG, kW.

The average number of wind turbine generators, ANWTG, can be estimated from the following Equation:-

$$\text{ANWTG}, N_w = \frac{P_{L,ave.}}{P_{e,ave.}} \qquad (4\text{-}13)$$

Where;

$P_{L,ave.}$: The average load, kW.

4-2-4 Output power form WTG at MPPs

The amount of mechanical power extracted from WTG is depended on the coefficient of performance, C_p and is given by the following Equation:-

$$P_m = 0.5\ C_p\ \rho\ A_w\ u^3 \qquad [114]\ (4\text{-}14)$$

Where;

C_p : The coefficient of performance.

ρ : The air density, kg/m^3.

A_w : The swept area of the turbine, m^2.

u : The wind speed, m/s.

The coefficient of performance is not constant, but varies with tip speed ratio, λ, as shown in Fig. 4-1. The tip speed ratio can be obtained from the following equation [114], [115]:-

$$\lambda = \frac{r_m * \omega_r}{u} \qquad (4\text{-}15)$$

Where;

r_m : The radius of turbine swept area, m.

ω_r : The mechanical angular velocity of the turbine, radians/sec.

The angular velocity ω_r can be determined from the rotational speed by the equation:-

$$\omega_r = \frac{2 * \pi * n}{60} \qquad [114] \qquad (4\text{-}16)$$

Where;

n : The rotational speed, revolution per minute.

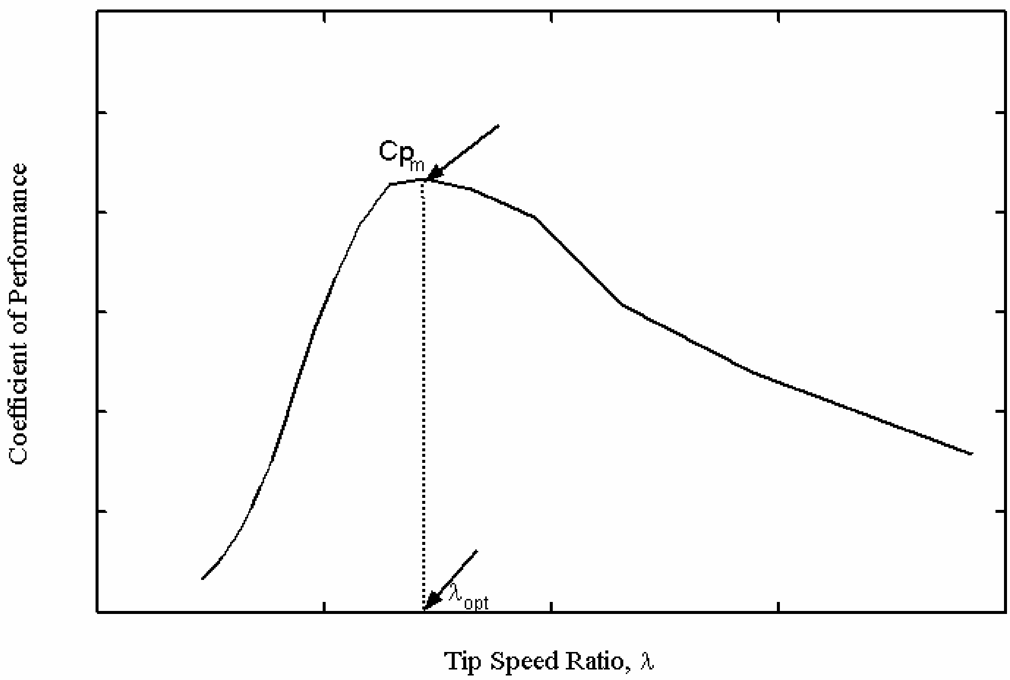

Fig. 4-1 Coefficient of Performance Versus tip speed ratio

As shown in Fig. 4-1, the performance coefficient which represents the efficiency of the wind turbine varies as the tip speed ratio. As the tip speed ratio increases, the wind speed decreases and the Cp increases until it reaches the maximum Cp at optimum tip speed ratio. As the wind speed continues to increase then the performance coefficient Cp declines. This process makes the wind turbine self regulate its output power by operating at lower efficiency at high wind speeds. It is clear from Fig. 4-1 that there is a value of λ for which C_p is maximized, thus maximizing the power for a given wind speed. Each wind speed has a variable turbine speed value that gives a maximum output power from WTG.

The mechanical output power in Eq.(4-14) can be rewritten as a function of rotor speed by the following Equation:

$$P_m = 0.5\ \rho\ A_w \frac{C_p(\lambda)}{\lambda^3}\ \omega_r^3 \qquad (4\text{-}17)$$

From the coefficient of performance curve Cp(λ) in Fig. 4-1, there is a λ_{opt} where Cp is maximum, i.e. $Cp(\lambda)^{max} = Cp(\lambda_{opt})$. Therefore, to extract maximum power from WTG, it is necessary to change the speed of the WTG to be proportional to wind speed in order to always keep $\lambda=\lambda_{opt}$. Substituting $Cp(\lambda)^{max}$ and λ_{opt} into Eq. (4-17) we obtain:

$$P_m^{max} = 0.5\ \rho\ A_w \frac{C_p(\lambda)^{max}}{(\lambda_{opt})^3}\ \omega_r^3 = M\,\omega_r^3 \qquad (4\text{-}18)$$

Where;

M : The constant for specified WTG.

The relation between output power from WTG and rotor speed (n) is shown Fig. 4-2.

4-2-5 Design Issue of the NN for MPPs

Design of WTG at maximum power extracted is an important issue. In order to extract maximum power from WTG the rotor must be held at its optimal tip speed ratio, which means that the WTG operates in variable speed. The optimal tip speed ratio is the value of λ corresponding to maximum coefficient of performance. In order to achieve this ratio the induction generator, IG load line should be matched very closely to the maximum power line of the WTG. So, the rotor angular velocity must vary proportional to wind speed to force the WTG at the optimum tip speed ratio to get maximum C_{pm}. The relation between the electrical power output from WTG and rotational speed for different wind speed is shown in Fig. 4-2. This power can be supplied to the load/grid at a grid frequency through back to back converter. The function of NN is to operate the generator speed at maximum power output condition. For wind speed u_1 in Fig. 4-2, the maximum output power will be at point (1), therefore the NN will send a signal to an electronic switch which controlled the speed of the GB to reach the speed at n_1 where the output power is at maximum point. If the wind speed increases to u_2 , the output power will jump to point (2) and NN will bring the GB through an electronic switch at n_2 to extract maximum power from WTG at this wind speed and so on.

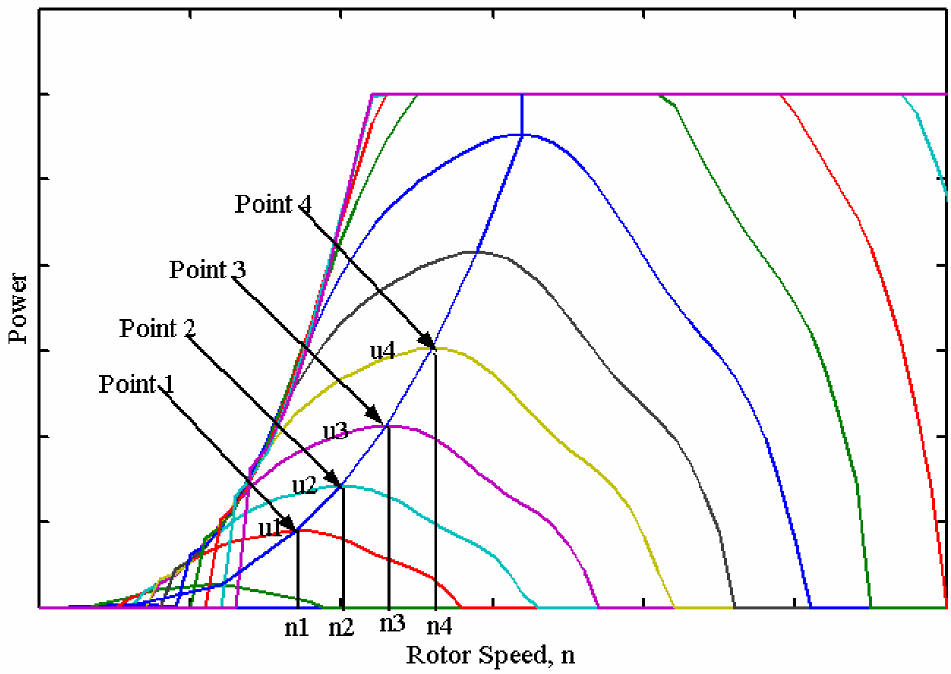

Fig. 4-2 Shaft Power Output Versus Generator Speed

4-3 CALCULATION OF OPTIMUM NUMBER OF WTG'S

The energy balance between the load and the output of WES should be carried out to compute the optimum number of WTG's, N_w. The hourly generated power, $P_{WTG,out}(t)$, and hourly load power, $P_{Load}(t)$, are compared with each other. If $P_{WTG,out}(t)$ is larger than the load power demand then there is an hourly surplus power, but if $P_{WTG,out}(t)$ is smaller than the load power demand then there is an hourly deficit power. At any value of N_w, if the summation of hourly surplus power approximately equal to the summation of hourly deficit power then this value of N_w represents the optimum number of WTG. The following equations have been used to get the optimum number of WTG's [69].

$$\text{If} \sum_{t=1}^{ty} [N_w * P_{WTG,out}(t) - P_{Load}(t)] > 0 \tag{4-19}$$

Where;

ty :The yearly hours.

$P_{WTG,out}(t)$:The hourly generated power from WTG. It can be described by the following formula [114].

$$P_{WTG,out}(t) = \begin{Bmatrix} 0 & : u < U_c \\ C_p \ \eta_m \ \eta_g \ 0.5 \ \rho \ Aw \ u(t)^3 & : U_c \le u \le U_r \\ P_{rated} & : U_r < u < U_f \\ 0 & : u > U_f \end{Bmatrix} \tag{4-20}$$

Where;

η_m :The mechanical efficiency.

η_g :The generator efficiency.

Then, number of WTG's must be decreased by one WTG and repeating the foregoing process:

$$\text{If} \sum_{t=1}^{ty} [N_w * P_{WTG,out}(t) - P_{Load}(t)] < 0 \tag{4-21}$$

Then, number WTG's must be increased by one WTG and repeating the fore-going process.

If $$\sum_{t=1}^{ty} [N_w * P_{WTG,out}(t) - P_{Load}(t)] \cong 0 \qquad (4\text{-}22)$$

Then, N_w is the optimum number of WTG's which satisfy the energy balance condition. The value of N_w has been taken as the optimum number of WTG's and can be named ON_w.

4-4 METHODOLOGY OF ECF [62], [114]

The ECF of WTG/EU can be estimated as follows:

Total cost of WTG, TCWTG= TW $*ON_w*$ R (4-23)

Where;

R : The rating of WTG, kW

TW : The price of WTG, $/kW

ON_w : Optimum number of WTGs.

Total cost of microprocessor, TCMIC=TP$*ON_w*$R (4-24)

TP : The price of microprocessor, $/kW

Total cost of main substation, TCMS= TS$*ON_w*$R (4-25)

TS : The price of main substation, $/kW

Total cost of modem for remote control, TCRC=TM$*ON_w*$R (4-26)

TM : The price of modem for remote control, $/kW

Total cost of control in central control station, TCCC=TC$*N_w*$R (4-27)

TC : The price of control in central control station, $/kW

Total cost of transmission line, TLC=TR$*ON_w*$R (4-28)

TR : The price of transmission line, $/kW

Total cost of WTG, TCC=TCWTG+TCMIC+TCMS+TCRC+TCCC+TLC (4-29)

Levalized annual cost of WTG, LACw= K_w * TCC (4-30)

Where;

$$K_W = \frac{r*(1+r)^{nw}}{(1+r)^{nw}-1} \qquad (4\text{-}31)$$

nw : The life period of WTG.

r : The interest rate of WTG.

Operation and maintenance cost, O&MC=0.05*LAC_W (4-32)

Total levalized annual cost for WTG, $TLAC_W$= (LAC_W+O&MC)/0.9 (4-33)

Energy cost figure, ECF, $/kWh

=$TLAC_W$/Total expected yearly energy generated. (4-34)

4-5 APPLICATIONS AND RESULTS

4-5-1 Design of WES

A new proposed computer program has been designed depended on the above methodology for calculating optimum number of WTG. The flowchart of this program is shown in Fig. 4-3.

The input data of this program is:

1- Hourly wind speed, m/s.

The hourly wind speed for the selected site is the first data required for design of WES. The data has been obtained from the Egyptian Metrological Authority for Zafarâna site. Figure 4-4 shows the hourly wind speed over the year seasons as a sample data for months January, April, July and October.

2- Characteristics of each type of WTG.

In this study, fifteen different selected types of WTG's have been used. The characteristics of these WTG's are revealed in Table (4-1).

3- Hourly load demand, kW.

It is assumed here that the load demand varies monthly. This means that each month has daily load curve different from other months. Therefore, there are twelve daily load curves through the year. Hourly load demand are shown in chapter 2 (Fig. 2-9) for months January, April, July and October.

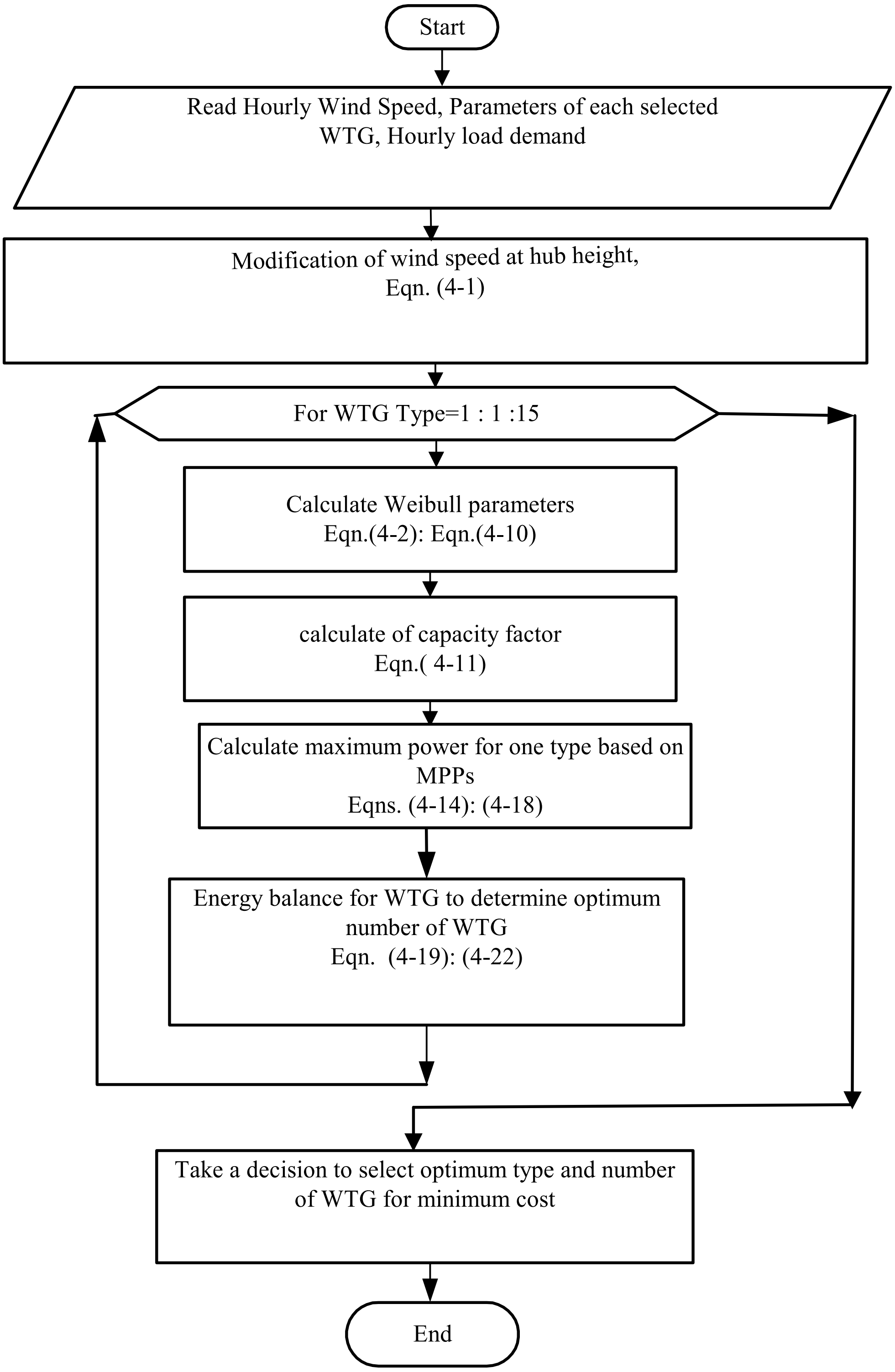

Fig. 4-3 Flowchart of the Proposed Computer Program.

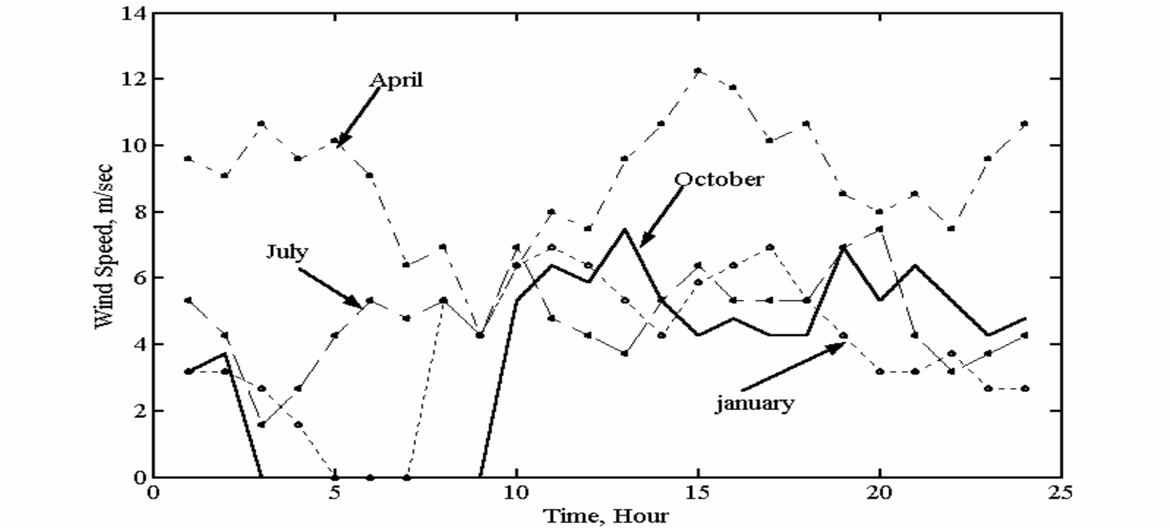

Fig. 4-4 Wind Speed during January, April, July and October for Zafarâna site, Egypt.

Table (4-1) Characteristics of the selected WTG's

Type of WTG / Characteristic		Rated Power kW	H (m)	D (m)	U_c (m/s)	U_r (m/s)	U_f (m/s)
1	Mod-A [72]	500	45	40	5	13	25
2	Bonus 1000 [116]	1000	50	54	4	14	25
3	Nursuden II [116]	3000	78	80	6	14	25
4	NedWind 50 [116]	1000	40	52.6	4	14	20
5	Gamma 60 [116]	1500	66	60	4	14.5	27
6	HAMILTON [72]	3000	80	77.6	6	14.2	21
7	Mod-1 [72]	2000	46	61	7	14.6	19
8	GEDSER [72]	200	24	24	5	15	38
9	WINCON [72]	100	25	20	4.5	13	25
10	KKRV-HS [72]	3000	80	77.6	6	14.2	21
11	TVIND-WT [72]	2000	53	54	5	14.8	20
12	WTS-4 [72]	4000	80	77.6	7.1	16.2	27
13	MS4-600 [116]	600	40	41	4	14	25
14	WTN 329 [116]	300	30	29	4	13	25
15	T600-48 [116]	600	55	48	3	12.5	25

4- The Price of Each Component of WTG's.

The price for each component of WTG's is shown in the Table (4-2).

The output of this program is:

1- Optimum number for each type of WTG's.

2- Cost of kWh generated for each type of WTG's, $/kWh.

3- Optimum type for each type of WTG's based on its ECF.

4- Monthly surplus energy, kWh.

5- Monthly deficit energy, kWh.

6- Yearly purchase or selling energy to or from EU, kWh.

Table (4-2) The Price of Each Component of WTG's [72]

Item	TW	TP	TS	TM	TC	TR
Price, $/kW	600	2.3	10.4	2.5	4.16	1.6

Table (4-3) revels some of the results form computer program such as Weibull parameters, capacity factor, optimum total number for each type of WTG's and energy cost figure, ECF, for each type of the selected WTG's. From this Table it can be seen that the WTS-4 has maximum value of C and K because it has high cut, rated and furling wind speed. On the other hand WTN 329 has minimum value of C and K because it has low cut and furling wind speed. From the Table (4-3), Fig. 4-5 and Fig. 4-6 it can be seen that the T600-48 type has the largest of CF (0.30639), optimum number of WTG's required equal to 300 turbines with planned annual energy output equal to 429.5749 GWh with the lowest ECF form all of the selected WTG's (ECF=0.03247 $/kWh). On the other hand, the highest ECF equal to 0.079245 $/kWh. This means that the T600-48 is the best suitable of WTG from all selected WTG's types. On the other hand GEDSER has the lowest value of CF from all selected WTG's types (CF=0.11663) optimum number of WTG's required equal to 1606 turbines with planned annual energy output equal to 421.94 GWh with the ECF form all of the selected WTG's (ECF=0.058989 $/kWh). If we resize WES at their MPP's for the type of T600-48 wind turbine, then the computer program will produce optimum number of WTG equal to 290 wind turbines with planned annual energy output equal to 431.193 Gwh with ECF equal to 0.0292 $/kWh .

Table (4-3) Parameter of Selected WTG's

Modes	Rated Power kW	C	K	C.F	N_w	Annual Energy, GWh	Cost $/kWh
Mod-A	500	8.1049	2.4875	0.2386	451	426.0335	0.041017
Bonus 1000	1000	8.2563	2.3112	0.24845	234	431.5756	0.042016
Nursuden II	3000	9.1897	2.7177	0.24323	91	453.7700	0.046621
NedWind 50	1000	8.1942	2.3306	0.24171	272	430.0803	0.049009
Gamma 60	1500	8.4604	2.5573	0.22105	167	435.3668	0.044587
HAMILTON	3000	9.1897	2.7177	0.23468	94	448.6652	0.04870
Mod-1	2000	8.8355	2.8335	0.15965	189	436.2583	0.067144
GEDSER	200	7.5516	2.7296	0.11663	1606	421.9479	0.058989
WINCON	100	7.6892	2.6911	0.1996	2319	420.8816	0.042697
KKRV-HS	3000	9.1897	2.7177	0.23468	94	448.6652	0.048706
TVIND-WT	2000	8.6941	2.6495	0.20106	221	432.2231	0.079245
WTS-4	4000	10.7842	3.2371	0.21536	93	451.8414	0.063799
MS4-600	600	8.1942	2.3306	0.24205	444	426.3356	0.048422
WTN 329	300	7.5373	2.4722	0.21714	1004	422.4609	0.055249
T600-48	600	8.1949	2.5389	0.30639	300	429.57585	0.032470

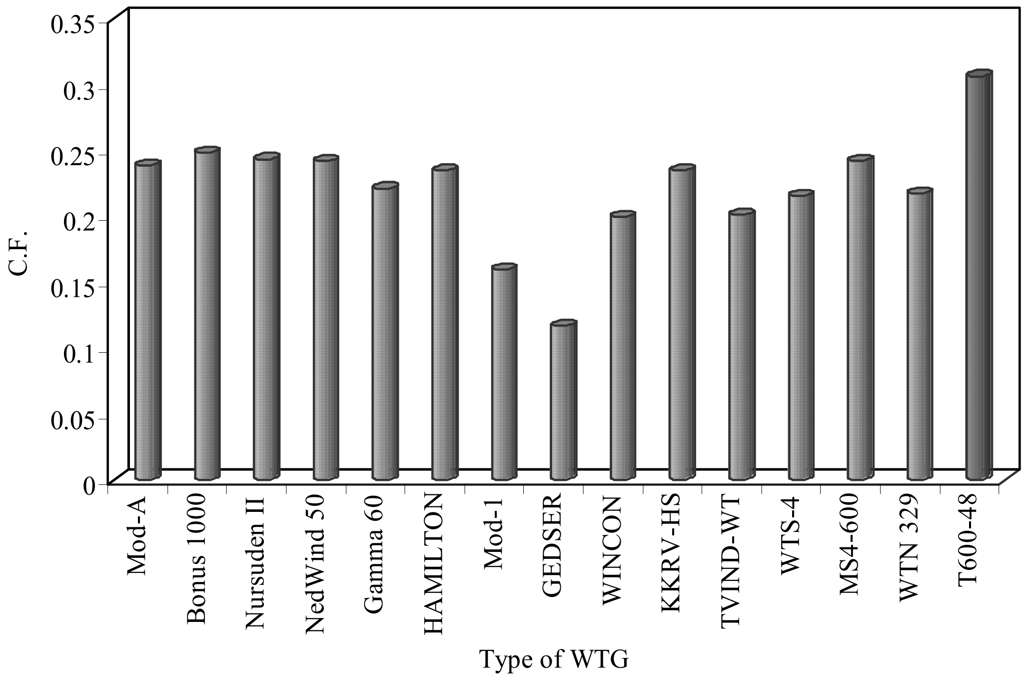

Fig. 4-5 The Capacity Factor of the Selected WTG's for Zafarâna site, Egypt.

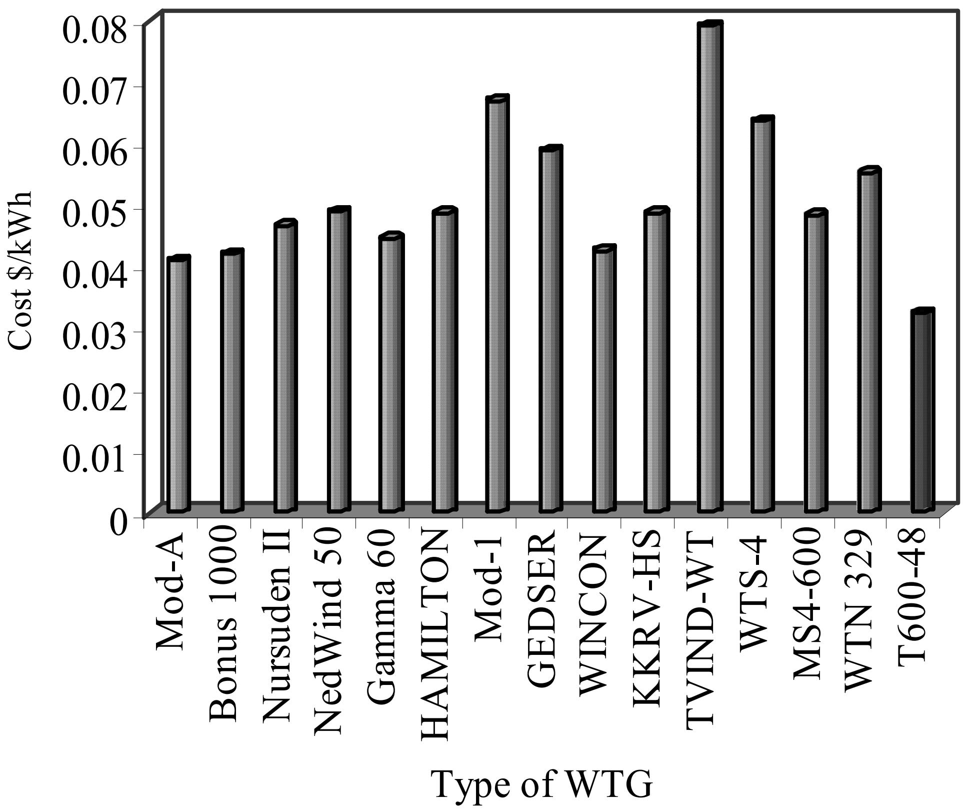

Fig. 4-6 Energy Cost Figure of the Selected WTG's for Zafarâna site, Egypt.

Finally, the output of the computer program after selecting WTG's is the power, energy purchased and sold to EU. Table (4-4) and Fig. 4-7 show the surplus and deficit power for each month. Negative power is deficit and positive power is surplus. Fig. 4-8 and Table (4-5) show the total energy generated form WES and energy demand for each month. Form the Fig. 4-8 and Table (4-5) it can be seen that the design is the best matching between WES and load demand. The left axis is for WES and the second is for load demand. The total energy generated from WES during the year equal to 14176.531302977*30.416 MWh. On the other hand the total energy demands for supplying load during the year equal to 14119*30.416 MWh. The difference between the energy generated and demand is sold to the EU.

Table (4-4) Surplus Power and Deficit Power for WES

Month	Power MW
January	-291.274029589225
Feb.	441.251240442878
March	857.791123278304
April	2276.52071998931
May	-621.225485394272
June	433.323889914989
July	-572.530235190287
August	-941.530160397247
Sept.	-332.683437007442
Oct.	-525.689756848359
Nov.	-200.233898980859
Dec.	-169.595379915881
Total	354.12459030191

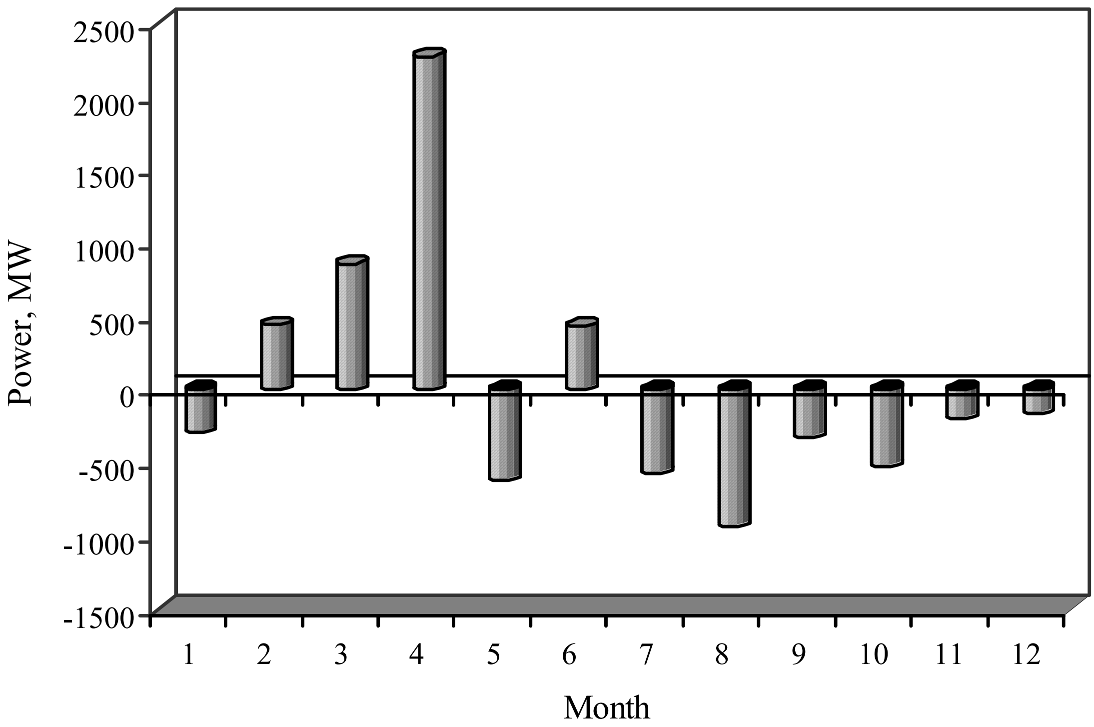

Fig. 4-7 The Total Power Surplus and Deficit Power for each Month for T600-48 Wind Turbine Type for Zafarâna site, Egypt.

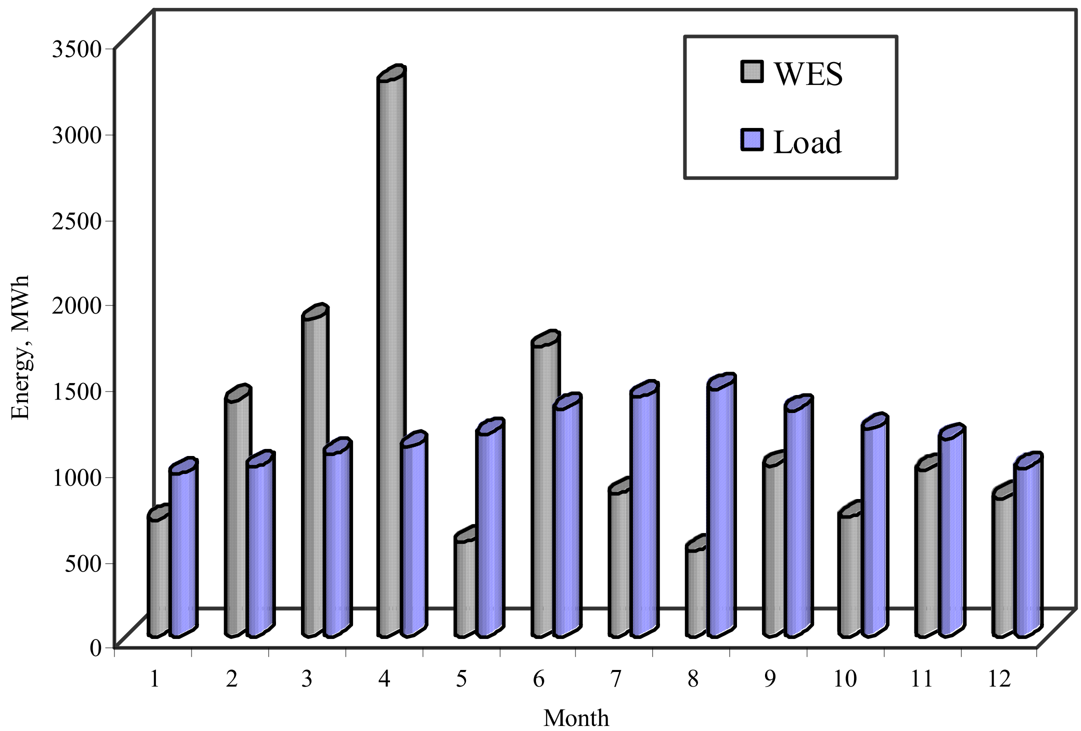

Fig. 4-8 The Total Energy Generated and Energy Demand for each Month for T600-48 Wind Turbine Type.

Table (4-5) The Total Energy Generated form WTG's and Energy Demand for Each Month for T600-48 Wind Turbine Type.

Month	Wind Energy generated , MWh	Load Energy demand, MWh
January	679.892684620143	948
Feb.	1372.81047160661	989.5
March	1847.7506996142	1064
April	3240.52071998931	1105.5
May	548.737337689501	1182
June	1691.28346625089	1327.5
July	831.95093708707	1395
August	494.432662686526	1443.5
Sept.	992.940704270836	1319
Oct.	697.282965450049	1208.5
Nov.	970.92275236465	1152
Dec.	808.005901347028	984.5
Total	14176.531302977	14119
Yearly Energy	431193.376	429443.504

4-5-2 Design NN for Optimum Operating Speed of WTG

A computer program has been developed to predict rotor speed as a function of wind speed using Matlab software. The variation of rotor speed with wind speed is shown in the upper part of Fig. 4-9. The computer program has been developed also to generate training cases for neural network. The results of simulation are stored in a file containing the samples of wind speed and rotor speed; n. The training and test cases have been calculated with the help of a computer program. The training process has been done with different structures; 2+2+1, 2+4+1, 2+6+1, 2+8+1 and 2+10+1. The training data have been processed with Back-Propagation, BP, learning algorithm to compute the weights for the network architectures under study. Figure 4-10 shows the number of epochs required to make the sum of squared output error of the multilayer perceptrons smaller than 5.4E-6 for the 2+10+1 NN. Once the network has been trained to the desired accuracy BP was disabled. Weights and bias of the NN have been fixed. Table (4-6) shows weights and biases for 2+10+1 NN. Fig. 4-11 shows the structure of 2+10+1 NN. Following the training of the NN a separate set of test patterns which were not used in training set was supplied as input to the NN in order to evaluate its performance. It is necessary for the neural network to be able to generalize the situation from the provided training patterns and correctly identify the optimum operating speed for the turbine for all wind speed. Figure 4-12 shows the performance of 2+10+1 NN. It's clear that the NN identify correctly the optimum rotor speed for each input wind speed.

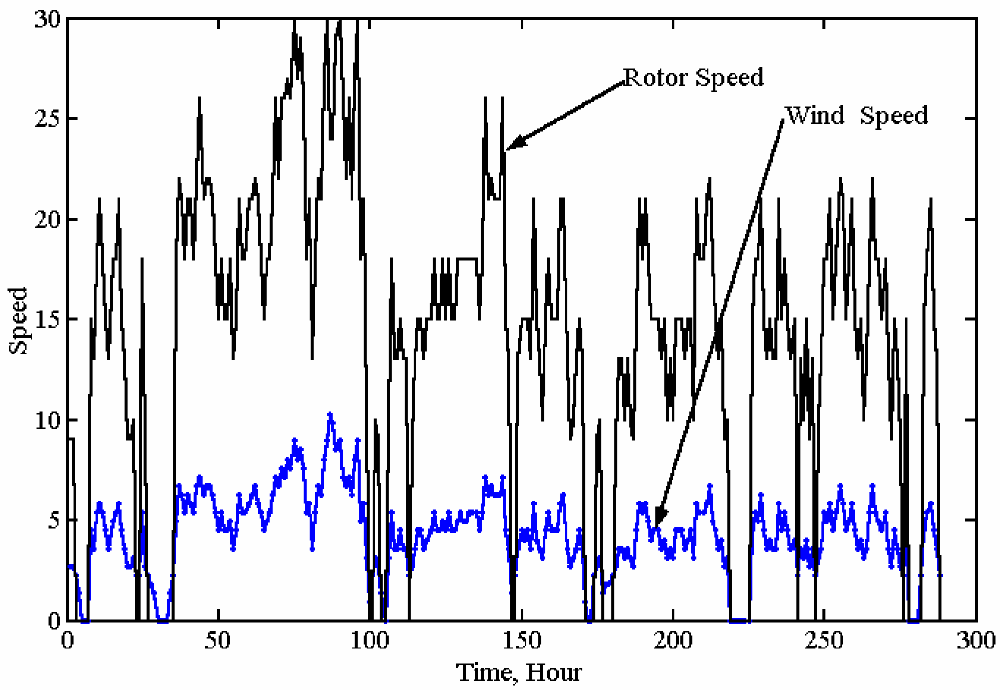

Fig. 4-9 Variations of Wind Speed and Rotor Speed with time

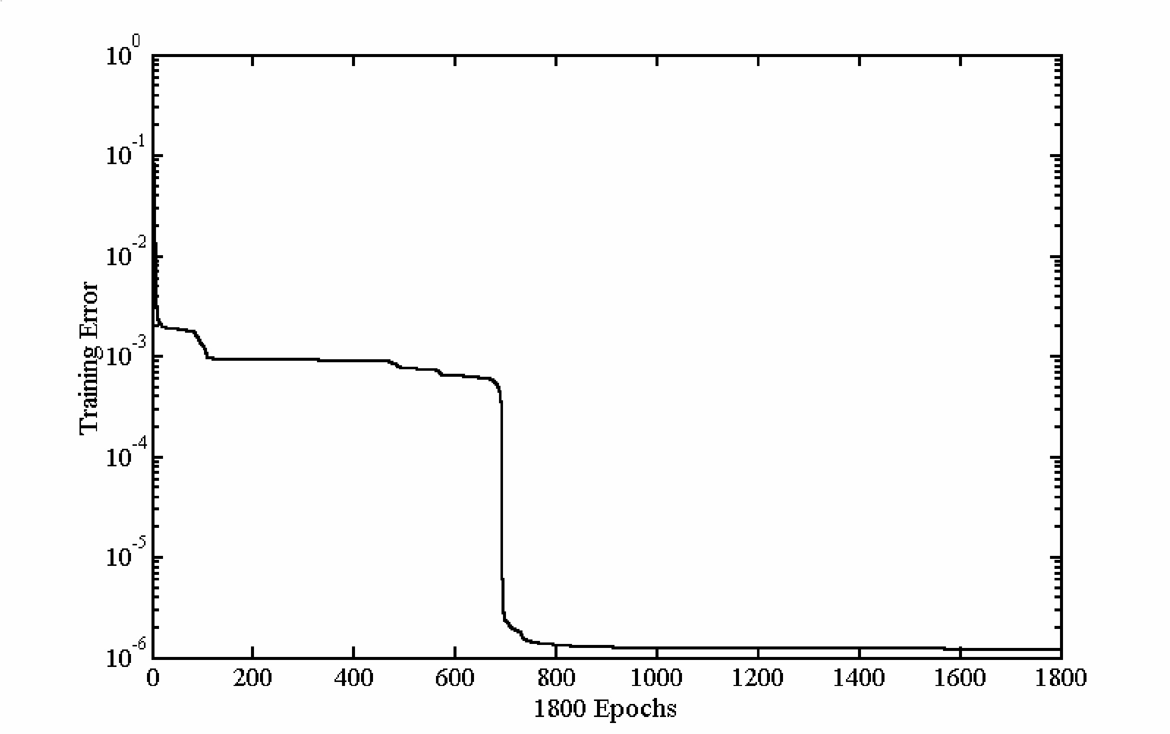

Fig. 4-10 Relation between Error and Epoch for the NN 2+10+1

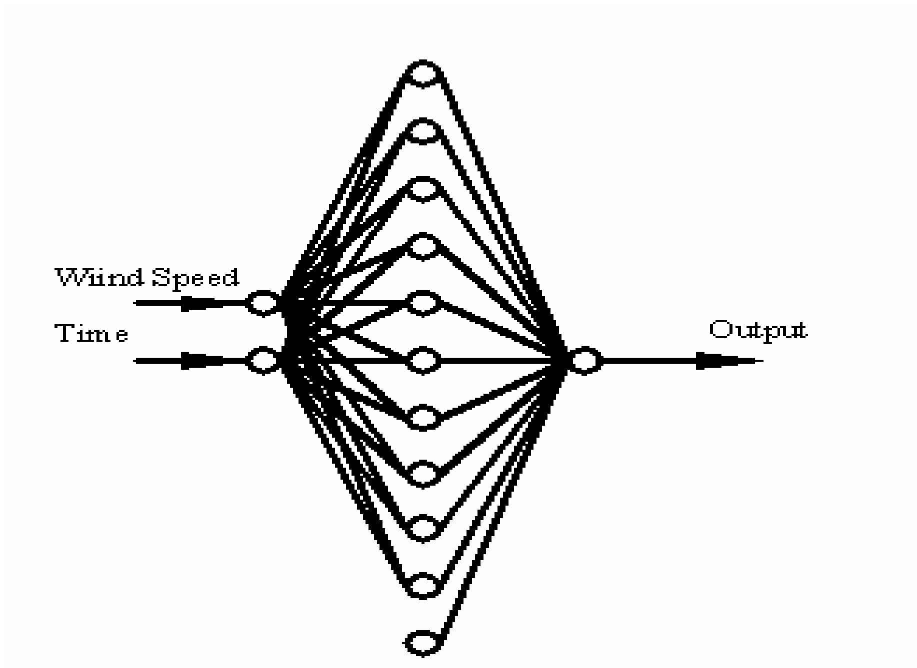

Fig. 4-11 Proposed NN for Optimum Operating Speed.

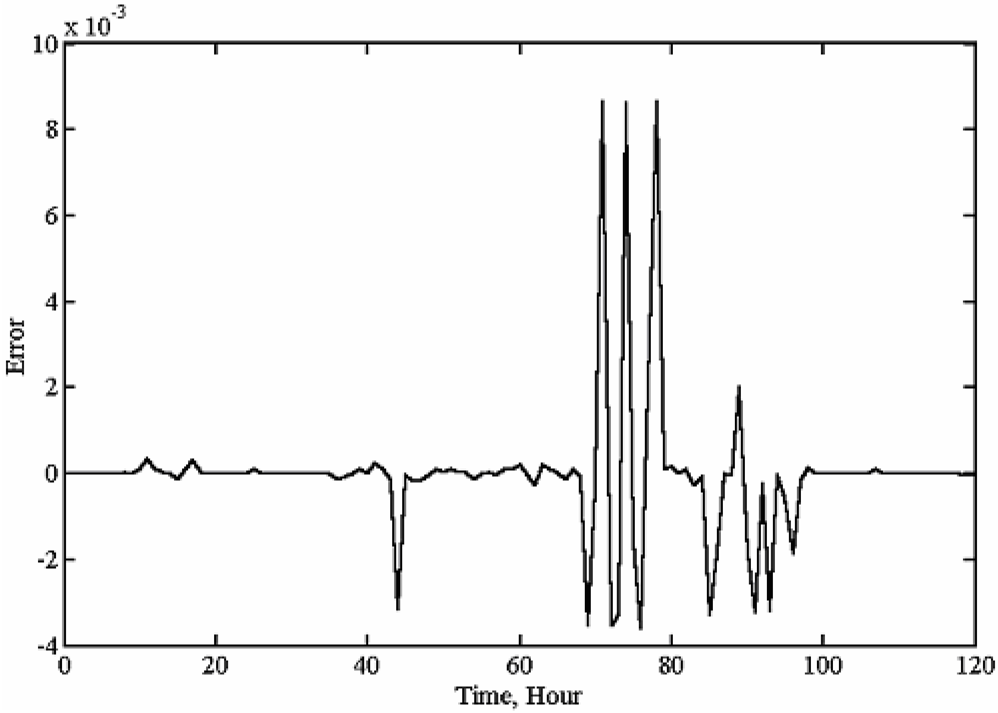

Fig. 4-12 The Performance of 2+10+1 NN for Period Five Months

Table (4-6a) Weights W1 and Biases for 2+10+1 NN for MPPs of WTG

W1		b1
1.60488652371768	9.17261782239323	-6.70461
-3.9710470678784	-10.062641940685	7.308347
2.7823797561e-06	55.0127695172283	16.97294
1.0324196952e-07	40.5990775138329	21.96201
0.00088585348091	-78.694033164202	17.26679
3.12913993185788	9.40552629892027	-7.42519
-0.2417529481797	110.292156656483	9.982691
-0.0008856097068	39.6764291398574	-8.78526
1.23876800644362	-12.060554388426	10.69589
-1.3706778428325	11.2673258629014	-10.1246

Table (4-6b) Weights W2 and Biases for 2+10+1 NN for MPPs of WTG

W2										b2
4.399245133304368	-0.652110579106921	0.173263455531056	6.299701305529879	150.964425860409	-5.64300574655989	0.101308244533082	151.32452433151	65.7725904179893	65.9599558551156	-6.415526552145

4-6 CONCLUSIONS

This chapter presents a technique to design WTG interconnected with EU. This technique uses energy balance to reduce the cost of electricity while meeting the load demand. From the results obtained above, the following are the salient conclusions that can be drawn from this chapter:

1- A computer program for optimal design of a WES to be interconnected with EU has been proposed. This computer program can be applied in any site in the world.

2- Purchased and sold energy from EU have been calculated.

3- Maximum power point for WTG has been taken into account for calculation the size WES.

4- A NN have been designed to operate the WES at MPPs. The suitable NN to operate the WES installed in Zafarâna site 2+10+1.

5- Perform the necessary preliminary studies before investing and connecting wind turbines to the grid where purchased and sold power from EU have been calculated.