Photovoltaic Systems

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The aim of the present paper is the description of various types of photovoltaic systems, basic calculation and design principles, the scopes of application and their operation investigation.

Various types of the PV stations are described in this paper.

The basic principles of calculation of the photovoltaic systems, the description of the basic design components of each type and the principles of each component choice are given. The scopes of application of photovoltaic systems are reviewed.

The practical applications of PV systems in grid on systems, beacons, telecommunications and street lightings are given in Russia, Poland and Germany. The performances of grid on station in Germany are investigated for four years period.

The possibility of low power applications like photographic and video cameras, mobile phones, music players and so on is considered.

Keywords- photovoltaic systems, PV application

I. Introduction

The potential of solar energy that to the Earth surface is great. Solar irradiation power for unit area is up to 1000 W/m^2. And it must be emphasized that its potential is completely renewable, moreover it is inexhaustible.

Use of solar radiation is in direct thermal application for getting thermal power and in thermal- and PV conversion for getting electrical power.

Photovoltaic systems (PV systems) operate on the basis of direct conversion of solar power in semiconductor materials. Nowadays scope of application is growing rapidly. Installed power of the systems is between several Watt (even less) up to several MegaWatt.

PV generation has significant advantages:

- application on areas that are not suitable for economical affairs * easy to use;
- no water needs;
- no moving parts that allows cheaper maintenance;
- effective use of both direct and scattered (diffuse)radiation;
- no need in high qualified personnel;
- noiseless performance;
- no hazardous substance emissions, made of green materials
- can be used for systems of any capacity;
- flat construction allows to integrate the systems in both new and existent buildings;
- can be used as building materials, no additional buildings and infrastructure are necessary;
- It is possible to create a distributed system;
- Attractive outside can be made, especially it is achieved by using color solar cells, which can even make a building outside to look special; * easily integrated in electrical network

The main shortcomings of PV generation are:

- low power density;
- no constant and probability nature of power entry;

II. Types of PV-systems

The main shortcoming of a PV-generator is cyclicity of power production. The cyclicity is caused by alternation of day and night and also by seasonality and overcast days. Thereby all PV-systems can be divided into two types:

- without energy accumulation;
- with energy accumulation

Due to accumulating components absence the system of first type has lower power loss and it can be good in systems where load operation is available under insulation only. For example, water pumping stations and the most popular type of PV systems— grid connected systems, where power load comes from electrical grid. Thus structure scheme of these PV systems may be represent as on Fig. 1.

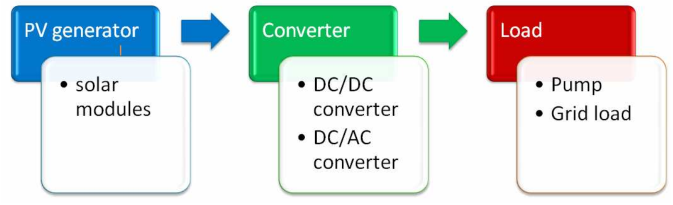

Figure 1. Functional PV-system scheme without energy accumulation.

Grid connected systems transfer generated power to electrical network, where it is accumulated and distributed. The systems mounted on city buildings allow both powering the building and compensating power shortage on peak demand. Such systems are actively embedded in developed countries. They are considered to be green power sources allowing to decrease ill effect to the environment. In many countries governments encourage using of PV systems, they allow to private persons to sell power to electrical companies on higher prices. Such measures stimulate common price decrease for PV systems. There are developed and implemented different projects of larger PV systems (up to several MegaWatt). It helps to get good experience and at the same time it encourages production growth of companies that produce units for PV by lowing their prices and cost of power [1,2].

Required part of the second type PV-system is an electrochemical or electric double layer accumulator, which reserves power while PV generator operates, and gives it to the consumer when it is necessary. Thus structure scheme of these PV systems may be represent as on Fig. 2.

These systems may be called as standalone systems. Standalone systems are used for power supply of mobile and distant from main power lines objects. One of main features in this case is cost of the system, sometimes it is lower than development of power lines, another feature is social effect. The programs on implementing such systems are actively supported by international organizations, and the World Bank subsidizes them.

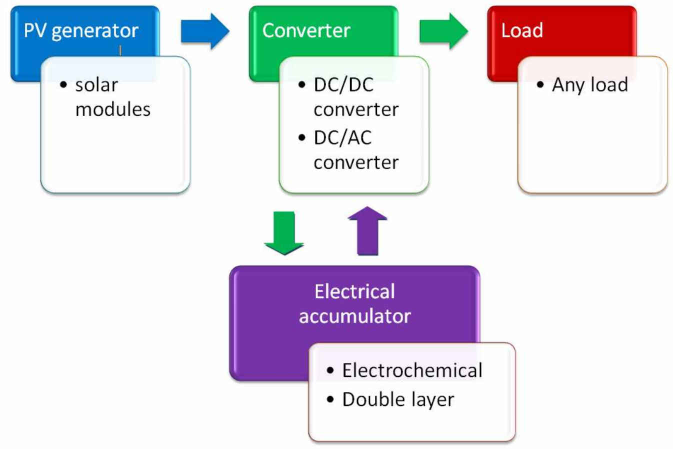

Figure 2. Functional PV-system scheme with energy accumulation.

III. PV SYSTEMS CALCULATION

Tasks for any PV system calculation are of two kinds: analysis and synthesis. Method of PV system calculation is chosen depending on the task.

The analysis task is applicable for grid connected PV systems calculating, where, as a rule, the square of a PV generator is certain on the basis of architectural decisions and financial restrictions. The analysis task can also be applicable for standalone systems while making more accurate and checking previous calculation. The block scheme of calculation may be represent on Fig.3.

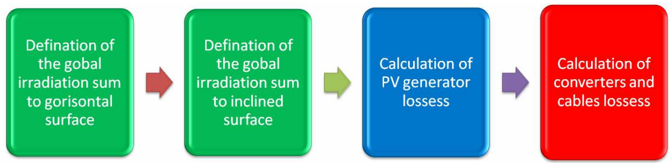

Figure 3. Calculation scheme of synthesis task solution.

The synthesis task is used for standalone systems with batteries calculation that are intended for particular consumers. Size of the system and quantity of components in it are calculated in accordance with demands of the customer (power and schedule load).

Here are determined load operation seasonality, monthly power consumption, operation hours during the day, requirements to quality of power supply and nature of current (for an inverter).

Operation seasonality has significant influence to composition of a PV system. Total irradiation difference even in southern region of Russia is about 4…6 times. Thereby the system calculation is made with an allowance for the worst operation month (it is commonly December). Such irregularity of seasonal power supply causes the loss of generated power in summer (up to 80%). As a rule, seasonal fluctuations of power supply are not compensated by battery capacity. For this reason it is important to adjust and correct the load according to monthly solar irradiance for a particular location.

To a large extent, capacity of a battery is determined by the requirement of power supply quality (LLP— loss of load probability), that is defined as dependence of real time when there was no power loading to required time of power loading. For domestic loads this value is 0.1...0.2, while for industrial loads (for example telecommunications) this value can be reduced to 0.0001. Required quality of power supply can be achieved by increasing of battery capacity in N+1 time, N is number of overcast days.

Operating mode during the day has less influence battery capacity. Because of incomplete electrochemical conversion, that is 70…90%, there happens loss in loading at night

The main data provided by meteorological stations, include monthly quantity of global solar irradiation to horizontal surface. For calculation of PV stations it is better to use hourly quantity of radiation, which is accurate enough. However the meteorological stations that do not intentionally collect data for PV systems, seldom provide such information. Calculation of hourly quantity of radiation makes the calculation methods more difficult and demands a significant amount of input data. However it allows taking into account such effects as module heating by solar insulation, influence of ambient temperature, influence of shading from local objects, changing efficiency of PV generator resulted in replacing of solar rays angle during the day.

For less accurate but cheaper and faster calculation there used monthly quantity of global radiation to horizontal surface data. Monthly average quantity of midday radiation is used to make calculations. For southern regions we can use the following formula [3]:

$$G_{dm}(\beta) = \left(G_{dm}(0) - D_{dm}(0)\right)R_b + \left(\frac{1+\cos(\beta)}{2}\right)D_{dm}(0) + \frac{(1-\cos(\beta))\rho G_{dm}(0)}{2}$$

where

β угол наклона фотоэлектрического генератора к горизонту, рад.

Gdm(β) Gdm(0) global irradiation on and horizontal surface, MJ/(day m^2)

Ddm(0) diffuse irradiation on horizontal surface рассеянная, MJ/(day m^2)

Rb ratio direct irradiation on inclined and horizontal surface.

In this model an isotropic nature of diffused irradiance that comes from all over the celestial sphere is supposed. As a rule, such kind of model is good for spring and summer seasons. Due to lower position of the Sun and bad weather, isotropy of diffused irradiance changes and the inaccuracy can be 50% in winter season. It is possible to eliminate inaccuracy by correcting of diffused irradiance entry in proper months or using different hourly quantity methods.

General efficiency of the system with an allowance of all loss is evaluated by:

$$Y_F = \frac{E_{load}}{P_0}$$

where

E_{load} power in the load;

P_0 nominal power of PV generator.

The parameter can be daily, monthly and yearly averaged. It is applicable for economical evaluation of PV systems and power cost.

IV. Practice Application of PV Systems in Russia and Poland

There is the description of real standalone and grid connected PV systems, situated in Russia and Poland.

A. *Light beacons in Far Eastern and Baltic margins.*

Despite rapid development of satellite navigation, system light beacons (LB) are still required for shipping secure an particularly for ships maneuvering in case of bad weather in coastal zone and in “narrowings” where using GPS is not enough. In such conditions it is preferable to use LB for orientation.

Until now LB were powered by radioisotope thermoelectric generator (RITEG). However in present time they need to be replaced.

Due to remoteness and difficult to access location of LB that secure shipping it is necessary to use stand alone power systems (with low maintenance) instead of RITEG, to power them.

Conception of power source for LB was developed by RNC “Kurchtatovskiy Institut”. After long-term monitoring of different types of power system requirements to newly-developed set of equipment for LB powering instead of RITEG appeared.

According to the monitoring data, it was found that for regular power supply to LB it is mo effective to use PV systems with nominal power about 150W.

At the end of 2007 several tens of PV systems had been installed and put into operation on navigation units in Dalnevostochniy region. Equipment is prepared to be installed on LP in Khabarovsk region and Sakhalin (Fig. 4). Furthermore, equipment for PV systems is recognized and in demand among the consumers of the systems. First of all it is demanded by firms that develop and deliver navigation equipment for hydrographic service "Navitel", "Noveltech".

To provide secure and regular operation of standalone power systems remote monitoring by a wireless channel with recorders iBDL. Thanks to it beacon service is able to monitor LB remotely. And after analyzing the data they can decide whether it is necessary to visit the unit or not.

Figure 4. Light beacons in Russia.

B. *Grid on PV systems investigation.*

The PV system was put into operation in January, 2005. Location - Meppen, Emsland, Germany.

The PV system was installed on a slopping roof of a one-storey building. The supporting structure is made of stainless steel on the roof plane. The PV modules are fastened with aluminum cramps. The tilt is 25˚, orientation is south-east. The arrays consist of 8 groups, 6 of them are assembled 4x10, another two were 3x10. Total quantity of modules is 300, nominal power is 30kW. Single module size is 880x1000x28mm. The modules are made of solar cells 103x 103mm. Number of cells in a module 72, connected in serials. Weight of each module is 14kg. The modules are framed with painted aluminum alloy, the thickness is 28 mm. Functional scheme of PV system represents on Fig. 5

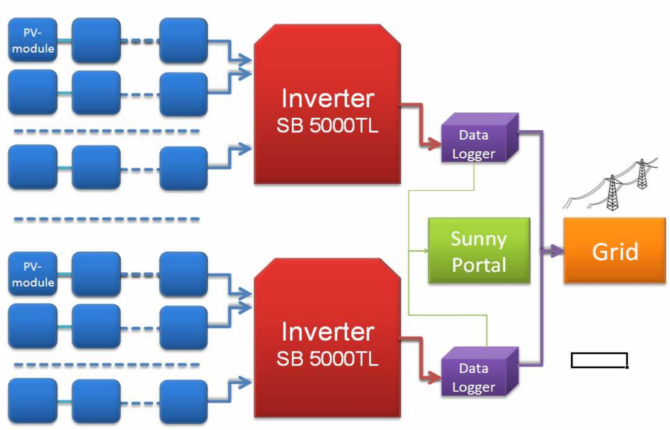

Figure 5. Functional scheme of grid connected PV system

The PV modules are divided into 6 groups by 50 modules in each, they are connected with three-phase inverters, nominal power 5.5 kW each. Each group has 5 arrays, connected to inverter. Maximum voltage is 410V. Operating voltage at 50˚C is 290V. Power of each array at 50˚C is 4.5 kW. Operating current is 15 A.

Analyzing of the system operation was made in accordance with the data received from the system, collected in the period of January, 2005 till August, 2009. The following performance was monitored:

- hour sums of power (by each inverter)
- total hour sums
- string power (three per inverter)
- total power (by each inverter)

As there are no sensors of solar radiation intensity, average monthly sums, based on data of a typical meteorological year (TMY) were calculated. Using PVSYST program for existing configuration of the system there was calculated monthly power production near Amsterdam (about 170km to the west of Meppen) and near Bremen (about 100 north-east from Meppen. Values of deviation real energy production from calculated values for Bremen и Amsterdam TMY are represent on Fig. 6.

The most significant deviations of monthly system production of this period is winter season. The deviation reaches minus 50%. Probably it depends on the snow cower, that was not taken into account. Moreover in this period significant average data deviation appeared. The lowest percentage of deviation is in spring-summer-fall period, it is average 15%.

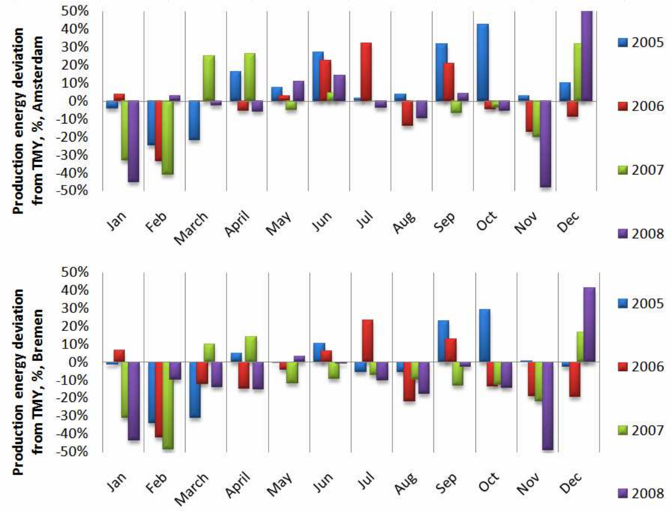

Figure 6. Deviation real energy production from calculated values for Bremen и Amsterdam TMY.

System performance can also be evaluated by analyzing the efficiency taking into account solar hours a day. It should be noted, when having at least several fully radiated days a month, maximum value of quantity for one month does not depend on deviation from real weather conditions concerning TMY, while may characterize technical performance of the system [4].

For analyzing the system efficiency medians of maximum values of solar hours a day in each month were calculated. (Fig. 7).

It should be noted, that most negative deviations happen in winter season. It is supposed to be dependent on the snow coverage on modules surface. The median of the values is minus 4.29 %. It can be considered as deviation value for solar modules for an observable period, it perfectly reconciles with papers [5-7].

The 4 year analysis of the system performance shows that system efficiency is stable enough and deterioration of the efficiency does not exceed acceptable values.

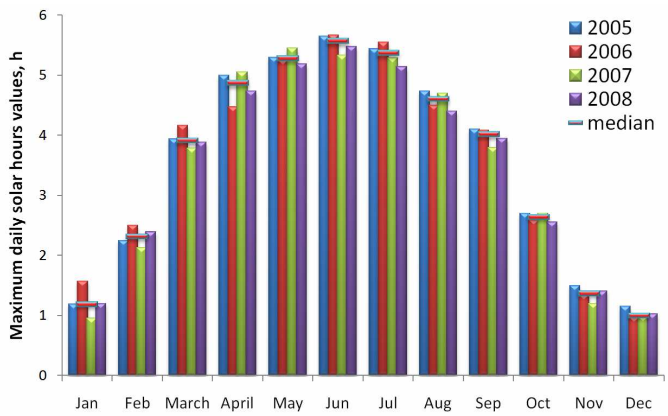

Figure 7. Maximum daily solar hours values and median.

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