SZENT ISTVÁN UNIVERSITY

Energetical modelling
of solar wind energy systems

Thesis of PhD work

Sándor Bartha

Gödöllő, Hungary
2009

Doctoral school Denomination: Mechanical Engineering PhD School

Science: Energetics of Agriculture

Leader: Prof. Dr. István Farkas
Dr. of Technical Sciences
Institute of Environment Industrial System
Szent István University, Gödöllő, Hungary

Supervisor: Prof. Dr. István Farkas
Dr. of Technical Sciences
Faculty of Mechanical Engineering
Szent István University, Gödöllő, Hungary

....	....
Affirmation of program leader	Affirmation of supervisor

CONTENTS

1. INTRODUCTION

1.1. Importance of the topic

It is well known that the amount of the conventional energy sources is limited and they may cause fundamental problems with the pollution of the environment during their usage. The aim of the European Union is to reach the 20 percent rate of the renewable energy sources in the energy production until 2020. One option to achieve this aim is to increase the rate of the solar and wind energy in the energy production mixt. In Renewable Electricity Directive”2001/77/EC”, for member states until 2010 the European Commission proposed for electricity consumption, 22.1 % can be delivered by these energy sources. These targets can be realised by growing the green energy production. This target can be realised by member states in function of geographical and economical ability. Recently in Eastern part of Europe we can find a lot of farms, situated in remote area, which electricity supply is not solved. One obvious solution for electrification of these regions is the installation of small-scale stand-alone solar, wind and hydro energy production systems. The importance of this topic is timely because we can find a lot of applications, which energy supplying is resolved by renewable energy sources. For a god performance application is necessary to realise a preliminary planing, a feasibility study, which indicate an optimal technical solution for this application sites. Is necessary to elaborate one optimal model for which can be answered for this technical solution for the energy system.

1.2. Aim of the work

The detailed aims are as follows:

1. Analyse the specific literature in field of PV wind application.
2. Evaluate the solar and wind energy potential from measured data realised at the Black Sea coast.
3. Study and definition the complementarity phenomena between the solar and wind energy potential.
4. Developing and modelling a small-scale PV wind energy system, which can supply with electricity a rural application sited in remote area.
5. Examining and analysing a small-scale wind turbine used for this stand-alone application.
6. Examining and evaluating the optimal relation between renewable energy fraction and PV wind rate.
7. Definition the mathematical expression between Array load ratio and the optimal inclination digress of the PV panel in case of the stand-alone system.
8. To examine the cup anemoeter in wind tunnel.
9. To analyse the energy storage possibilities, design the PV and the battery storage systems, and evaluate the parameters and characteristics of the solar module, which is used in PV generator.
10. To evaluate the sun path diagram used in design process of PV applications.

2. MATERIAL AND METHOD

In this chapter the examined solar PV and wind energy system is presented, it is detailed that which physical parameters and on what points of the system were measured. In this chapter hereinafter is presented to as the model and the method for the energetically analysis of the hybrid system.

2.1. Wind energy measurement

These measurements are divided in their groups, i.e.:

Informative wind measurements, which are realised by the national meteorological stations, which store the average data of the wind potential and wind speed.

Based measurement for windgenerator planting in village with a good wind potential. These measurements offer data with height precision of the wind potential and wind speed of the application site.

Control measurments, this category are used inall at least case of wind parks, which can be offer data for control of the wind energy potential.

In all cases, the necessary measurement period is one year. The used sensor is a cup anemometer, which expose to the wind the cups is begin to rotated, whatever is a wind direction. From the rotation of the sensor is determined the average wind speed. The measurements are informative character and the height of tower used in this application is 30-m. The sensors 10, 20 and 30 m in height is placed. As in case of low power windgenerator, which operate up to a height 10-20 –m, therefore the wind energy potential is evaluated in this tower height region. The sensors should be fixed to the tower, which structures do not affect the airflow around the anemometers and wind direction sensors. The wind parameters, the windspeed with 0.1-m/ s and the wind direction with 1º precision are measured. The sampling time is fixed to 1 minute and the daily average wind sped has been evaluated from the hourly average values recorded from this measured data. The measurement system is data logger is an NRG Symphonie, which can measured three-wind speed and two-wind direction sensors. These instruments are designed for wind turbine market and generally are more expensive than those used in meteorological evaluation. The anemometer type is NRG 40 C and the wind direction sensor is NRG 200P. The measuring system structure is presented in 2.1. Figure.

Fig. 1. NRG wind energy measurement system

2.2. Used equation in performance evaluation power of Wind

- **Wind speed distribution;**

The formof the Weibull distribution can be found from:

$$f(v)=\frac{k}{C}\left(\frac{v}{C}\right)^{k-1}e^{-\left(\frac{v}{C}\right)^{k}}, \qquad (2.1)$$

Where:

v is the wind speed, [m/s]

f(v) is the frequency of occurrence for the wind speed in frequency distribution

C is the empirical scale factor, [m/s]

k is the shape factor.

If k= 2

- **Rayleigh distribution form** :

$$f(v)=\frac{\pi}{2}\frac{v}{v_a^2}e^{-\frac{\pi}{4}\left(\frac{v}{v_a}\right)^2} \qquad (2.2)$$

where: v_a is an average of the wind speed

- **Wind speed dependence on height and the on ground impact factors**

The wind speed in any given height, h is determined according to the following

$$v(h_2) = v(h_1)\frac{\ln\left(\frac{h_2 - d}{z_0}\right)}{\ln\left(\frac{h_1 - d}{z_0}\right)} \quad (2.3)$$

where:

$v(h_1)$ is the wind speed at the original height and $v(h_2)$ is the wind speed at the new height.

d, is a height parameter substitution, which indicates the presence of environmental barriers, in case of barriers free location this parameter is equal to 0, in case of barriers the parameter values is 70 % of the value of the barrier height.

$z_{0,}$ is the surface roughens scale it is function of the type of the vegetation located in the application site.

Power of the windgenerator

From Betz low indicated that an ideal windturbine could extract 16/27 (59%) of the total power of the wind. Consequently the Betz limit is the maximum efficiency theoretically obtainable from a wind turbine. The power of the wind turbine can be defined for one site from characteristics power curve in function of the average wind speeds measured at reference height. For one given annual average wind speed, the power density can be seen in table 2.1.

2.1. Table Power density values as a function of average wind speed

Annual Average Wind Sped (m/s)	5	10	15	20	25
Power Density (W/m^2),at normal air pressure and in case of air density at the standard temperature 1,225 kg/m^3 1	76.6	612	2067	4900	95700

In the literature for the performance calculus of the wind power the Rayleigh distribution, is used Paul Gipe estimate the power with apply an scale factor named Energy Pattern Factor (EPF), which value in this wind speed distribution case is 1.91. For the annual values of the wind speed data by using the former to model the power and the energy density this parameter can be evaluated. The used method can be realised using the following equations. The base of the method is the Betz former, for a given swept area (A).

$$\frac{P}{A} = \frac{P_{max}}{A} = 0.6125 v^3 EPF, [W/m^2] \quad (2.4)$$

where : v , is the annual average wind speed in [m/s],

EPF is the Energy Pattern Factor in case of Rayligh distribution is 1.91,

A, is a rotor swept area in square meter

And once we know the annual power density at a site, we can quickly estimate the annual wind energy density in kilowatt- hours per year per square meter of the wind stream. In this case is the number of hours per year (t= 8760). Estimating the amount off energy available annually to the wind turbines becomes simply the product of energy density (E/A) and the turbines swept area in square meter.

$$\frac{E}{A} = \frac{P_{max}}{A} \times t = 0.6125 v^3 \frac{8760}{1000} EPF, [kWh/m^2] \qquad (2.5)$$

2.3. Characterisation of Photovoltaic, (PV) energy system

The main component of solar photovoltaic system, which transforms solar energy into electricity, are the solar panels. Theier propereties are important the current-voltage and the output power and voltage characteristic. The last characteristics curve has a maximum point, which corresponds to the maximum power point (MPP). The I V curve has an maximum point named ISC- short circuit current and a maximum voltage (VOC) open circuit voltage, which value also characterise the PV module, the manufacturer normally provide this values for a Standard testing condition. The figure 2.2. is shows this characteristics curve for one solar cell with the listed typical parameters for the PV modules.

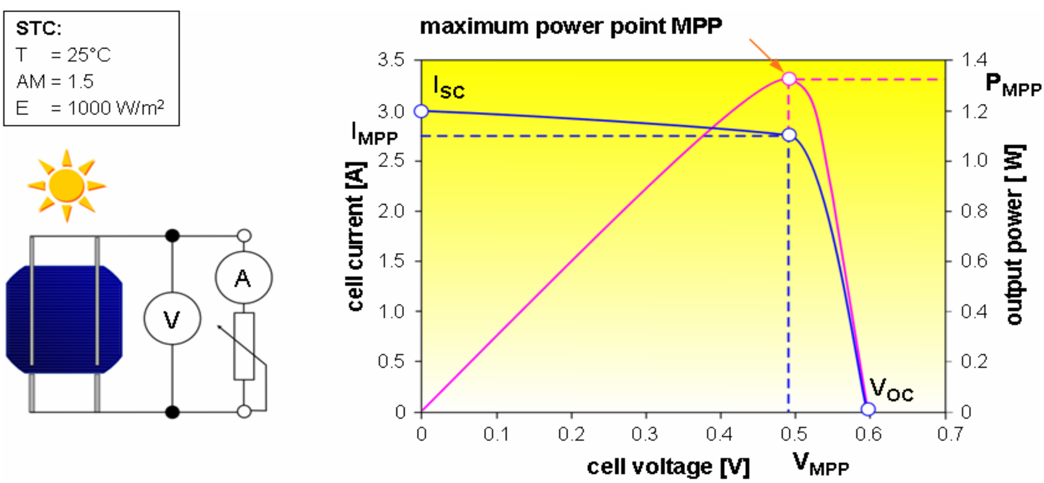


Fig. 2.2. I-V and PV characteristics for on PV module at STC condition

The used PV panel in experiments is made from Kyocera KC 40 type solar modules. The modules have the following data at STC.

Maximum power rating, P_{MPP}: 43 Wp
Efficiency, module/ cell: 13/16%
Short circuit current, I_{SC}: 2.65 A
Open circuit voltage, V_{OC}: 21.7 V
Maximum power voltage, V_{MPP}: 17.4V
Maximum power currents, I_{MPP}: 2.48 A

This PV panel is used for energy production and in case presented in figure 2. 3 work like a stand alone energy production system. The produced energy is stored in lead acid battery, while the consumer is supplied trough an inverter, which realise the height quality AC energy production.

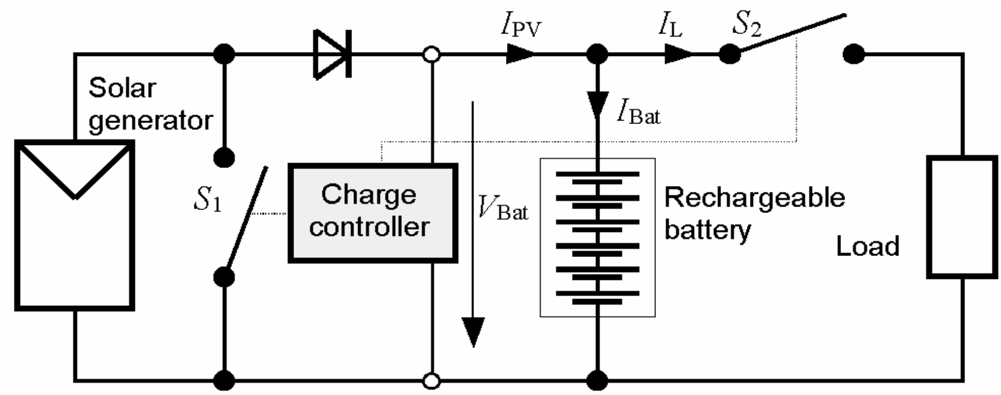


Fig. 2.3. Stand alone PV system

2.4. Performance evaluation of PV wind Hybrid energy system

The total energy production in case of stand-alone system using only PV modules is an expensive technical solution. This requires a large surface, and in winter period when the solar potential is low the consumers can be supplied with energy trough a large storage capacity. The above disadvantages suggests that during the using design procedure of the stand-alone system is necessary to analyse the possibility to use other green energy production equipments. In effective operation, mixing the produced energy by this green source the designed stand-alone system can operate economically. In the case of hybrid energy system several types of generators are used, the figure 2.4 shows the switching mod of this green energy sources type. As shown along a PV generator into this stand-alone system a wind turbine is incorporated into this energy production unit.

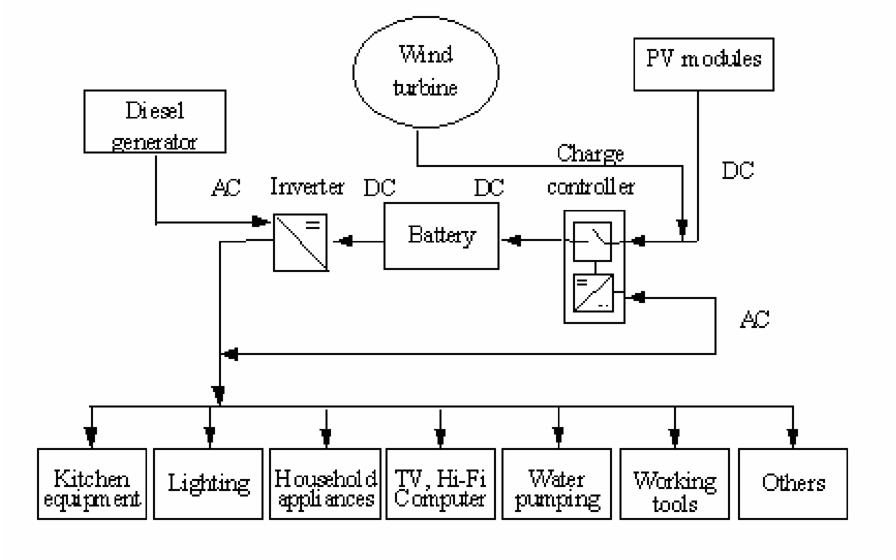


Fig. 2. 4. The structure of hybrid PV wind energy system

In practice, in case of stand alone hybrid systems it is iimportant to use that kind wind turbine, which cut in wind speed is low. The produced energy is stored in batteries and the consumer is supplying with god quality energy (constant voltage and frequency) through an inverter. In case of low power system the Steca type inverter is propused but in case of more energy production the SMA Sunny Island model can be used. It is compatible with a local network and has connection ports for directly switch the wind or diesel generator in the system. During the measurement in this PhD work, I used a small wind turbine with 1 KWp power, which operates at he Black Sea cost in Agigea village. The used windgenerator is Bergey Windpover XL 1 made, which properties are displayed in the following table.

Table 2.2. Propreties of the used windgenerator

Manufacturer	Type	Nominal rotor diameter, (m)	Swept area, (m^2)	Nominal power,(kW)	Rated Wind speed * (m/s)
Bergey windpower	XL 1	2.5	4.91	0.98	11

3. RESULTS

In this chapter those results are summarised briefly for which the thesis was composed.

3.1. Analysing the meteorological data of location

For modelling adequate number of data pairs were necessary as the behaviour of the system is trained from these data. For such purposes the following data were used:

Meteorological data: a meteorological station installed on the spot every 10 seconds measured solar radiation and ambient temperature. Average hourly data were calculated from these

3.1.1. Analysing Wind speed data

The measurements for wind energy potential were realised at Agigea. The wind speed distributions for 10 and 20 m level height is shown in figure 3.1 and 3.2.

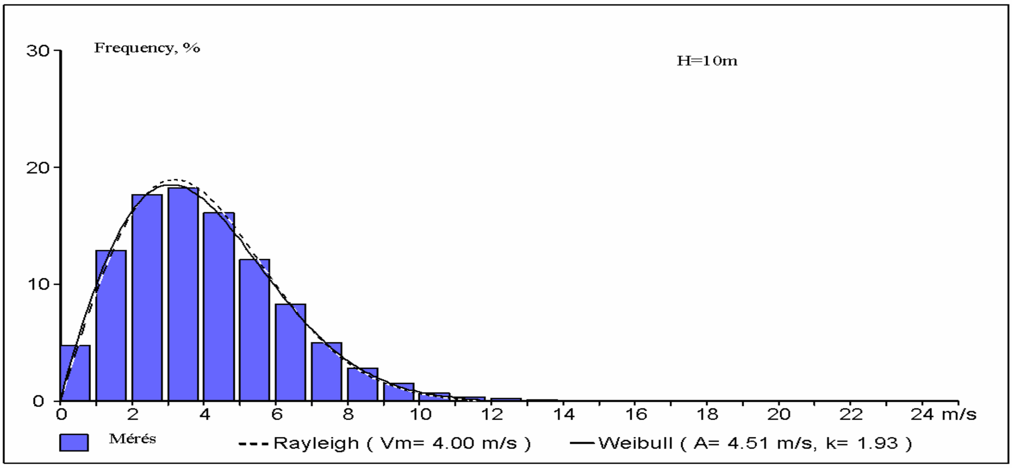


Fig. 3.1. Wind sped distribution at 10 m height

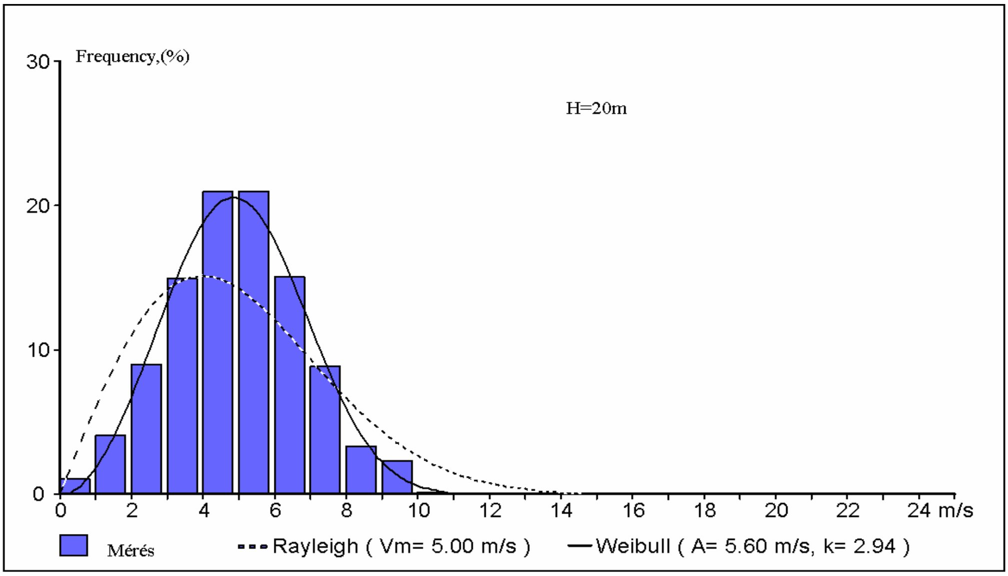


Fig. 3.2. The wind sped distribution at 20 m height

From the measurements data for the location using the method defied by the NREL –(National Renewable Energy Laboraty) used in the USA, which established 7-wind power classes our location can be set at in a class 2. The wind speed and windpower density data for these classes can be seen in table 3.1. It can be compared with data from 1. or 3. Classes. In fact the location has an annual average wind speed between 4,4-5.1 m/s range at the height 10m and this corresponds for 2 indexed wind class.

Table 3.1. Wind power class from NREL Classification

H[m]	10		30		50	
Index of class	v[m/s]	P[W/m^2]	v[m/s]	P[W/m^2]	v[m/s]	P[W/m^2]
1.	0- 4,4	0-100	0-5,1	0-160	0-5,6	0-200
2.	4,4-5,1	100-150	5,1-5,9	160-240	5,6-6,4	200-300
3.	5,1-5,6	150-200	5,9-6,5	240-320	6,4-7,0	300-400

3.1.2. Estimating the Energy production of small-scale Wind turbines

In case of model experience, I determined the energy production of a same nominal power windgenerator from different manufactures for the wind condition measured at Agigea. This value is evaluated in different case of the height of the tower, indicated by the windgenerator producer. The results can be seen in figures 3.3 and 3.4.

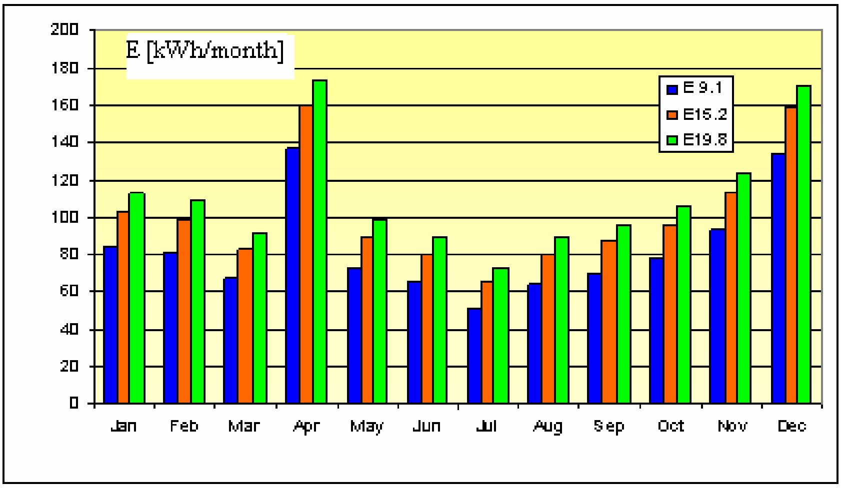


Fig 3.3. Southwest Whisper 200 wind generator energy productin at different height

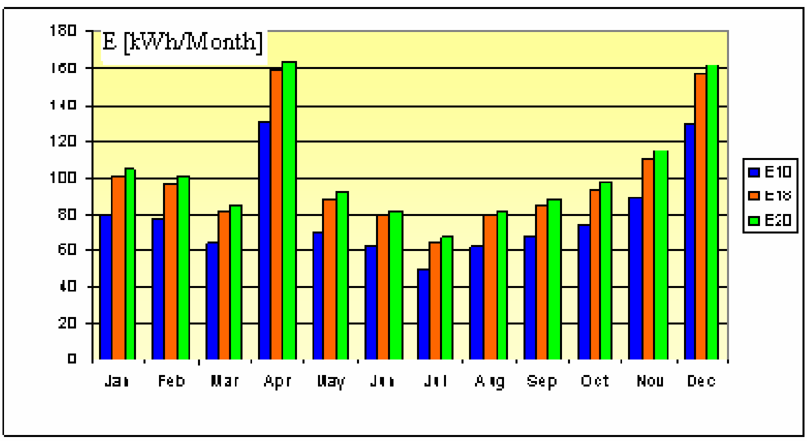


Fig.3.4. Bergey XL 1 wind generator energy productin at different height

3.1.3. Measurements and results data in wind tunnel for the used cup anemometer

In case of the used Gunt wind tunnel installed for educational activity the wind speed can be measured in range of 0- 28 m/s. The wind tunnel shape is a square form and its dimension is 298x298mm. The airflow can be modified in the range of

0-900m^3/h. The differential manometer connected to the tunnel can be used in range of pressure 0-500Pa. From the pressure, difference of the manometer the wind speed can be determined. The created statical model elaborate in Lab View, which will carry out this conversion, can be seen in figure 3.5.

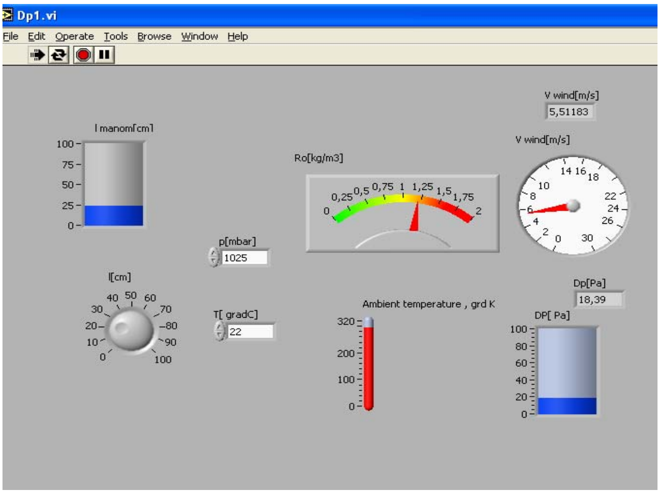


Fig. 3.5. Wind speed measurements, Lab View Model

3.1.4. Analysing of the solar radiation data

The experimental analysis was carried out at Agigea sited at Black Sea coast; several measurements have been realised to determine the value of the solar radiation data. The measurements and analysis of the database has been realised by Enerpack made data logger. The measurements are processed daily. The measured global radiation data incoming on square meter is presented monthly distribution. The intensity of the solar radiation in the surface of the PV panel is in accordance with orientation of the South, 45º-angale inclined. This sensor measured the global radiation data in this plane, the daily maximum value of the solar radiation was also recorded. For example, in South orientation, 45˚ angle inclined plane the value of global radiation in one summer day, in July 2007 is shown in figure 3.6.

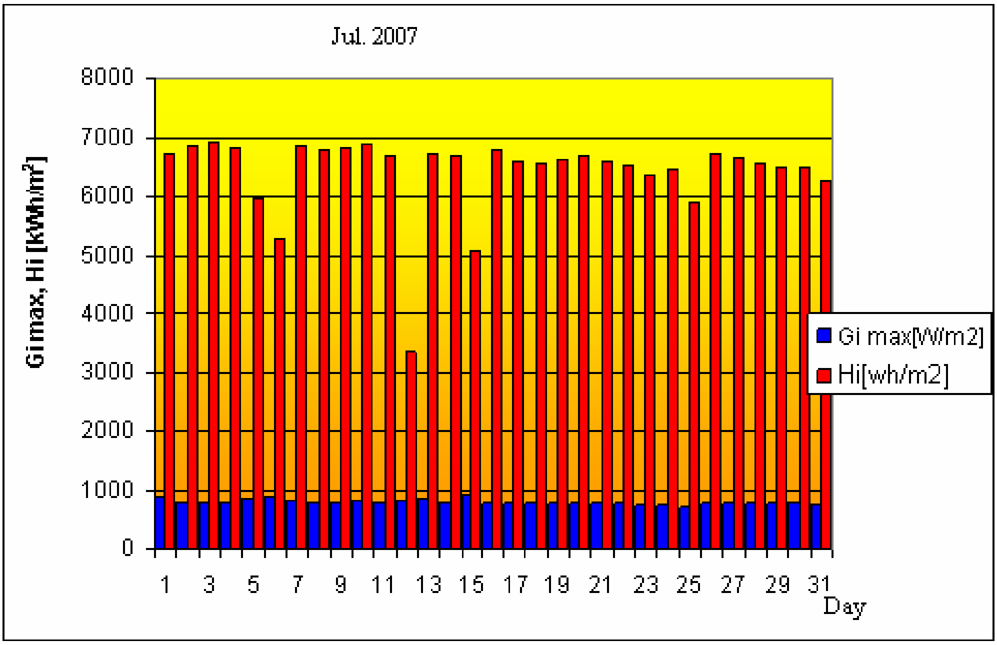


Figure 3.6. Global daily solar radiation in South 45° inclined surface in July 2007

From the measured date, we can see that in winter period the solar radiation data is 300-600 W/m^2 and in summer month this value is in range 600 -100W /m^2. The value of the diffuse radiation in this region is up to 40-50% of the values of global radiation data. The measured date has been compared with information existent Meteonorm database for village Constatnta, which is form 20 km away from the location of the measured site. From the measurements data it can be show that the yearly values of the global solar radiation is 1350kWh/m^2 and this value from Meteonorm database is approximate, 1400 kWh/m^2. For determine the daily global radiation value one Matlab Simulink model has been created, which calculates this value directly from data logger data, and determined the daily energy output from the solar radiation.

3.2. Analysing of PV wind electrical energy production system

For the measurements for the energy productions of 1 kWp peak power PV generator and 1KWp wind turbine have been determined. This system seats at Black Sea cost and supply the electrical energy on “green house” equipped with on intelligent control and sequrity system, built for research application.

3.2.1. The specific parameters for analysis of hybrid systems

Characterised parameters for Hybrid PV wind energy system are:

PV and wind generator nominal power

Ratio of the two power supply in produced energy mixt

The storage capacity of the battery system and the value of the state of charge, (SOC), which is an important factor in the storage system characterisation

The number of autonomy days of the hybrid system, that can be considerate equal of numbers of continuos cloudy day in selected area

The loss of load probability (LOLP) which is used for determine the battery capacity by definition is the probability at any point in time that the load will be not be satisfied by the hybrid system.

Knowing this parameter can than analysed on of basis of cost to determine the least cost approach to satisfying system specifications.

3.2.2. PV array sizing equations

The size of the PV array can be estimate as follow first the PV panel area is evaluated for on daily load energy requirements (El):

$$\mathrm{PV(area)} = \frac{\mathrm{E_l}}{\mathrm{H}\eta_{\mathrm{PV}}\mathrm{TCF}\eta_{\mathrm{rendszer}}} \tag{3.1}$$

where : H is an average solar energy input/day(kWh/m^2/day)

TCF is a temperature correction factor, if the temperature is assumed to reach 60º C then the TCF will be = 0.8. In the evaluation procedure we need into account the efficiency of the system, where is a multiply of a PV module (12%) the battery (0.9) and the inverter efficiency (0.9).

$$\mathrm{PV(area)} = \frac{2.4}{3.68 \times 0.8 \times 0.12 \times 0.765} = 8.88, \mathrm{m}^2$$

The PV panel areea multiply with system efficiency and the PSI value-peak light intensity (1000W/m^2) can be evaluate the PV panel peak power(4.5 equation):

$\mathrm{PV_{WP}} = \mathrm{PV_{area}PSI}\eta_{\mathrm{PV}}$, using the evaluated data this value is:

$$PV_{WP} = 8.88 \times 1000 \times 0.12 = 1056, Wp$$

For this application the number of the chose Kyocere KC 50 type modules wit 53 Wp peak power for this given daily energy requirement can be established by the following equation.

$$Nr_{PV\,\mathrm{mod}ol} = \frac{PV_{WP}}{P_{WP\,\mathrm{mod}ul}} = \frac{1056}{53} = 19.92$$

In this case 20 modules type KC 50 or 24 KC 40 are used to supply the application with the required energy. The modules can be connected to give the desired voltage according to the design of the other parts of the PV system and the load specification. The storage capacity can be calculated according to the following relation, in this case the DOD = 80% was take into accont.

$$C_{bat} = \frac{N_c E_l}{DOD \times \eta_{rendszer}};$$

$$C_{bat} = \frac{3 \times 2.4 \times 1000}{0.8 \times 0.765} = 11765 \cdot Wh$$

$$C_{bat} = \frac{11765}{24} = 490 Ah$$

Where N_c is a system autonomy day, in this present case Nc = 3 day. The system availability is defined as the percentage of time that the power system capable of meeting the loade requirements. The present system has been designed for 3-day autonomy. The target of may work is to minimised the storage capacity and this can be assured by 12 Fulmen lead acid battery, with cell voltage 2 V the used battery type is Solar 470.

3.2.3. Study on the complementarity of the solar and wind energy potential

During the design process of the hybrid PV wind energy system in a given location analysing the meteorological data, the solar and the wind potential values, using a classical statistic method I established that this sources are complementary variation during the year. In summer the sun and in winter period the wind energy is the dominant. Based on the measured data I defined a method using in the statistic available definition function to determine the cross- correlation coefficient for the wind and solar energy potential complementarity. In this process I defined this coefficient and if this value is negative that means this values are complementary. The 3.2-matematical equations are used in this model.

$$\chi(X,Y) = \frac{1}{n}\sum_{1}^{N}(x_i - \mu_{xi}) \times (y_i - \mu_{yi}).$$

$$\mu_{xi} = \frac{1}{n}\sum_{1}^{n} x_i \qquad (3.2)$$

$$\mu_{yi} = \frac{1}{n}\sum_{1}^{n} y_i$$

where, x is the average monthly value of the windenergy potential, y is the average monthly value of the global solar radiation. Using the presented statistical method the cross correlation value for Agigae renewable energy potential data is SI $_{SAT}$= –

1033W/m^2, which demonstrates the complementarity of this two energy potential. The monthly values of the coefficient are presented in chapter of new scientific results.

3.2.4. Model for describing of PV modules Characteristics

The practical used graphic for PV module properties, is the so- called current voltage characteristic. That can be evaluating with several algorithms, which can be solved with analytical or numerical methods. In this work I used the analytical model, using the Matlab software I have developed one algorithm, which evaluate the parameters for graphical representation of the Current –voltage characteristic. This algorithm is elaborated based on the technical parameters of the solar module, given by the producer. The simulation results are shown in figure 3.7.

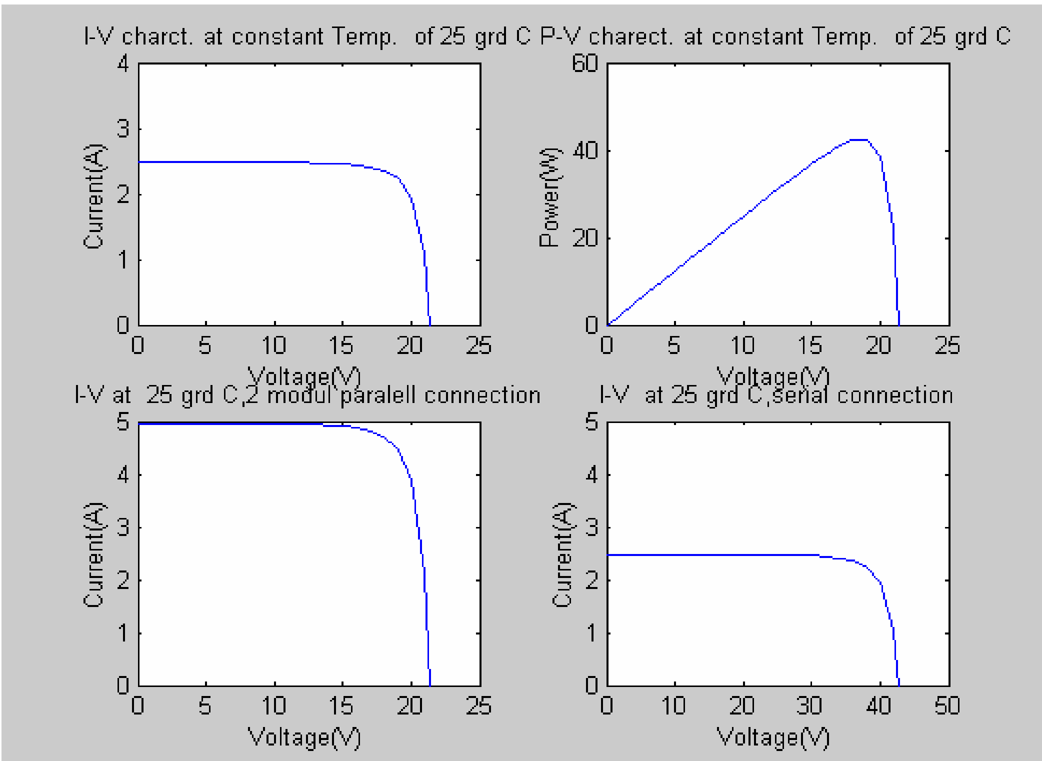


Fig.3.7. I-V and P-V characteristic for Kyocera KC 40 solar module at constant temperature

3.2.5. Hybrid Solar Wind energy recovery system analysis

From measured data the theory of Sangli is so far. In case of hybrid system the PV wind rate is a function of the energy requirements. For increasing consumption in case of hybrid system the share of renewable is reduced. In case of increasing the storage capacity for a given limit, value is no longer talking about hybrid system. The aim in design for hybrid systems is small storage capacity. Analysing a hybrid system built from 1 KW_p PV module and 1 KW_p wind power generator I evaluate the energy balance in different cases. Analysing the energy balance of one hybrid system built with one 1-kWp-wind turbine, which peak power is constant. In my model I varied the PV power in range from 200 Wp to 1000 Wp. Therefore I determine the energy balance in different case built from a 200, 400, 600, 800 and 1000W_P peak power PV generator and the one wind turbine. In all cases I evaluate the produced energy and compared the obtained result data for each case, I determined the rate of renewable energy in power generation process. The energy balance in all cases has been evaluated with Solar Design Studio Pro software. By graphically representation of the simulation result I obtained the share of renewable in rate of PV and wind power for a given installed capacity. The results, the data from measurement and the calculated fitted values can be seen in graphic shown in chapter" new scientific results".

3.2.6. Modell for editing sun position diagram

In this chapter a model for solar position diagram is presented. From the presented algorithms for sun height diagram in technical literature I elaborate a model, which can used in the sun -path diagram construction for a given location in base of the geographical parameters. The position of the sun is essential for many further calculations fore solar energy systems. The two angels sun height the solar attitude and the solar azimuth defines the position of the Sun. The sun- path diagrams are used to visualise the path of the sun in course of a day. That diagram construction model can be used for editing one diagram for an on site analysis with an ecliptic analyser. That analyser can be used for a quickly localisation of the possible shading obstructions, if the surroundings are viewed from the position of the planed system with its diagram can be determined the altitude and azimuth of the obstructions. In this case can be prevented the hot spot phenomena representative for PV panels, which phenomena could lead to destroy this shaded module. The model has been elaborated in Delphi programming language, which for a given location (geographical latitude, longitude) and the time zone can realised this sun path diagram in geometrical dimension applicable for an ecliptic analyser. The sun path diagram for location Constanta can be seen in figure 3.8

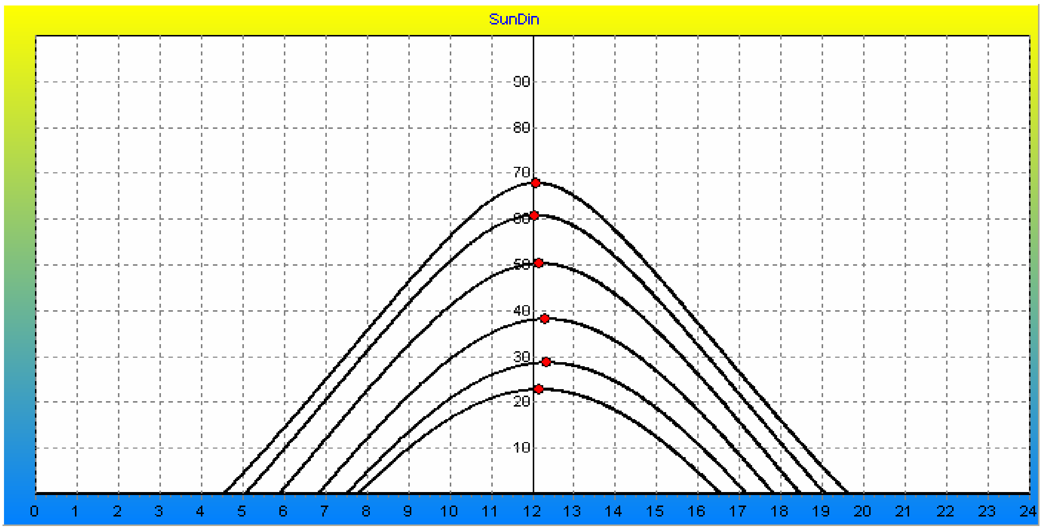


Fig. 3.8. Solar position diagram for Constatnta

3.2.7. Energy production of small scales Hybrid Wind - PV system

In generally an energy production design begins with the energy consumption analysis of the application. The objects of my study are to create a hybrid green energy system, which ensure the energy supply for a small remote application for a typical house. The average daily load is 2kWh and the average daily load energy during different seasons can be seen in figure 3.9.

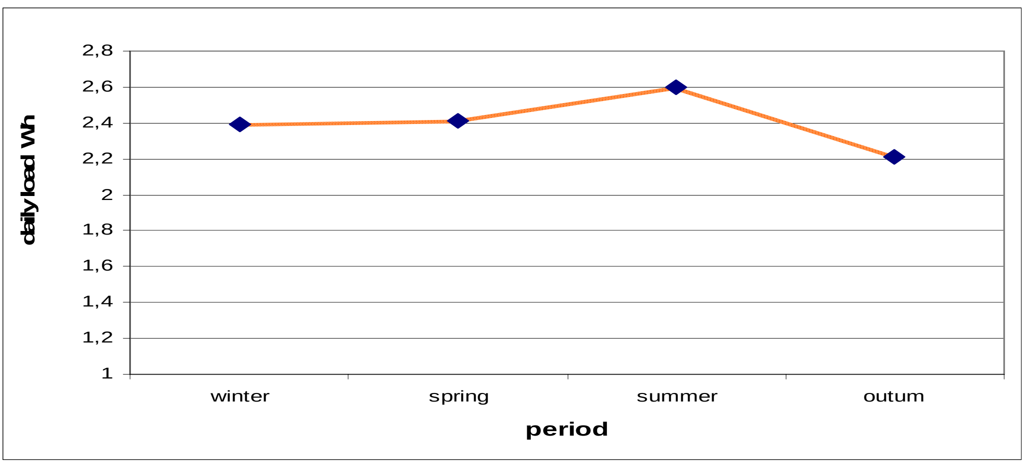


Fig. 3.9. The average daily load energy during different seasons.

In addition I estimated the daily energy consumption, the load curve for a complete typical day is presented in figure 3.10.

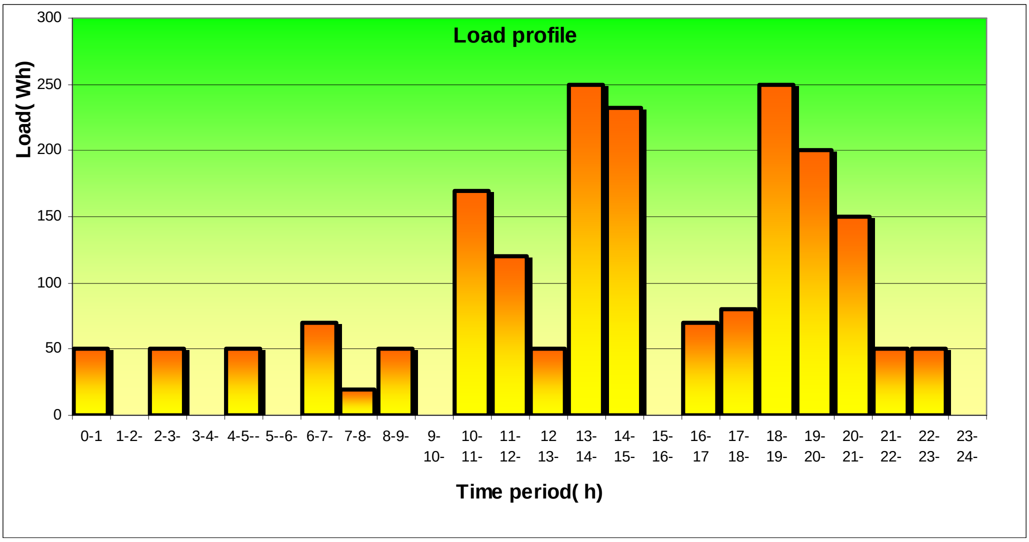


Fig. 3.10. The load curve of typical complete day consumption

As the chart illustrates in this load curve the energy consumption of day in 40% is concentrated at noon, when the solar radiation and accordingly the output power of the PV array reach its maximum. In evening and night period the energy necessary (60%) for supplying the consumer is assured by battery system. These values can be taken into account in case of design the storage, battery capacity. The design technique of the hybrid system based on this; because the daily winds speed distribution in this period show a downward trend. The PV system energy production presented in chapter 3.2, in monthly distribution compared with the monthly energy demand can be seen in figure 3.11.

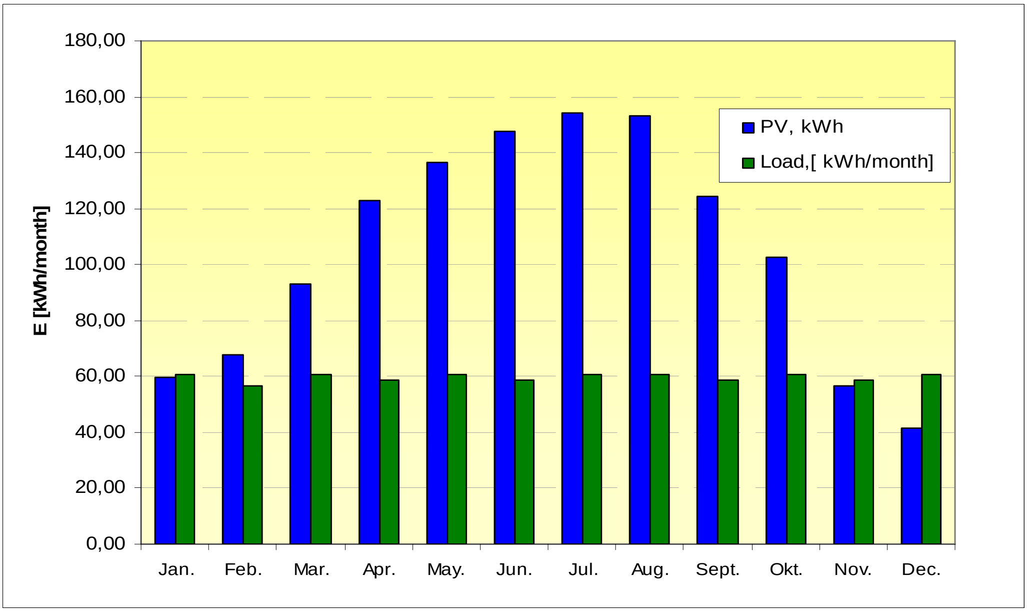


Fig. 3.11. The monthly average energy production of 1 kWp PV system and the monthly load

As we can see the presented PV system except in November, December and January can be cover the energy demand of the consumer. During the summer period energy surplus are detected. For the mentioned month in winter period it is necessary to use a diesel generator to feed the application with energy. The energy balance of the PV system in monthly distribution can be seen in table 3.2.

Tab. 3.2. Energy balance and the principal parameter of the PV system

Month	E_{PV},[kWh]	Monthly load, [kWh]	Excess of energy, [kWh]	Energy deficit, [kWh]	SOC, [%]	Pr. LOL [%]	Necessary gasoline, [litre]
Jan.	59,50	60,50	-1	1	24	16,90	6,1
Feb.	67,80	56,60	11,2	0	71	0	0
Mar.	93,20	60,50	32,7	0	84	0	0
Apr.	122,70	58,50	64,2	0	95	0	0
May.	136,60	60,50	76,1	0	97	0	0
Jun.	147,60	58,50	89,1	0	96	0	0
Jul.	154,20	60,50	93,7	0	96	0	0
Aug.	153,10	60,50	92,6	0	97	0	0
Sep.	124,60	58,50	66,1	0	94	0	0
Oct.	102,40	60,50	41,9	0	95	0	0
Nov.	56,80	58,50	-1,7	1,7	61	0,2	0,1
Dec.	41,40	60,50	-19,1	19,1	18	41,8	16,2
Year	1259,9	714,1	545,8	21,8	77,3	5	22,4

If the hybrid system in case of this presented energy consumption is expanding with one wind generator with 1 kWp power analysing the hybrid system properties we can evaluated the energy balance for the give application site, the results in this case is presented in 3.12 and 3.13 figures.

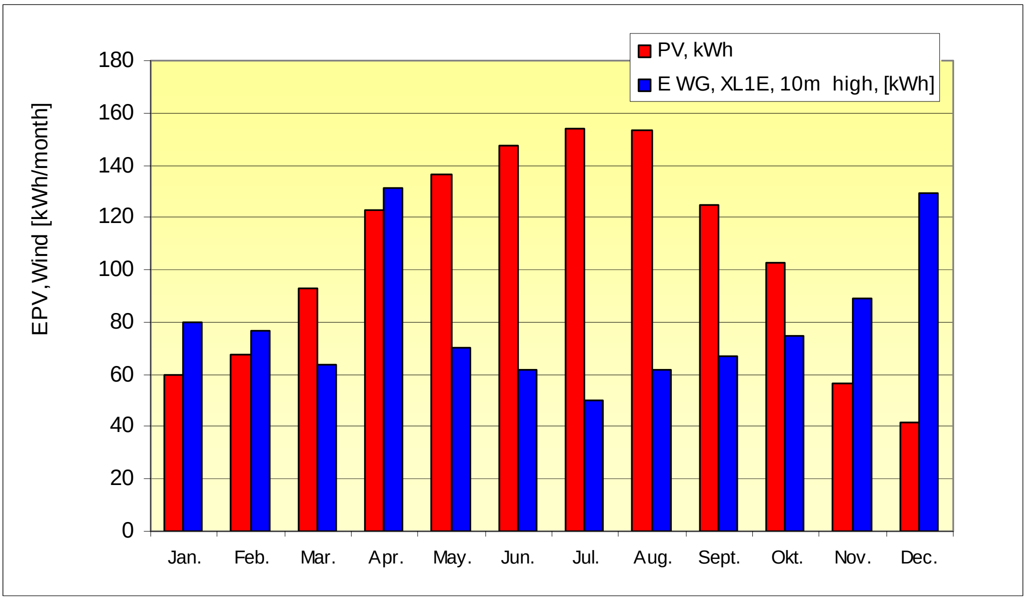


Fig. 3.12. The monthly average energy production of 1 kW_p power PV and Wind hybrid system

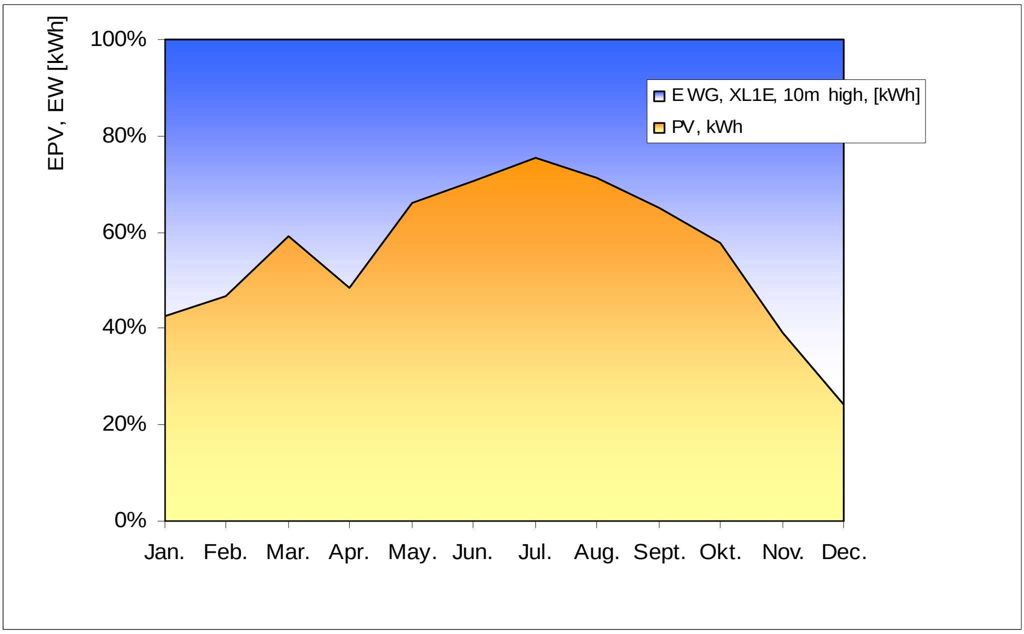


Fig. 3.13. The monthly average energy production of 1 kW_p PV 1 kWp Wind energy hybrid system

If the rate of the PV increasing to 30% the resulted PV wind energy system can be assured the energy need of the consumer. In this case the resulted energy balance monthly distribution can be seen inn figure 3.14.

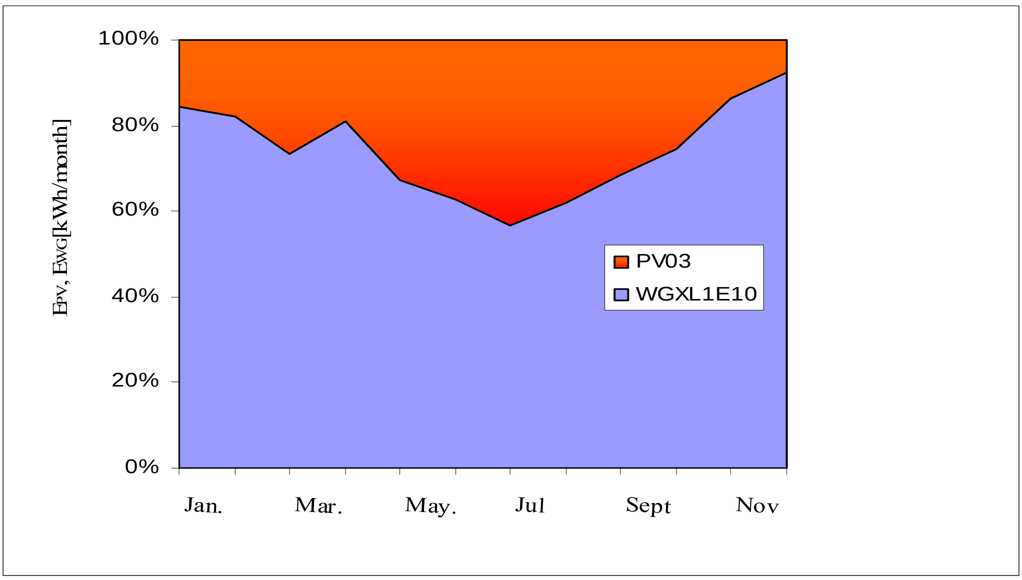


Fig 3.14. The energybalance of1 kW_p wind and 0.3kW_p PV hybrid system

3.2.8. Economic estimation of the hybrid system

The green energy using hybrid system differs from congenital sources as it is characterised by height investment and low operation cost. The price of the PV system and its installation are important factors in economics of PV systems. For economic estimation of the RES system the life cycle method can be used successfuly. The life cycle of the system components will be considered as 25 years except for the battery, which will be considered to have a lifetime of 8 years. The economical analysis I realised for a hybrid green energy system built from one 1 kWp power wind generator and 0.3-kWp-power PV unit. The produced energy is stored in lead acid battery and the consumer is supplied trough one AC inverter. The investment cost of the system is presented in table 3.3.

Table 3.3. Investment cost of the hybrid system

System component	Number. of components	Cost of component [Euro]	Total (Euro)
PV module KC 50	6	309	1854
Battery	12	178	2136
BCC, Charger, Steca tarom 234	1	265	265
Inverter AJ 1000	1	699	699
Conductors and mounting elements	1	400	400
Wind generator	1	2500	2500
Investment cost			7854
Installation cost is 10% from initial cost			785.4
Total cost			**8639.4**

The life cycle cost of the installation is formed from initial cost of the installation and from annual operation and maintenance cost of the system. For the life cycle analysis I determined the initial cost and the installation cost, which can be considered 10 % from the equipment and installation cost. The annual operation and maintenance cost are considered 2% of the initial cost. The lifetime of the system is 25 year and in this period we need to replace the battery two times. This investment is realised in the 8^{th} and 16th years. The present worth (Present Value) of the second group of batteries after 8 year can be evaluated with the following expression:

$$PV = \sum_{n=1}^{N} \frac{C(1+i)^{n-1}}{(1+r)^n} \quad (3.\ 3)$$

The life – cycle analysis procedure use the following parameters:

N- The life cycle of the components (25-year)

r-the market discount rate (10%,)

i- the annual inflation rate (7%, in Romanian long therm investment case)

n- the current year when the battery is replaced

C- the initial cost of the battery

Using the economical data from the presented table determined the present value of the investments cost (in Euro) necessary for replacing the battery in 8th (PV 8) and16th years.

$$PV_8 = \frac{2136(1+0.07)^{8-1}}{(1+0.1)^8} = 1600$$
$$PV_{16} = \frac{2136(1+0.07)^{16-1}}{(1+0.1)^{16}} = 1283 \quad (3.4)$$

In this application the operation and maintenance cost is considered 2 % of the initial cost.

The life cycle cost (LC) in this case can be evaluated with the following expression:

LC= initial cost + installation cost 2nd +3rd group battery +operation and maintenance cost

$$LC = 7854 + 0.1 \times 7854 + 1600 + 1283 + 0.02 \times 25 \times 7854 = 12566$$

The cost of one kWh green energy from hybrid system can be evaluated using the value of the annual energy production. From energy balance data in this case the produced energy for the life cycle period is:

$$E_{Tot} = (E_{PVgen} + E_{Wg})N = (377 + 1194) \times 25 = 39275kWh$$

The cost is a rate between life cycle cost (LC) and the produced energy value(Etot) in this life time period(aprox. 25 year):

$$p = \frac{LC}{E_{Tot}} = \frac{12566}{39275} = 0.32\left[\frac{Euro}{kWh}\right]$$

This value is heighter than the current market price of the electricity, but is much lower than what same EU states offer for 1 kWh green electricity. In Germany this value is 0. 53 Euro/ kWh produced, by PV application.

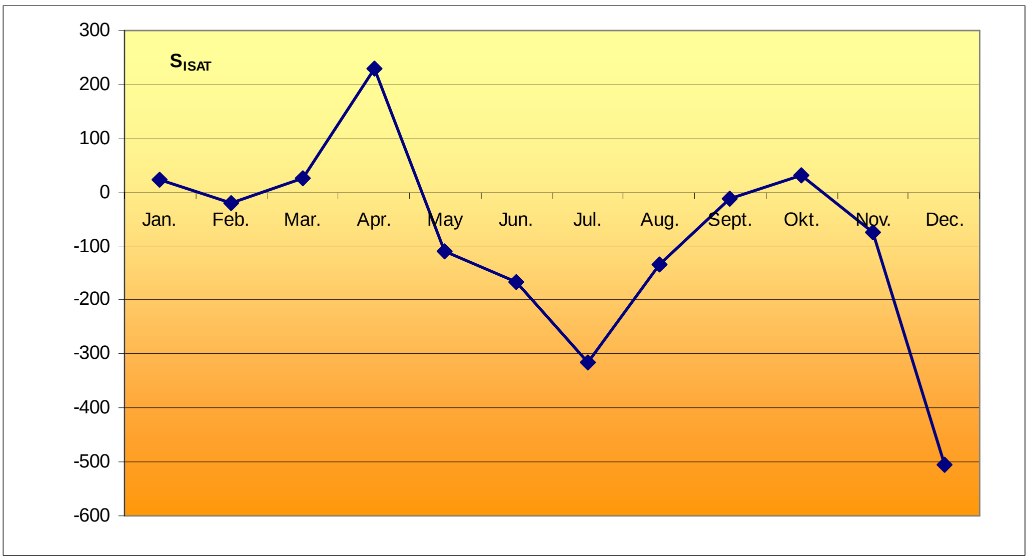
4. NEW SCIENTIFIC RESULTS

1. Sun path diagram editor model

I developed a model for editing the sun path diagram for a given location. The realised diagram with this model can be used with one ecliptic analyser for detecting the possible shading obstruction, which caused the partial shading of the PV panel. For analysis, these obstructions are plotted in a solar ecliptic diagram and this help to detect the elements causing shading from environment. In this case with can be prevent the hot spot phenomena, which can caused the damage of the PV module.

2. Complemetarity of the solar and wind energy potential

Analysing the solar and wind energy potential for a given location based on the measured solar radiation and wind sped data and using a statistical evaluation we can come to the conclusion that the two energy sources has a complementary variation in a time period. During in summer period the solar and in winter period the wind energy is the dominant. These results can be demonstrated with measured meteorological data. If the evaluated cross correlation (Si_{STAT}) constant values is a negative number that means than the analysed values are complementary. The following figure sown the monthly distribution of the cross correlation (Si_{STAT}) constant for one-year period. In case of Agige the location seat at the Black Sea cost the annual value of this parameter is: (Si_{STAT})= $-1033(W/m^2)^2$. Which demonstrates the complemetarity of this energy sources in this region.

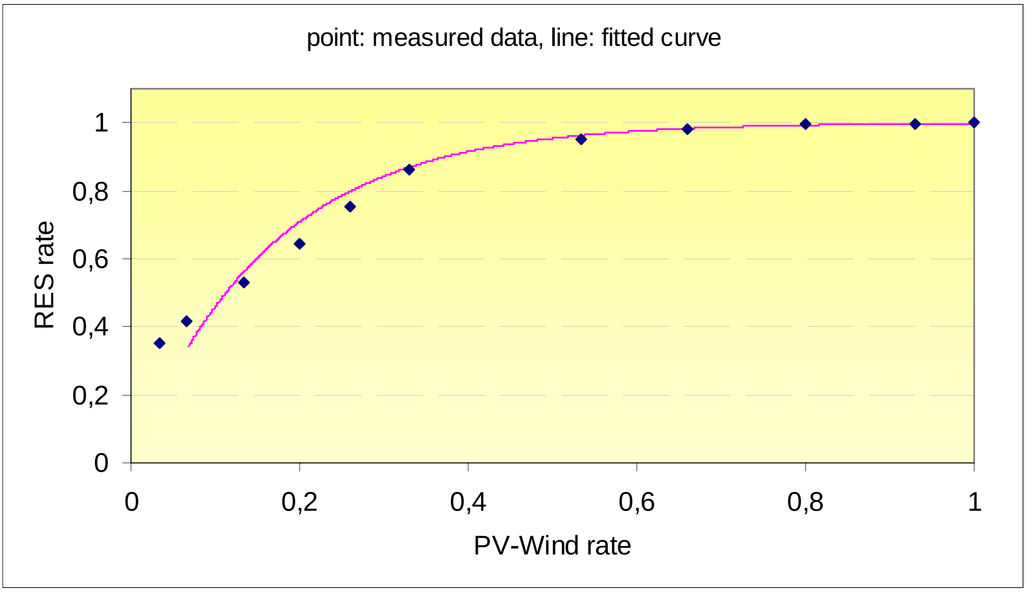


3. The energy balance of the hybrid solar wind energy system

Using the solar radiation data and wind energy potential of a given location take into account the energy needs of the consumer I developed a model, which determines the energy production in daily and monthly rate. The presented model is for a given fixed storage capacity and daily load requirements. Take into account the complemetarity of the solar and wind energy potential, as well I determinate a relationship between the share of renewable energy sources (f_R) and share of PV-wind, which can be estimated by the following functions:

$$f_R\left(f_{PV/W}\right) = 1 - e^{\left(a \times f_{PV/W}\right)}$$

The range of the validity of the usual practice is heighter than 50% for the share of the renewable. ($f_R > 0.5$). I identificated the parameters of the functions as a= -6,158 and the correlation coefficients in this model: R^2= 0,97. The measured data and the evaluated fitted values are presented in the following figure.

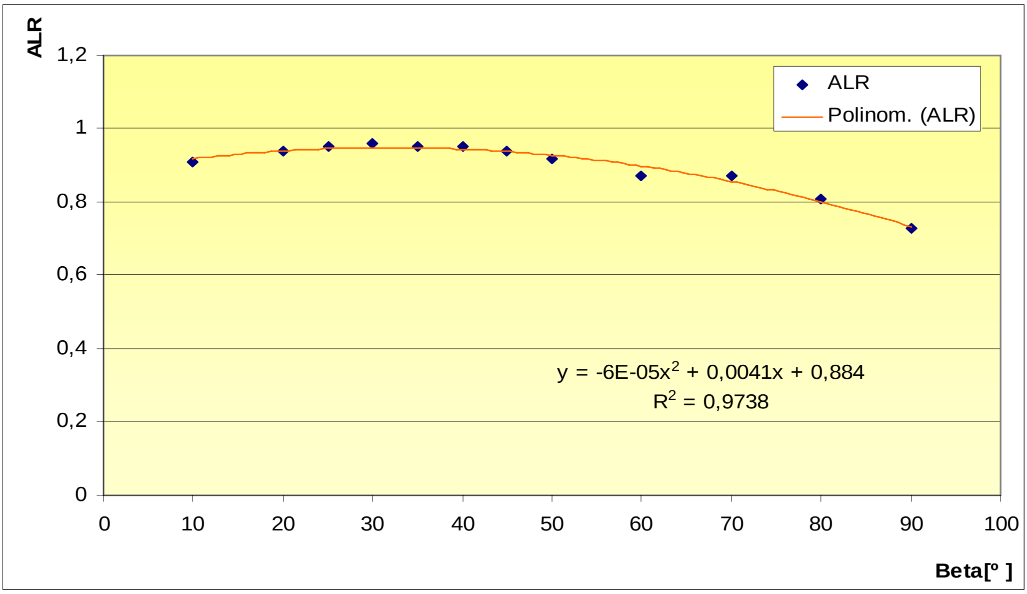


4. The energy production and load (ALR) ratio as a function of the tilt angle of the PV panel

I developed a general model, which can give relation between the repesentaive parameter of hybrids energy system, the ALR parameter and the tilt angle of the PV panel for a given storage capacity. This relationship can be described with a second order function, which form is:

$$ARL(\beta) = a\beta^2 + b\beta + c$$

This will help to determine the optimal tilt angle of the PV panel in function of the solar radiation data and a given load energy requirements. The model take into account that the battery bank dos not work under a defined DOD (Deep of Discharge) values. The model accuracy is demonstrated with experimental data. In range of 44-46º geographical latitude the ARL parameter changes as a function of the tilted angle of the PV panel can be seen in the below figure. The optimal tilted angel in this case is β=45 º.



5. <u>The k parameter evaluation in Weibull function</u>

The most common function used for describing the wind speed distribution is the Weibull distribution which can be written by the following relationship:

$$f(v)=\frac{k}{C}\left(\frac{v}{C}\right)^{k-1} e^{-\left(\frac{v}{C}\right)^{k}}$$

From the measured wind speed data evaluated in monthly distribution I determined the principal parameter k and C of the Weibull distribution function. That is a shape k parameter and scale C parameter for a given location situated at the Black Sea cost. The obtained result the value of these parameters in monthly distribution is presented in following table:

Month	I	II	III	IV	V	VI
k(-)	2,008	2,007	2,0012	2,003	2,007	2,007
C(m/s)	4,62	4,74	4,28	5,64	4,4	4,28
Month	VII	VIII	IX	X	XI	XII
k(-)	2,004	2,007	2,003	1,997	2,007	2,005
C(m/s)	3,9	4,23	4,4	4,51	4,8	5,52

The main conclusion is that this k parameter value is within 0.5% except is k= 2. i.e. the distribution is equivalent with a Rayleigh function. The practical experience has demonstrated that in case of small power wind generator, which working at low height, the Rayleigh distribution function can be used for estimattion the energy production of the windgenerator.

5. CONCLUSIONS AND SUGGESTIONS

Analysing the design procedure of the hybrid solar PV wind energy system it was concluded that the optimal photvoltaic PV and wind energy ratio, which above the over dimension, is 1/3 for PV and 2/ 3 for wind energy peak power. The technical problems in case of RES. application has been essentially resolved, but it can be find solution to the industry, which make it competitive against the conventional energy sources. The Central Eastern European region is still many settlements, which electrical energy supplying it is not resolved. So the presented design technique and methods in this dissertation and the technical solution proposed have been successfully solved the electrification problems in exemple this areas. The Romanian experience has shown, for exempla in case of mountain villages in West part of Carpaten where the homes can be found spread apart, several kilometres away from each other and far to the national electrical grid. The presented hybrid system structure can be used successfully in the energy supplying process of the regions. Using these technical solutions the electrical energy supply can be resolved for small farms and hoses sited in this remote area. Good technical solution can be obtained with a height precision analysis of the meteorological data for the application region. The measurements of this parameter, dates are indicated to realised for one-year period. Analysing the meteorological data we can obtain a favourite solution for the applicability of the green energy sources in this proposed application. The wind energy potential for the proposed application can be evaluated at 10-15m height, not more, because the small power wind turbine are operate at this tower height. The models presented in this dissertation can be used for estimate the annual energy yield from the measured solar and wind energy data. The model used for study of the complementarity of the sited energy sources is recommended for the energy balance evaluation. The VI method indicated for the sensor calibration in case of wind measurement technique can be easily used. The used anemometers was tested in a wind tunnel ust in eduactional activity, the resulting accuracy is sufficient to carry out the measurment. For the energy balance of the PV system is necessary to defined the optimal tilt angle of the PV panel, which can be evaluated using the presented method based on optimal ALR (array-to - load ratio) values. In case of design the storage capacity is necessary use the hybrid indicator graph, which has the load in Wh per day graphed on the vertical axis and the ALR graphed on the horizontal axis. That is the array power rating in peak watts (i.e. for 1 kW/m^2 insolation level) divided by the load in Watt- hours per day (i.e. W_p/Wh). From this graph it can be seen that hybrid system are preferable for larger loads and a heighter array – to load ratio. Is indicated to use a small optimal storage capacity, because the larger are height maintenainece cost. For the optimal orientation the PV panel is necessary to analyse the localisation of possible shading obstruction with an ecliptic analyser. For the monitoring of the current of the PV system with a datalogger card is necessary to use in DC side, one voltage-current converter in this case our data logger system work in security condition.

6. SUMMARY

During my research period the application of environmental friendly energy resources has been developed, and several EU Directive based programs supported these initiatives. These facts show the importance and opportunity of the programs.

After reviewing the theme-linked bibliography, I participate to the wind and solar energy potentials surveying process. I made my survey in different places, especially in the Black Sea shore situated Agigea city, and in the mountain area situated near Brasov city. In my work, I participate to the data assessment (evaluation), and I also used these in the energy balance studies. The wind velocity meter was tested in wind tunnel used in education purpose. For the data evaluation, I elaborated a Lab View static model. Based on the measurement data I defined a method using the functions to determine the cross-correlation coefficient for the wind and solar energy potential complementarity.

If there is a place where this phenomenon exists it can reduce the PV rate in the energy balance. As well known in this case there is an optimal 1/3 photovoltaic (PV), respective 2/3 wind rate, which I certified at a given consumption. I also defined, based on the measurement data, an optimal hybrid system, which can support the energy supply for a little household.

The components are a 1 kW_p peak power wind generator and 0.32 kW_p peak power PV module built from 8 pieces Kyocera KC 40 PV module and an 500 Ah battery, designed for 24 V voltage. This provides 3-4 day autonomy at a given consumption for the household. The methods and the models can be used in different places and in varieties energy-needs.

The measurement data can be used in choosing of the areas feasible for wind and sun energy exploitation, and in accordance with this choosing the area adapted wind generator.

In this case, it is necessary to take into account the relation between the mean of wind speed and the cut in wind speed of the wind generator.

In the development of methods and models, I focused on the simplicity and accuracy. These methods and models helped me to make general conclusions regarding to the possibility of using the measurement and data-acquisition systems and to determine the background for energy

Furthermore, I realised a study in field of small power wind and PV application and from evaluation of the energy balances of this units. This can be used easily, in vantage point in technical and economically evaluation process of this hybrid system.

7. PUBLICATIONS RELATED TO THE PHD WORK

Referred articles in Hungarian

1. Bartha,S.-Lágymányosi,A.-Farkas,I.-Predescu,M. (2002): Kombinált fotovillamos-szél villamosenergia-termelés a villamos hálózathoz nem kapcsolódó gazdaságban, Magyar Energetika, X. évf., 6. sz., 21-26.

Referred articles in English

1. Farkas,I.-Bartha,S.-Teodoreanu,D.I.-Lágymányosi,A.(2002): Design and simulation of a small scale PV system for a stand alone household, Hungarian Agricultural Engineering, No. 12/2002, Gödöllő, p. 86-88.
2. Farkas, **S. Bartha**, I. Seres, D.I.Teodoreanu, L. Kocsis,(2004): A small scale internal PV system for educational activity, Revista Electrotehnică, Electronică, Automatică, Vol. 52, Nr. 2-2004. p. 37-41.
3. Bartha, S. ,Farkas,I., Teodoreanu, Ursu V.,(2006): Characterisation of phtovoltaic modules and the use in a stand alone photovoltaic power supply, Revista Electrotehnică, Electronică, Automatică, Vol. 54, Nr. 1-2006. Pag 49-52.
4. Hegyi, K., Farkas, I., **Bartha,S**., Measuring Approch of Thermodynamical Parameters of Solar fluid, Revista Electrotehnică, Electronică, Automatică, Vol. 55, Nr. 3-4-2007. Pag 27-29.

International conference proceedings

1. Farkas, I. - Buzás, J.-Hegyi, K.-Fekete F , M.-Predescu, M.-**Bartha,** S.(1999): Use of PV-hydro-wind hybrid system in rural tourism, Proceedings of the Conference on Energy and Agriculture towards the Third Millenium, AgEnergy'99, Athen, Greece, June 2-5, 1999, Vol. II, pp. 574-581,
2. Farkas,I.**-**Predescu, M.**-**Lágymányosi,A- **Bartha,S**. (2001): Possibility of the use of a combined solar and wind system for a mountainous remote farm, ISES World Congress, Adelaide, Australia, November 25-30, pp. 1220-1228.
3. Bartha**, S**.: Probleme legate de utilizarea biocombustibililor în România, Conferința de Biocombustibili II ., Biodízel Konferencia -Kétpó-2002 Magyar Energiaközpont KHT, CD procedings
4. Farkas,I.**-Bartha,S.-**Teodoreanu,D.I.-Lágymányosi,A.(2002): Design and simulation of a small scale PV system for a stand alone household, The 4th ISES-Europe Solar Congress (EuroSun 2002), Bologna, Italy, June 23-26, 2002, CD-ROM Proceedings, pp. 11.

5. **Bartha,S**.-Farkas,I.-Teodoreanu,D.I.(2003): Modelling and simulation of a small scale PV system for a stand-alone application, Proceedings of ISES Solar World Congress 2003, Göteborg, Sweden, June 14-19, p. 6
6. Farkas,I.-Seres,I.-**Bartha,S**.-Teodoreanu,D.I.(2003): Designing of a middle scale PV grid connected system, CD-ROM Proceedings of the Solar and Wind International Conference and Workshop (SWIC 2003), ICPE-Agigea Test Facility Site, Romania, September 15-20,. pp. 6.
7. Farkas,I.-Seres,I.-**Bartha,S.-**Teodoreanu,D.I.(2003): Designing of a middle scale PV grid connected system, CD-ROM Proceedings of the Solar and Wind International Conference and Workshop (SWIC 2003), ICPE-Agigea Test Facility Site, Romania, September 15-20, pp. 6
8. **Bartha,S.-** Farkas,I.- Teodoreanu,D.I -Ursu,V.(2004): An optimal sizing model and simulation of a Photovoltaic system for family house sited in rural area, The 5th ISES-Europe Solar Congress (EuroSun 2004), Freiburg, Germany, June 23-26, 2004, CD-ROM Proceedings, pp. 101.
9. I. Farkas, I. Seres, J. Buzás, M Szücs, L. Kocsis, **S. Bartha,** (2004): Design and Constructional Aspects of a 10 KWp PV System, Solar and Wind Conference SWIC 2004-Agigea
10. **S. Bartha**, I. Farkas, D. I. Teodoreanu, (2004): Simulation method of a Photovoltaic System for Family House Sited in Rural Area CNSNRE Congress-2004-Targoviste
11. **Bartha, S.** Farkas, D.I.Teodoreanu,(2005): An optimal sizing and simulation of the stand- alone PV applications, Brasov CSE 01, p. 220-228.
12. Teodoreanu D. I.,Ursu,V., Teodoreanu, M, Atanasiu, B.Cristea, Gh, **Bartha, S.** ,Sontea, S,(2006): Sisteme hibride pentru alimentarea cu energie electrică a consumatorilor din zone izolate, Foren 2006, 15-20 iunie Neptun, s4-03 CD ROM Procedengs
13. Sizing aspects of small scale grid connected system, ISES Solar World Congress, 2007 Beijing **Bartha**, **S.** D.I.Teodoreanu, V.Ursu, C. Negreanu, I. Badarau,(2008): An optimal sizing and simulation of the small scale stand alone PV-Wind energy system for remoute area, Brasov, CSE 02, p. 151-156.

International conference abstracts

1. **Bartha,S**.-Nita,I.-Predescu,M.(2001): Modeling Lead-Acid Battery Capacity for Solar Typical Conditions E&E 7th Seminar on Energy and Environment, Gödöllő, November 5-6, p. 24
2. **Bartha, S.-**Teodoreanu, D. I-Ursu, V.-Pencioiu P.(2001): Sandia Photovoltaic Performance Modell for I-V Curve Tracer E&E 8th Seminar on Energy and Environment, Gödöllő, November 4-5, p. 18.

3. Pencioiu P- **Bartha, S**.-Teodoreanu, D. I-Ursu, V.(2001): PV-wind system for remoute multimedia application E&E 8th Seminar on Energy and Environment, Gödöllő, November 4-5, p. 23
4. **Bartha, S.-**Teodoreanu, D. I-Ursu.,(2004): Preliminary design and planning of a small scale integrated PV system for stand-alone houshold, Gödöllő, November 8-9, 2004, p. 17.
5. **Bartha, S.** Teodoreanu D. I, Ursu, V.,(2005): A simplified optimal method to sizing and simulation of the stand- alone PV-wind applications, E&E2005
6. **Bartha, S.** Teodoreanu D. I,,Ursu, V.,Sontea, S.,(2006):Characterisation and Modelling of Small Scale Grid Connected PV System, E&E2006Teodoreanu D, **Bartha, S.**. I, Ursu, V, Teodoreanu, M. (2006):Romanian PV Platform, E&E2006

Research reports

1. **Farkas**,I.-Buzás,J-Lágymányosi,A-Teodoreanu,D.I.-**Bartha,S**.,(2002): Overview of solar energy applications in Romania and Hungary, Research Report, Department of Physics and Process Control, Szent István University Gödöllő, No 26-research report
2. **Farkas**,I.-Buzás,J.-Hegyi,K.-**Bartha,S**.-Teodoreanu,D.I.,(2003): Modelling and simulation of a solar thermal system with Matlab/Simulink, Research Report, Department of Physics and Process Control, Szent István University Gödöllő, No 32, October 2003

Books:

1. **Bartha,** S., Farkas I., Teodoreanu, I.D., Seres,I., Farkas, M.(2006): Solar Photovoltaic Application, Bucuresti Editura Electra 2006 p 3-92.
2. **Bartha,** S., Badarau, I., Teodoreanu, I.D., Negreanu, C.(2009): Teoria sistemelor de reglare automata in ingineria mediului, Bucuresti Editura Electra 2006 p 128-182.

References

Farkas, I.,(2003): Napenergia a mezőgazdaségban, Mezőgazda Kiadó Budapest, p.283