

COMPUTER-AIDED DESIGN SYSTEMS

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USING PV/WIND HYBRID SYSTEMS IN THE AUTONOMOUS OUTDOOR ADVERTISING

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Abstract. Hybrid power system can be used to reduce energy storage requirements. In this paper, more accurate mathematical models for characterizing PV module, wind generator and battery are proposed. The present paper presents the optimal sizing of an autonomous hybrid PV/wind system for outdoor advertising and other application. Considering various types and capacities of system devices, the configurations which can meet the desired system reliability are obtained by changing the type and size of the devices systems.

Keywords: outdoor advertising; wind generator; battery; solar panel; hybrid system.

Introduction

Energy is vital for the progress of a nation and it has to be conserved in a most efficient manner. Not only the technologies should be developed to produce energy in a most environment-friendly manner from all varieties of fuels but also enough importance should be given to conserve the energy resources in the most efficient way. In recent years, hybrid PV/wind system (HPWS) has become viable alternatives to meet environmental protection requirement and electricity demands. With the complementary characteristics between solar and wind energy resources for certain locations, hybrid PV/wind system with storage banks presents an unbeatable option for the supply of small electrical loads at remote locations where no utility grid power supply. Since they can offer a high reliability of power supply, their applications and investigations gain more concerns nowadays [1]. To use solar and wind energy resources more efficiently and economically, the optimal sizing of hybrid PV/wind system with battery plays an important role in this respect. The mathematical model of hybrid PV/wind system, including PV modules, wind generators and batteries storage, is developed.

The block diagram of a hybrid autonomous energy supply system

The hybrid system – a system that consists of a wind turbine, solar panels and battery, which combine the two types of energy: wind and solar. Their joint work can stably generate electricity all seasons, in the worst weather conditions, when there is little sun, but the wind is much stronger, and in the summer, when solar energy is much more than the energy of wind.

Wind turbines, solar battery and the battery connected to a hybrid controller, which controls the charge of battery. To the output of the hybrid controller is connected inverter that converts the DC

voltage to AC 220 V power supply for equipment. A block diagram of a hybrid PV/wind system is shown in fig. 1.

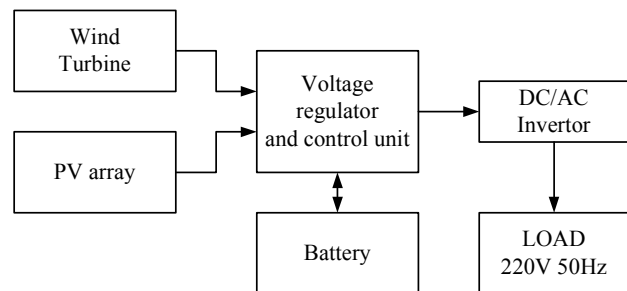


Fig. 1. Block diagram of the PV/wind hybrid system

Selection of the complex technical facilities

In this system, consumer of generated electric energy by the PV array and the wind turbine is for autonomous outdoor advertising. Depending on the power consumption and working time defines the basic parameters of the system components.

The calculating of autonomous energy supply system is very important to choose the capacity of the battery. Capacity, which should give the battery, is calculated based on the amount of electricity in W·h consumed from the battery in discharge mode.

At any hour the state of battery is related to the previous state of charge and to the energy production and consumption situation of the system during the time from $t - 1$ to t . During the charging process, when the total output of PV and wind generators is greater than the load demand, the available battery bank capacity at hour t can be described by:

$$C_{bat}(t) = C_{bat}(t-1)(1 - \sigma) + \left(E_{pv}(t) + E_{wg}(t) - \frac{E_t}{\eta_{inv}} \right) \eta_{bat} \quad (1)$$

On the other hand, when the load demand is greater than the available energy generated, the

battery bank is in discharging state Therefore, the available battery bank capacity at hour t can be expressed as:

$$C_{bat}(t) = C_{bat}(t-1)(1-\sigma) + \left(\frac{E_l}{\eta_{inv}} - (E_{pv}(t) + E_{wg}(t)) \right) \eta_{bat}, \quad (2)$$

where, $C_{bat}(t)$ and $C_{bat}(t-1)$ are the available battery bank capacity (W·h) at hour t and $t-1$, respectively; η_{bat} is the battery efficiency (during discharging process, the battery discharging efficiency was set equal to 1 and during charging, the efficiency is 0,65 to 0,85 depending on the charging current); σ – self-discharge rate of the battery bank. The manufacturer documentation gives a self discharge of 25 % over six months for a storage temperature of 20 °C, that is to say 0,14 % per day.

$E_{pv}(t)$ and $E_{wg}(t)$ are the energy generated by PV and wind generators, respectively, $E_l(t)$ is the load demand at hour t and η_{inv} is the inverter efficiency.

At any hour, the storage capacity is subject to the following constraints:

$$C_{bat\ min}(t) \leq C_{bat}(t) \leq C_{bat\ max}(t),$$

where, $C_{bat\ max}$ and $C_{bat\ min}$ are the maximum and minimum allowable storage capacity. Using for $C_{bat\ max}$ the storage nominal capacity C_{batn} , then

$$C_{bat\ min} = DOD \cdot C_{batn},$$

where DOD (%) represents the maximum permissible depth of battery discharge.

The total power $P_{tot}(t)$, generated by the wind turbine and PV generator at hour t is calculated as follows:

$$P_{tot}(t) = P_{pv}(t) + P_{wg}(t).$$

Then, the inverter input power, $P_{inv}(t)$ is calculated using the corresponding load power requirements, as follows:

$$P_{inv}(t) = \frac{P_{load}(t)}{\eta_{inv}},$$

where $P_{load}(t)$ is the power consumed by the load at hour t , η is the inverter efficiency.

During this operation of the hybrid PV/wind system, different situations may appear:

a) The total power generated by the PV and Wind generators is greater than the power needed by the load, P_{inv} . In this case, the energy surplus is stored in the batteries and the new storage capacity is calculated using equation (1) until the full capacity is obtained, the remainder of the available power is not used.

b) The total power generated by the PV and Wind generators is greater than the power needed by the load, P_{inv} . In this case, the energy surplus is stored in the batteries and the new storage capacity is calculated using (1) until the full capacity is obtained, the remainder of the available power is not used.

c) The total PV and wind generators power is less than the power needed by the P_{load} , the energy deficit is covered by the storage and a new battery capacity is calculated using (2).

d) In case of inverter input and total power equality, the storage capacity remains unchanged.

In case (a) when the battery capacity reaches a maximum value, $C_{bat\ max}$, the control system stops the charging process.

The wasted energy, defined as the energy produced and not used by the system, for hour t is calculated as follows:

$$WE(t) = P_{tot}(t)\Delta t - \left(\frac{P_{load}(t)}{\eta_{inv}} \Delta t + \left(\frac{C_{bat\ max} - C_{bat}(t-1)}{\eta_{bat}} \right) \right).$$

In case (b), if the battery capacity decreases to their minimum level, $C_{bat\ min}$, the control system disconnects the load and the energy deficit, loss of power supply for hour t can be expressed as follows:

$$LSP(t) = P_{load}(t)\Delta t - \left((P_{pv}(t) + P_{wg}(t))\Delta t + C_{bat}(t-1) - C_{bat\ min} \right) \eta_{inv}.$$

Where Δt is the step of time used for the calculations. During that time, the powers produced by the PV and wind generators are assumed constant. So, the power is numerically equal to the energy within this time step.

The loss of power supply probability, LPSP, for a considered period T, can be defined as the ratio of all the (LPS(t)) values over the total load required during that period. The LPSP technique is considered as technical implemented criteria for sizing a hybrid PV/wind system employing a battery bank. The technical model for hybrid system sizing is developed according to the LPSP technique. This can be defined as:

$$LPSP(t) = \frac{\sum_{t=1}^T LPS(t)}{\sum_{t=1}^T P_{load}(t)\Delta t}.$$

Where, T is the operation time.

If the hybrid energy systems are well designed, they provide a reliable service for an extended period of time.

A common inherent drawback of wind and PV systems is the intermittent nature of their energy

sources. Wind energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Solar energy is present throughout the day, but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc. These drawbacks tend to make these renewable systems inefficient. However by incorporating maximum power point tracking (MPPT) algorithms, the systems power transfer efficiency can be improved significantly. To describe a wind turbine's power characteristic, next equation describes the mechanical power that is generated by the wind.

$$P_m = 0,5\rho AC_p(\lambda, \beta)v_w^3.$$

The power coefficient (C_p) is a nonlinear function that represents the efficiency of the wind turbine to convert wind energy into mechanical energy. It is dependent on two variables, the tip speed ratio (TSR) and the pitch angle. The $TSR(\lambda)$, refers to a ratio of the turbine angular speed over the wind speed (fig. 2).

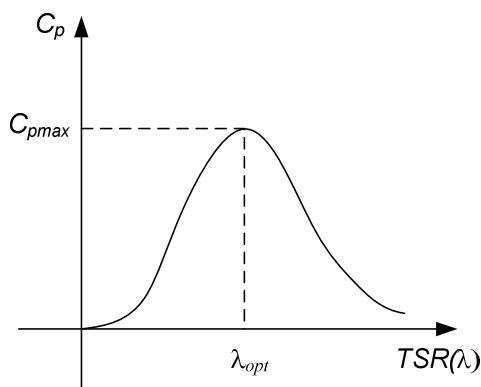


Fig. 2. Power coefficient curve for a typical wing turbine

The pitch angle, β , refers to the angle in which the turbine blades are aligned with respect to its longitudinal axis.

$$\lambda = \frac{R\omega b}{v_w},$$

where R – turbine radius; ωb – angular rotations speed.

Figs 2 and 3 are illustrations of a power coefficient curve and power curve for a typical fixed pitch ($\beta = 0$) horizontal axis wind turbine. It can be seen from figure 3 that the power curves for each wind speed has a shape similar to that of the power coefficient curve. Because the TSR is a ratio between the turbine rotational speed and the wind speed, it follows that each wind speed would have a different corresponding optimal rotational speed that gives the optimal TSR.

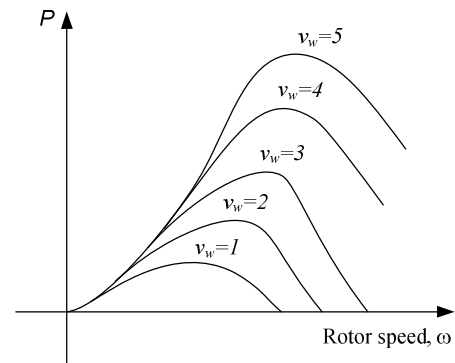


Fig. 3. Power Curves for a typical wing turbine

For each turbine there is an optimal TSR value that corresponds to a maximum value of the power coefficient (C_{pmax}) and therefore the maximum power. Therefore by controlling rotational speed, (by means of adjusting the electrical loading of the turbine generator) maximum power can be obtained for different wind speeds.

A solar cell is comprised of a $P-N$ junction semiconductor that produces currents via the photovoltaic effect. The resultant ideal voltage-current characteristic of a photovoltaic cell is given next equation and illustrated by fig. 4.

$$I = I_{ph} - I_0 \left(\exp \left(\frac{qV}{kT} \right) - 1 \right).$$

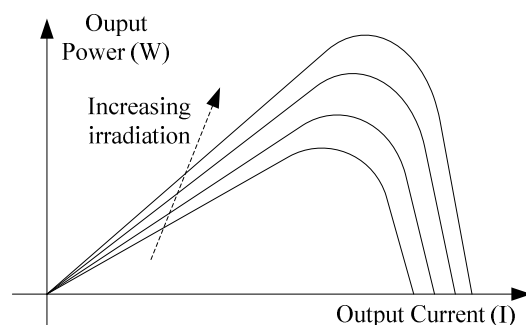


Fig. 4. Output power vs output current coefficient curve for a typical wing turbine

To select the power of the wind turbine and solar panel it's necessary to consider the annual average wind load factor and solar insolation. As used a hybrid wind solar system, the power of the wind turbine must cover at least 60 % of daily energy expenditure and solar power as 60 % of the daily rate.

Discussion and results

Finding the optimal number of wind turbines and solar arrays to meet the load, as well as the optimal wind turbine height and rotor diameter, was the focus of this study, as well as to test for good complementary characteristics between the wind and

solar power systems, and to assess the feasibility of using such a hybrid system to power of control system for autonomous outdoor advertising.

However, we need a hybrid system only to take advantage of their complementary characteristics, because wind and solar radiation are not constant over the year as we specified in our test. As show on fig. 5 wind turbines may not be able to meet demand on their own in summer, and may require another source to make up for the loss in power generation.

Figure 5 shows the solar radiation and the wind speed as a percentage of the maximum attainable from each resource separately, over the course of a year. The generated data was plotted, and a best-fit line was drawn.

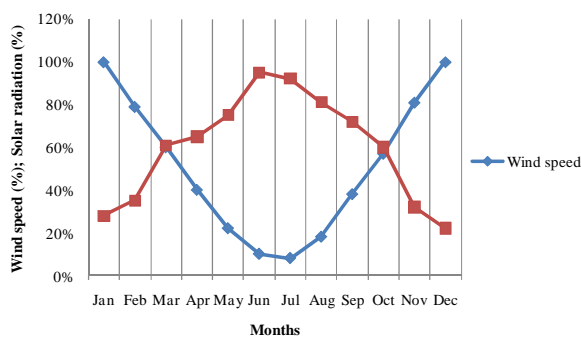


Fig. 5. Power curves for a typical wing turbine

This graph suggests a need for a complementary relationship between the wind and solar systems, as it shows a negative correlation between the two resources.

Monthly energy requirement for autonomous outdoor advertising is about 10 kWh. Our system that contains 6 bladed wind turbine with maximum power 300 W and solar panel with power 80 W was then used to measure the power output of the individual energy system components, and their combined total output, it shows on fig. 6.

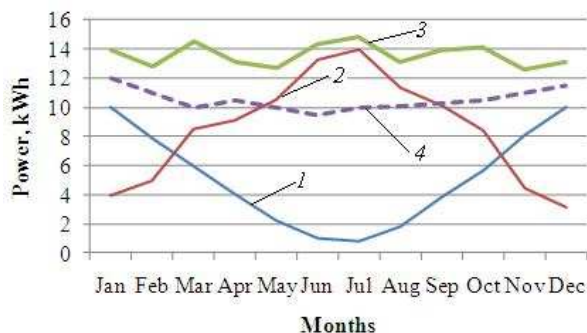


Fig. 6. Power generated from system components: 1 – Wind; 2 – Solar; 3 – Total; 4 – Demand

Examble of use

At the present time widely used supply promotional materials using walls, surfaces, high-rise

buildings. For these purposes, assumed the use of the laser projector. Not in all places where it is necessary to install this system, it is possible to connect to electrical grid, it is proposed to use a hybrid system of autonomous power supply based on wind/PV installation.

Laser advertising - a new progressive course in the advertising industry. Using a special laser equipment for advertising advertised object projected on buildings or on any other surface – this type of advertising is called laser projection advertising. Outdoor adverting using Laser is very spectacular - on the background of the laser beams company logo and its slogan look particularly bright and impressive.

In this system, the consumer of electric energy generated by the solar battery and the wind generator is a laser projector. Depending on the power consumption of the laser projector and the time his work defined the basic parameters of the system components.

- Laser projector has next characteristics:
- power supply 220 V 50 Hz;
 - power consumption 50 W;
 - total laser output power 1 W.

When calculating the autonomous power supply system is very important to choose the capacity of the battery. Capacity, which should give the battery is calculated based on the amount of energy in W·h drawn from the battery to discharge mode.

Then the formula for determining the required capacity will look like this:

$$E = \frac{Q}{V k},$$

where, E – the total required capacity of the batteries in A·h; Q – amount of energy to be obtained from the batteries in W·h; V – voltage of each battery; k – capacity utilization, taking into account how much of the energy of all used batteries can actually use to consumers.

Working time of the laser projector is 4 hours daily. To ensure the smooth operation of the system must also be borne in mind that for 7 days in a row can be unfavorable conditions for recovery charge batteries from hybrid system. Calculate the required amount of energy to operate the laser projector, W · h:

$$E = 50 \cdot 4 \cdot 7 = 1400.$$

In this system, it is advisable to use a maintenance-free gel battery 12 V. These batteries are not recommended to discharge more than 30 % of their maximum charge, thus battery capacity will be, A·h

$$E = \frac{1400}{12 \cdot 0,7} = 166.$$

For this system, for economic reasons, it is advisable to use two helium nonperforming battery capacity of 80 A·h each, connected in parallel.

To select the power of wind turbine and solar panel must consider the annual average wind load factor and sun insolation. Since a hybrid wind/PV system, the capacity of wind turbines should cover at least 60 % of the daily energy consumption and solar power and 60 % of the daily rate.

Daily consumption of energy will be, $W \cdot h$:

$$E = 50 \cdot 4 = 200.$$

Daily power generation of solar battery

$$E_{sb} = 200 \cdot 0,6 = 120.$$

Similarly, the total daily power generation for wind turbine will be $E_{wind} = 120W \cdot h$.

Based on the fact that the average ratio for the sun insolation Kiev is 3,1 solar power is required for this system will be:

$$P_{sb} = 120 \cdot 3,1 = 38.$$

Based on the calculation, solar power, necessary for the smooth operation of the system will be at least 40 W.

The average wind speed for Kiev is 4 m/s. With this indicator need to pick up a wind turbine, which, by the performance, power output will be at a wind speed of 3 m/s. These requirements correspond to the horizontal-axis wind turbines multibladed.

The amount of energy generated by wind generator for the day, should be not less than 120 W·h. On this, the required power will be $P_{wind} = 120 W \cdot h / 24 = 5 W$ at a wind speed flow 4 m/s.

Based on the characteristics of multibladed horizontal-axis wind turbine, at a rate of wind flow, wind turbine must be at least 250 W, as declared capacity specified for wind turbine wind flow speed of 10 m/s.

For this installation, select horizontal axis 6-bladed wind turbine rated at 300 W.

Charge Controller – a device that regulates the flow of charge from the sources of electricity to the batteries. He is one of the main parts of wind/PV power. Controller functions designed to conserve batteries and to increase energy production.

Mainly use two types of controllers: PWM – Pulse width modulation and MPPT – find Maximum Power Point Tracking. Controller using PWM conversion lowers PV voltage to the desired value and supports it. This allows up to 100 % battery level. Maximum power point tracking controller continuously monitors the stage at which the battery is charging (filling, saturation, alignment, support) and on this

basis determines how much current to be supplied to the batteries. Controller selection may depend on the choice of solar panels. If not high power modules (up to 300 W) suitable PWM controller, the price is below. MPPT controller is useful for a large capacity.

Results of tests

Placing advertising on laser building has some peculiarities. Typical buildings have a small width 12 – 15 m compared to the height of the building 25 – 50 m. Therefore, in order to hype a good read it should be placed on a vertical building – in order to get the maximum image size. The creation of commercials should abandon the fine details, because the first place - they are too loaded with a scanning laser projector system (flicker) in the – second – hard to read from a distance.

In each case, the image is advertising, so that the maximum effect was achieved.

Listed in the table relations “power – the distance to the surface projection” are given for a bright well readable images (table).

Power to distance of laser projector

Power of red laser, mW	Power of green laser, mW	Power of blue laser, mW	Total power laser, W	Recommended distance to surface, m
300	400	600	1,3	20
400	600	1000	2,0	30
500	800	1200	2,5	35
600	1000	1500	3,1	45
1000	1500	2000	4,5	60
1300	2000	3000	6,3	70
2000	3000	4000	9,0	90
2400	3000	5000	10,4	110
3000	4000	5000	13,0	130

Conclusions

Our study focused on designing of autonomous system that would allow us to find the optimal system design parameters of a hybrid solar-wind system, taking into consideration the power of solar arrays and wind turbines, as well as the wind turbine rotor diameter and height.

After the tests were carried out, a complementary relationship between both individual systems was visible in our results. In summertime, when solar radiation is abundant and there is little wind energy, the solar arrays supply most of the required energy. In wintertime, when wind velocities are higher and there is less solar radiation, it is the wind turbines that

supply most of the required energy, thus providing clear evidence of a complementary relationship between the two sources.

References

1. *Abouzahr, I., Ramakumar. R.*, 1990. Loss of power supply probability of stand alone electric conversion systems: a closed form solution approach. IEEE Transaction on Energy Conv. 5(3), P. 445–452.
2. *Deshmukh, M. K., Deshmukh, S. S.* 2008. Modeling Of hybrid Renewable Energy Systems, Renewable and Sustainable Energy Reviews, Vol. 12, No. 1. P. 235–249.
3. *Elhadidy, M.A., and Shaahid, S.M.* 2004. Promoting applications of hybrid (wind + photovoltaic + diesel + battery) power systems in hot regions, Renewable Energy, Vol.29, No.4. P. 517–528.

4. *Ekren, O., Ekren, B.Y., and Ozerdem, B.* 2009. Break-even Analysis And Size Optimization of A PV/Wind Hybrid Energy Conversion System With Battery Storage – A case Study. Applied Energy, Vol. 86, No.7-8. P. 1043-54.

5. *Duffie J. A. and Beckman W. A.* 1991. Solar engineering of thermal, The second ed., John Wiley and Sons, Inc., New York. 893 p.

6. *Yang, H.X., J. Burnett. L. Lu,* 2003. Weather data and probability analysis of hybrid photovoltaic wind power generation systems in Hong Kong, Renewable Energy 28. P. 1813–1824.

7. *Borowy, B. S., Salameh., Z. M.* 1994. Optimum photovoltaic array size for a hybrid wind/PV system. IEEE Transactions on Energy Conv. 9(3). P. 482–488.

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Б. І. Дмитренко. Використання гібридних вітро-сонячних енергетичних установок в системах зовнішньої реклами

Розглянуто характерні особливості використання гібридних вітросонячних установок. Наведено приклад розрахунку автономної системи зовнішньої реклами з використанням лазерного проектора.

Ключові слова: зовнішня реклама; вітрогенератор; сонячна панель; акумуляторна батарея; гібридна система.

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Б. И. Дмитренко. Использование гибридных ветро-солнечных энергетических установок в системах наружной рекламы

Рассмотрены характерные особенности использования гибридных ветросолнечных установок. Приведен пример расчета автономной системы наружной рекламы с использованием лазерного проектора.

Ключевые слова: наружная реклама; ветрогенератор; солнечная панель; аккумулятор; гибридная система.

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