Available online at www.sciencedirect.com

ScienceDirect

Materials Today: Proceedings XX (2016) XXX–XXX

materialstoday: PROCEEDINGS

www.materialstoday.com/proceedings

PMME 2016

Design and Optimization of Hybrid PV-Wind Renewable Energy System ☆

Ms. Jyoti B. Fulzele[a], Dr. M. B. Daigave[b]*

[a]*Assistant Professor, Bapurao Deshmukh College of Engineering, Sevagram, Wardha 442001, India*
bProfessor,GHRIETW, Nagpur, India

Abstract

Hybrid renewable energy system is the combination of two or more energy sources which is used to supply the targeted load. One of the most important applications of renewable energy system is the installation of well design hybrid energy system in remote areas where grid extension is very difficult and costly. But the proper design of such system is the challenging task as the coordination between different energy sources; energy storage and load are very complicated. An optimization of hybrid renewable energy system is the process of selecting suitable components, its sizing and control strategy to provide efficient, reliable and cost effective alternative energy to the society. This paper presents the design of an optimized hybrid renewable energy system consisting of photovoltaic, wind generator with battery and converter. The system has been optimally simulated by using IHOGA (Improved Hybrid Optimization Genetic Algorithm) tool developed by the Electric engineering department of the university of Zaragoza, Spain. The paper also described the sensitivity analysis of hybrid system which help to access the effect of uncertainty or change in the variable and finding the most suitable solution for hybrid system.

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

Keywords: Hybrid renwable energy sytem; IHOGA; Optimization; PV-wind; Simulation

* Corresponding author. Tel.: 9890984178; fax: +0-000-000-0000 .
E-mail address: bhongade10@gmail.com

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

1. Introduction

Now an energy being a vital issue. No one can imagine life without electricity. The role of energy generation is one of the most important factors for the development of any country. The main sources of energy now depleting and conventional systems have failed to provide reliable electricity in rural areas or remote areas which away from the grid [1]. Hence now it is essential to look towards alternative energy sources like renewable sources PV, wind, biomass, hydro etc. But the high installation cost especially for photovoltaic made its growth slow one. Now a day due to advance material, new manufacturing process and advance technology made them a more attractive solution for the energy problem.

Hybrid energy system is the combination of two or more energy resources to supply the load. Various considerations must be taken into account while working with the hybrid energy system for electricity production. The reliability and cost are the two important aspects must be considered while designing the hybrid energy system. Many researchers worked on the design, simulation and optimization of hybrid renewable energy system.

In 2010 Ahmad Rohani, Kazem Mazlumi and Hossein kord [1] proposed a system to design the aspects of a hybrid power system. The main power of the hybrid system comes from the photovoltaic panels and wind generators, while the fuel cell and batteries are used as backup units. The optimization software used for this system is HOMER. Also N. Razak, M. Othman & I. Musirin [2] has discussed on optimization, sizing & operational strategy of HRES which refers to the minimum TNPC. They compare the two hybrid energy model, PV array, battery and converter but this system provide the electricity at night additional battery storage and converter are require this will increase the cost of TNPC on the other hand the combination of wind turbine, diesel generator, battery storage & converter brings to the TNPC value lower than earlier one. In 2011 M. Hossan, M. Maruf Hossain and A. Reazul Haque [3] proposed a small scale hybrid renewable system consist of the PV array, small hydro plant with battery and diesel generator for backup. In this paper the initial optimum planning of hybrid system can be done with the help of HOMER secondly a dynamic model has been derived with the required formulation. The authors G. Vuc, I. Borlea [4] presented the optimal mix solar wind system for grid connection and it was found that optimal mixture of wind power produces approximately 50% of total electricity and PV contributes with about 1%, so the PV share rest lower and strongly dependent on capital multiplier. Such system can permit to respect some important principles of sustainability in the energy system. Rui Huang [5] developed the PV-wind system based on empirical weather and load data. To determine the system size, they formulate an optimization problem that minimizes the total construction and operation cost subject to maximum tolerable risk by using HOMER and assuming the weather resources and load keeps unchanged.

From the literature survey cleared that the selection, sizing of individual component and control strategy play very vital role in the overall cost of the hybrid energy system. Researchers developed and used different techniques for simulation and optimization. This paper presents the simulation and optimization model of hybrid energy system using IHOGA which worked on genetic algorithm. This tool calculates the optimum system configuration and allows the designer to evaluate economic and technical feasibility of a large number of technologies. The main aim to minimize the total net present cost of the system.

Nomenclature

T	Temperature (K)
P	Pressure (Pa)
P	Density (kg/m3)
H	Height above sea level (m)
Po	Standard pressure at sea level, 101325 (Pa)
To	Standard temperature at sea level, 288,15 (K)
G	9,80665 (m/s2)
L	The variation rate of temperature vs. height 0,0065 (K/m)
R	Ideal gas constant, 8,31432 (J/mol·K)
M	Molecular weight of dry air, 289644(g/mol)
Isc	Short circuit current of PV panel

G	Solar irradiance
LF	Loss factor
Npanels_series	Number of panels in series
Npanels_parallel	Number of panels in parallel
Tc	Internal cell temperature
Ct	Temperature coefficent

2. Mathematical Modeling of Hybrid Renewable Energy System

For the design of a hybrid renewable energy system the mathematical modeling of different system components that used by IHOGA can be found from [2][3][4]. For every component the mathematical model will be developed and presented below.

2.1 PV Generator

A photovoltaic system uses one or more solar modules or solar panels to convert solar energy into electrical energy. The basic unit of the PV system is photovoltaic cell, which when connected in the series or parallel fashion to form a module and number of modules gives rise to PV array. The power generated by the PV panels depends on solar irradiation and ambient temperature. IHOGA permits the PV system design with and without maximum power tracking [6][7].

A. Without Tracking

For no tracking system the output of PV generator is considered fixed by battery voltage so

VbusDC=Vn_panel*Npanels_series (1)

Where Vbus dc is the dc bus voltage, Vn_panel is the nominal voltage of the PV panel and Npanels_series is the number of panels in series.

In such case power supplied by the photovoltaic generator is calculated by eq (2)

P=Isc*G*Vn_panel*Npanels_series*Npanels_parallel/LF (2)

Where I_{sc} is the short circuit current of panel, G is the irradiance on the surface of the panels in KW/m2 and L.F is the loss factor . In this case output power practically does not depend on ambient temperature.

B. With Maximum Power Point Tracking

The power generated by the PV generator considering the effect of temperature is calculated by eq. (3)

P=Pn*G*(1+Ct/100*(Tc-25))*Npanels_series*Npanels_parallel /FS (3)

Tc=Tamb+G*(TONC-20)/800 (4)

Where Pn is the nominal power (Wp) of PV panel, Tc is the internal cell temperature, Ct is the maximum power temperature coefficient, Tamb is the ambient temperature and F.S is the safety factor.

In a small PV system with battery storage number of panels in series is calculated by eq. (5)

Npanels_series = VbusDC / Vn_panel (5)

For high power the number of panels in series are calculated by eq. (6)

Npanels_series = VbusDC/Vmax_p_panel (6)

Where Vmax_p_panel is the voltage of the maximum power of the PV panels.

$$Npanels\_parallel < Peak\ power\ of\ generator * Npanels\_series / Vn\_panel \quad (7)$$

2.2 *Wind Turbine*

The power generated from wind turbine is given by [4]

$$Pw = Cp * \rho * A * Vw^3 / 2 \quad (8)$$

Where Cp is the power coefficient, Vw is the wind speed, A is the area of swept by the rotor and ρ is the air density. Amount of aerodynamic torque Tw is given by

$$Tw = Pw/Ww \quad (9)$$

Where Pw is the power extracted from the wind and Ww is the turbine rotor speed.
Air density and atmospheric pressure are given by eq. (10) & (11).

$$\rho = Pa\ M / 1000*R*T \quad (10)$$

$$Pa = Po(1- LH/To)^{gM/RL} \quad (11)$$

2.3 *Battery System*

In the absence of renewable sources like solar and wind, battery system play an vital role in ensuring uninterrupted power in supplying loads. The capacity of battery is determine based on daily energy consumption and the time during which load is supply from the battery bank. In the absence of renewable sources this time is represented in terms of number of autonomy days(AD). The battery storage capacity (Cwh) is calculated using eq. (12) [8].

$$Cwh = (E_{DL} * AD) / (\eta_{BDI} * \eta_B * DOD) \quad (12)$$

Where AD is number of autonomy days, DOD is the allowable depth of discharge of battery, η_{BDI} is the bidirectional inverter efficiency and η_B is the battery efficiency.

2.4 *Charge Regulator*

A charge regulator is a device that controls the flow of charge from a battery to load or from a solar panel / wind generator to the battery. Its role is important, as the output of solar panel and wind turbine are invariant in nature according to the atmospheric condition. The charge regulator protects the panels, wind turbine and battery bank against the overcharging and fast discharging also blocking of reverse charge and maintaining the proper use of natural energy.

2.5 *Bidirectional Converter*

The bidirectional converter is used to connect dc as well as ac load. The rating of the converter is selected as per the peak demand of load which suitable for both battery bank and load. Most of the bidirectional converter in market includes the PV battery charge controller (the bi-directional converters may include management of renewable photovoltaic and / or wind energy).

3. Hybrid System Design

The proposed hybrid system has been designed and simulated with the use of IHOGA software. IHOGA software is used to determine the optimal sizing and operational strategy for a hybrid renewable energy system based on genetic algorithm. IHOGA perform three different analysis, optimization, sensitivity and probability analysis.

3.1 Study Area

The site selected for hybrid renewable energy system is located in Yavatmal district, Dudhagon village, near Dharva in Maharashtra, India is having latitude 20^0 24'N and longitude 78^0 8'E.

3.2 Data Collection and Input for IHOGA

Methodology used for data collection is divided into two parts: primary and secondary sources. Primary sources, mainly consist of interviews and questionnaire surveys with the villagers. Secondary sources consist of a literature survey, peer reviewed articles, research papers and government published documents [1].

3.3 Load Profile

In the present study the electrical load profile is considered according to the seasonal variations i.e. during summer, winter and rainy seasons. The average estimation of daily energy consumption is 781.69 KWh/day and the peak requirement of the load is about 90.05 KW peak.

3.4 Resource Input Data

The resource inputs for the proposed site are solar and wind. Solar and wind resource input for latitude 20^0 24'N and longitude 78^0 8'E are collected from [9][10]. Table 1 represents the monthly wind speed and solar radiation data for the site

Table 1. Resource Input Data

Months	Wind Speed	Solar radiation
Jan	2.96	4.798
Feb	3.28	5.595
Mar	3.24	5.978
Apr	3.44	6.615
May	3.78	6.685
Jun	3.87	5.149
Jul	3.67	4.326
Aug	3.46	4.044
Sep	2.72	5.148
Oct	2.54	5.632
Nov	2.8	5.051
Dec	2.84	4.779
Average	3.22	5.312

3.5 System Component Description

The system includes solar photovoltaic panels, wind turbines, converter and batteries. The system has been designed for 300V DC voltage and 230V AC voltage. The solar photovoltaic panels of 190 Wp each of type Sip12Suntech ST. The nominal voltage is 24V. The initial cost of the panels is 255.6$ and other and maintains cost of each panel is 2.55$. The lifetime of panels will consider being 25 years.

The wind turbine type Hummer HWP has a power of 50Kw and its hub is proposed to locate at 22 m height. The initial investment cost is 76700$, its replacement cost is 62400$ and other & maintains cost of 1534$/yr. The lifetime is assumed for 20yrs. Wind turbine which is selected i.e Hummer 50 Kw is one of the most advance generator in the world. It is made up of refined permanent magnetic material, special copper alloy, aviation aluminium alloy, stainless steel. It is highly efficient in generating power. Due to its size it is able to be placed in the nose cone to reduce air resistance and increase efficiency. Due to its advanced technologies, refined materials and unique design, its wind energy utilization factor is as high as 0.42 while generator efficiency is higher than 0.92. Its working wind speed is from 2.5 to 25 m/s [11].

Converter size is selected as per the maximum peak load of the system. The bidirectional converter type is ACME 150 CRGE 150KVA. For storage purpose batteries are used with nominal voltage is 12V, 106Ah and life is about 12yrs. The initial investment cost is 253.5$. The depth of discharge for batteries is set at 80% to protect the battery from over discharge. The number of batteries in series is 25(300V/12V =25). These strings of batteries are connected in parallel.

3.6 *Control Strategies*

In this hybrid operation of PV-wind system strategy of operation depends on different situations. If the total energy or current generated by PV and wind is greater than the required energy or current by the load, in this case the excess energy is stored in the battery and battery put in the charge condition. When the battery SOC(State of charge) reaches the maximum value, the control unit stops the charging process. Whereas if total energy generated by PV and wind is less than the energy required by the load, the energy deficiency is covered by the storage system. In such case controller puts the batteries in discharging condition. If the battery charge decreases to its minimum state of charge, the controller unit disconnects the load and in such situation system is under the energy shortage. For optimum selection of control strategy wished to try both load following and cycle charging [12][13][14].

3.7 Objective Function

In this study the objective function is to minimize total net present cost (NPC). Net present cost made up of capital cost, replacement cost and other and maintains cost of each component of the system like PV generator, wind turbine, battery bank and converter [9].

$$NPC = Min\sum(C_k + C_{kr} + TC_{omk}) \quad (13)$$

4. IHOGA Simulated Hybrid Renewable Energy System

For the design of any hybrid system model IHOGA permits five different tabs to the designer in which the necessary data must be entered by the designer according to the requirement of the system. The tabs contain general data, optimization, control strategies, financial data and result charts. In this paper the system model consists of PV WG, Batteries and converter shown in fig 8. In normal operation PV and wind turbines feed the load demand. The excess energy from PV and WG is stored in the battery to full capacity of the battery is reached. The main importance of introducing energy storage is to import/export energy depending on the situation.

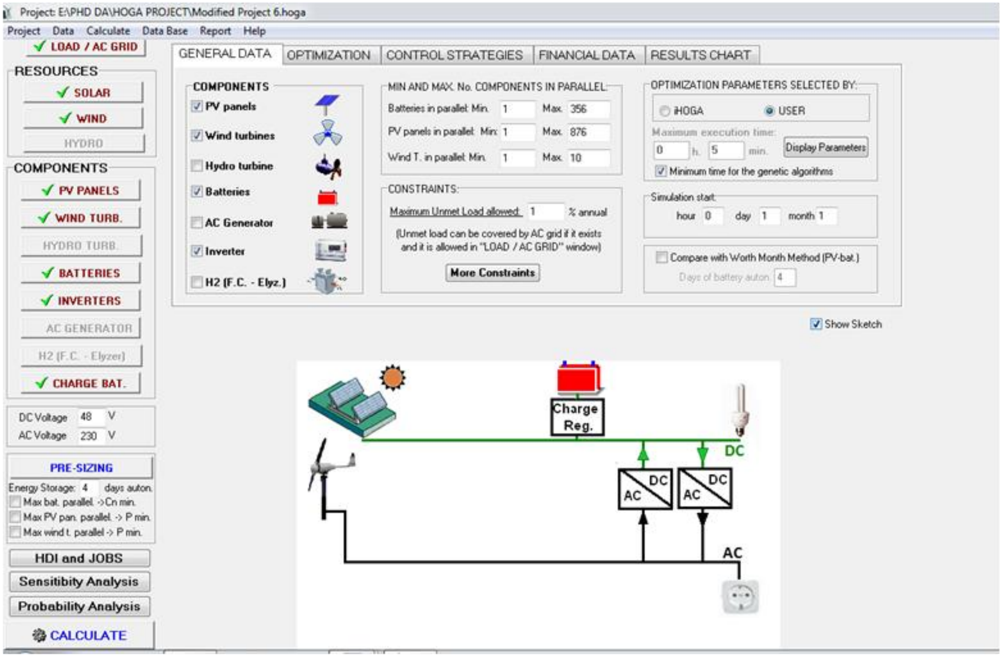


Fig. 1. IHOGA simulated Model of PV-Wind system

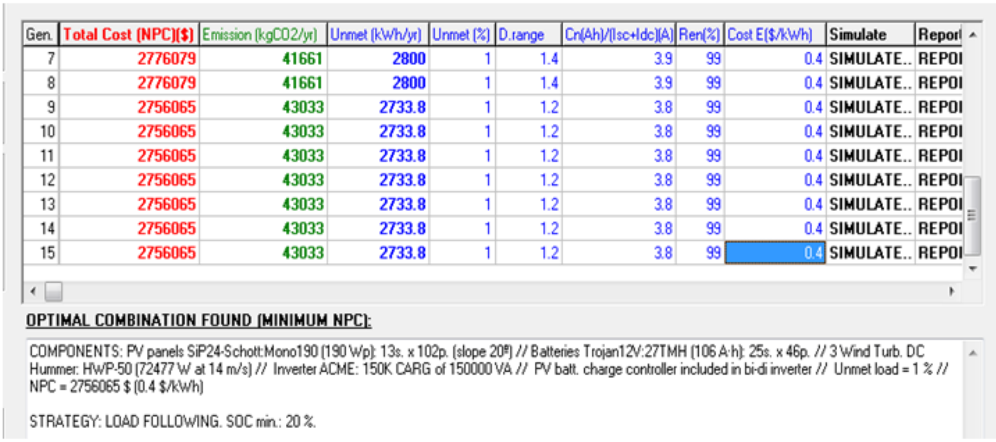
5. Results and Discussion

In this study IHOGA perform mono-objective function. The Objective function is to minimize total net present cost for the user define constraints such maximum unmeet load allowed, minimum number of days reserve, nominal capacity of the batteries bank, minimum renewable fraction and maximum levelized cost of energy. The control strategy of the system uses both load following and cycle charging.

This paper presents the results of the hybrid system on the basis of the optimization process without sensitivity variables and by considering the effect of sensitivity variables.

5.1 Optimization of HYRES without considering sensitivity variables

The simulated optimized results of hybrid renewable energy system are shown in fig 2. In this study the number of generations evaluated by IHOGA is 15 and total 20504 cases are evaluated for the determination of total net present cost. Fig 2 shows the optimum solution of hybrid PV wind renewable energy system with lowest net present cost is 2756065$ and cost of energy equal to 0.4$/Kwh. This solution is acceptable as a minimum because after 15 generations with the same parameters no better result has been given by IHOGA. The optimum configuration of hybrid PV-wind renewable energy system consists of PV panels of 13 series x 102 panels parallel with nominal power of 190Wp, 25 batteries series x 46 batteries parallel with the voltage of 12V,106Ah, Three wind turbine with 72477W at 14m/s, bidirectional inverter of 150KVA, PV battery charge controller included in bidirectional inverter.



Gen.	Total Cost (NPC)($)	Emission (kgCO2/yr)	Unmet (kWh/yr)	Unmet (%)	D.range	Cn(Ah)/(Isc+Idc)(A)	Ren(%)	Cost E($/kWh)	Simulate	Report
7	2776079	41661	2800	1	1.4	3.9	99	0.4	SIMULATE..	REPOI
8	2776079	41661	2800	1	1.4	3.9	99	0.4	SIMULATE..	REPOI
9	2756065	43033	2733.8	1	1.2	3.8	99	0.4	SIMULATE..	REPOI
10	2756065	43033	2733.8	1	1.2	3.8	99	0.4	SIMULATE..	REPOI
11	2756065	43033	2733.8	1	1.2	3.8	99	0.4	SIMULATE..	REPOI
12	2756065	43033	2733.8	1	1.2	3.8	99	0.4	SIMULATE..	REPOI
13	2756065	43033	2733.8	1	1.2	3.8	99	0.4	SIMULATE..	REPOI
14	2756065	43033	2733.8	1	1.2	3.8	99	0.4	SIMULATE..	REPOI
15	2756065	43033	2733.8	1	1.2	3.8	99	0.4	SIMULATE..	REPOI

OPTIMAL COMBINATION FOUND (MINIMUM NPC):

COMPONENTS: PV panels SiP24-Schott:Mono190 (190 Wp): 13s. x 102p. (slope 20º) // Batteries Trojan12V:27TMH (106 A·h): 25s. x 46p. // 3 Wind Turb. DC Hummer: HWP-50 (72477 W at 14 m/s) // Inverter ACME: 150K CARG of 150000 VA // PV batt. charge controller included in bi-di inverter // Unmet load = 1 % // NPC = 2756065 $ (0.4 $/kWh)

STRATEGY: LOAD FOLLOWING. SOC min.: 20 %.

Fig. 2 Optimization results of hybrid PV wind renewable energy system without sensitivity variable

5.2 Optimization of HYRES considering sensitivity variables

In this process, firstly the sensitivity variables are selected as change in global solar radiations and average annual wind speed. Table 2 shows the IHOGA optimized sensitivity results by considering global solar radiations and wind speed. For the different combination of solar radiation and wind speed IHOGA optimized the best configuration of hybrid renewable energy system and the results show that for every combination system configuration is consisting of PV, wind turbine, battery and converter yields cost of energy of slightly changes from 0.42 to 0.35 $/KWh shown in table 2.

Table 2. Optimization Results considering global solar radiation and wind speed as a sensitivity variable

Sens.#	Wind Speed(m/s)	Solar Rad(kWh/m2/d)	Lev. cost Energy ($/kWh)
1	3.22	5.79	0.4
2	3.22	6.95	0.38
3	3.22	4.05	0.42
4	3.22	5.79	0.4
5	3.86	5.79	0.36
6	3.86	6.95	0.35
7	3.86	4.05	0.38
8	3.86	5.79	0.36
9	3.7	5.79	0.37
10	3.7	6.95	0.36
11	3.7	4.05	0.39
12	3.7	5.79	0.37
13	4.02	5.79	0.35
14	4.02	6.95	0.35
15	4.02	4.05	0.37
16	4.02	5.79	0.35
17	3.22	5.79	0.4
18	3.22	6.95	0.38
19	3.22	4.05	0.42
20	3.22	5.79	0.4

Another sensitivity variable considered is the PV panel price. Due to advance material and better manufacturing process the price of solar photovoltaic system will be reduced in near future. Hence, by considering PV panel price as a sensitivity variable, system should be simulated. Several prices of panels are checked against the cost of energy and it is observed that if the panel price reduced to 20% cost of energy changes from 0.4 to 0.1$/kwh shown in and table 3.

Table 3. Optimization Results considering solar panel cost as a sensitivity variable

Sens.#	Price.PV(x)	Lev. cost Energy. ($/kWh)
1	1	0.4
2	0.95	0.1
3	0.9	0.1
4	0.85	0.1
5	0.8	0.1

6. Conclusion

This paper discusses the design and optimization of hybrid renewable energy system by considering the effect of sensitivity variables such as global solar radiation, wind speed, and PV panel cost. The result shows that for each variable system consisting of solar, wind with battery and converter bring out the most economical and viable solution for the proposed site. The sensitivity analysis helps the designer for proper future predictive planning before installation of the hybrid energy system. By considering the main objective of rural energy, planning hybrid renewable energy system has been optimized for economic viability. Economic viability should be the top priority over the technical feasibility while designing the hybrid system for rural electrification in a developing county like India, where end users are not always in a position to incur the high costs of power due to their poor economic condition.

References

[1] A. Rohani, K. Mazlumi, H. Kord, Modeling of a Hybrid Power System for Economic Analysis and Environmental Impact in HOMER, IEEE transaction, ICEE 2010, May 11-13.
[2] N. Razak, M. Othman, Optimal sizing and operational strategy of hybrid renewable energy system using HOMER, IEEE transaction, pp. 495 – 501, June 2010.
[3] M. Shakawat Hossan, M. Maruf Hossain, A. Reazul Haque, Optimization and Modeling of a Hybrid energy system for off-grid electrification, IEEE transaction, 2011.
[4] G. Vuc, I. Borlea, C. Barbulescu, Optimal energy mix for a grid connected hybrid wind – photovoltaic generation system, IEEE transaction, pp. 129 – 132, March 2011.
[5] Rui Huang, S. Low, U. Topcu, K. Chandy, Optimal design of hybrid energy system with PV/Wind Turbine/ Storage : A Case study, IEEE transaction, pp. 511 – 516, 2011.
[6] www.unizar.es/manual del usuario
[7] R. Dufo-Lopez, J. L. Bernal-Agustin, IHOGA software version 2.2, Electrical Engineering department, University of Zaragoza, Spain(2012).
[8] M. S. Ismail, M. Moghavvemi, T.M.I. Mahlia, Design of an optimized photovoltaic and microturbine hybrid power system for a remote small community: Case study of Palestine, Energy conversion and mangement 75, pp. 271 – 281, 2013.
[9] http://rredc.nrel.gov/solar
[10] http://eosweb/arc.nasa.gov/cgi-bin/sse/grid.cgi
[11] www.mipower.co.uk/Hummer-50kw-Wind-Turbine.html
[12] Anita Gudelj, Maja Krcum, Simulation and optimization of independent renewable energy hybrid system, TOMS transactions on maritime science, pp. 28-35, 2013.
[13] M. S. Ismail, M. Moghavvemi, T.M.I. Mahlia, Genetic algorithm based optimization on modeling and design of hybrid renewable energy systems, Energy conversion and mangement 85, pp. 120 – 130, 2014.
[14] Corsiuc Georgiana, Marza Carmen, C. Emilian, Hybrid solar-wind stand alone energy system: a case study, applied mechanics and materals, vol 772, pp. 536-540, 2015.