ANALYSIS OF THE INFLUENCES OF GRID-CONNECTED PV POWER SYSTEM ON DISTRIBUTION GRIDS

Dumitru **POPANDRON**, Marian **OŞAN**, Claudiu **DAMIAN**, Marius **BĂLDEAN**
Technical University of Cluj-Napoca, Electrical Power Systems Department
dumitru.popandron@yahoo.com

Keywords: photovoltaic, inverter, distributed generation, drop voltage.

Abstract: *This paper presents the analysis of producing an electric power of 2.8 MW using a solar photovoltaic plant. The PV will be grid connected to the distribution network. The study is focused on the influences of connecting to the grid of a photovoltaic system, using modern software for analysis, modeling and simulation in power systems.*

1. INTRODUCTION

The concept of a sustainable and efficient energy start to materialize through number of installations of renewable energy around the world. In last years, engineers and investors helped and supported by governments start to develop power plants using renewable energy (e.g. wind farm, photovoltaic plant, hydro plant). Grid – connected solar PV continued to be the fastest growing power generation technology.

In Romania the installations of PV systems starts to increase in last few years stimulated by green certificates.

Power installed in PV systems grid-connected an evolution is described below [1]:

- 0,009 MW at the end of year 2010;
- 1,011 MW at the end of year 2011;
- 18, 88 MW at the end of year 2012;
- 78.72 MW at the end of March 2013;

In 25 March, a power of 78.72 MW is installed in grid-connected PV systems in Romania, and all PV systems obtain six green certificates [1].

2. GRID OVERVIEW

The grid (in Romania) is a layered system defined by the voltage level (high medium and low-voltage) and designed to cover a region. The inter-connection is made in electric substations. The high-voltage substations including the substation connecting to the medium lager or highly automated [2].

The PV analyze will be integrated in medium voltage layer of the grid, which is a part of the distribution network. The distribution systems are usually regulated through tap changing at substation transformers and by the use of voltage regulators and capacitors on the feeders. This form of voltage regulation assumes power flows circulating from the substation to the loads [3]. Major of these sources generate electricity in a distributed way, as their number growth will change the situation and require a much higher automation degree in the low and medium voltage level.

The substation analyzed has a single distribution transformer with several feeder lines, and the voltage for these lines is adjusted in a block. PV system is situated at a distance of 9 km away from substation.

3. MATHEMATIC MODEL OF CELL PHOTOVOLTAIC SOLAR CELL- SCIENCE DEFINITION

A photoelectric cell designed to convert sunlight into electrical energy, typically consisting of layers or sheets of specially prepared silicon. Electrons, displaced through the photoelectric effect by the Sun's radiant energy in one layer, flow across a junction to the other layer, creating a voltage across the layers that can provide power to an external circuit [10]. The principle is detailed in figure 1.

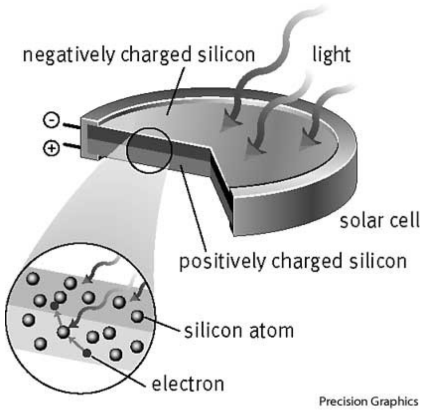

Fig. 1. The principle of solar cell.

When light penetrates a solar cell and reaches the lower charged layer, its energy causes atoms there to release electrons, which drift to the upper layer, giving the upper layer a net negative charge and the lower layer a net positive charge. This voltage difference can be used as a source of electrical energy [10].

Mathematic model of photovoltaic cell photovoltaic can be obtained starting form p-n junction. At this a current noted I_{ph} which is proportional with solar irradiance is added and a term who represent intern phenomena of cell [11].

Current I produced by cell and current crossing the equivalent diode can be evaluated by equations:

$$I = I_{ph} - I_d \times \left(e^{\frac{q\times(U+R_S\times I)}{k\times T}} - 1\right) - \frac{U+R_S\times I}{R_{sh}} \tag{1}$$

$$I_d = I_d \times \left(e^{\frac{q\times(U+R_S\times I)}{k\times T}} - 1\right) \tag{2}$$

Where:

I_{ph}= electric current generated by solar irradiance;
I_d= electric current of saturation;
R_s= equivalent series resistance;
R_{sh}= equivalent parallel resistance
k= Boltzmann constant ($k=1.3806504\text{x}10^{-23}$ J/K)
q=electron charge ($q=1.602\text{x}10^{-19}$ C)
T= cell temperature

The equivalent scheme of a solar cell is presented in figure 2.

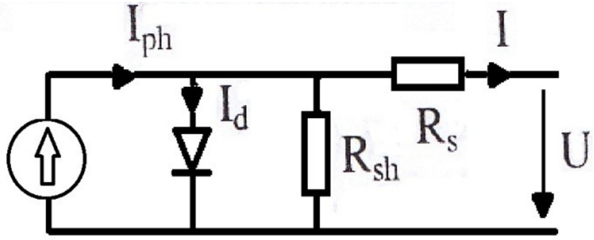

Fig. 2. Equivalent scheme of a PV cell.

Diode is modeling cell behavior in the absence of light (dark). The current source is modeling current generated by lighting. Electrical resistances is modeling internal energy losses in solar cell: series resistance correspond to losses in the cell material and parallel resistance R_{sh} is modeling transverse currents (parasites) flowing through solar cell [11].

4. GRID-CONNECTED PHOTOVOLTAIC SYSTEMS

Currently interconnected photovoltaic system is being used as a complement to a conventional generation in many countries [4]. In this study is analyzed a photovoltaic system with a storage and all energy produced will be delivered to the system, using distribution system existing in the local area.

This type of photovoltaic system does not use storage for energy produced. The energy is injected into the grid. Figure 1 shows schematically a block diagram of a typical PV system grid-connected with no storage of energy.

The functional blocks are described below:

a) photovoltaic generator;
b) inverter;
c) point of common coupling;
d) transformers;
e) bi-directional meter of AC power;
f) electric grid.

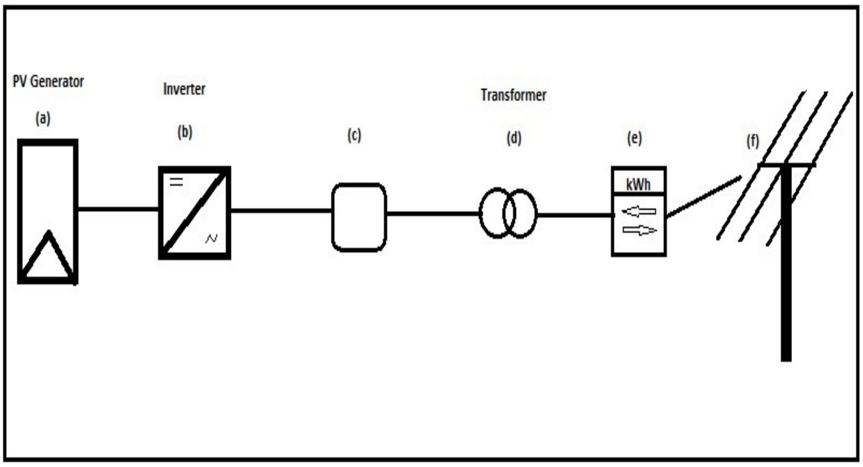

Fig. 3. Grid-connected PV power system with no storage.

5. DISTRIBUTED GENERATION TECHNOLOGIES

The power plant will be connected directly to the distribution network at a distance of 9 km fare away from electric substation and the maximum power delivered is limited by the local network conditions.

A general definition for distributed generation suggested here is “Distributed generation in an electric power source connected directly to the distribution network or customer site of the meter” [3].

The maximum power of 2.8 MW installed considering different ratings of distributed generation include this PV system as small distributed generation, which is rated between 5KW-5MW.

Distributed generation takes place on two levels: the local level and the end-point level. Local level generation plant often include renewable energy technologies that are site specific such as wind turbines, geothermal energy production, solar systems (photovoltaic and combustion), and some hydro-thermal plants. They are also more energy and cost efficient and more reliable. Since these local level distributed generation produce often take into account the local context, the usually produce less environmentally damaging or disrupting energy than the larger central model plants.

At the end-point level, the individual energy consumer can apply many of these same technologies with similar effects. At this level, distribution technology can operate as isolated “islands” of electric energy production or they can serve as small contributors to the power grid. Most studies confirm, however, that the penetration of distributed generation up to a level of 10-15% of maximum load can be easily be absorbed by the electricity network without major structural changes [3]. The PV system analyzed is one of the first PV systems in the local area; the only disadvantage is the length to the substation.

The distribution generation allows producing, store and managing the energy in the same place of consumption. This brings many benefits for distribution companies. Within these advantages, it is worth nothing the following:

- It avoids or defers s investments in transmission and distribution by location generation close to consumption.
- Depending on network configuration and the load and generation location, the decentralized energy produced prevents an equivalent amount from being transported over long distances, with the added looses. Similarly, it reduces congestion in transport system to the final consumer.
- It improves the supply reliability. It reduces the chance or failures when outages occur in the high voltage transport lines by decreasing the percentage of its use. This is essential in applications that require continuous service for health and safety reasons.
- Receive power control and voltage regulation in distribution network: One of the ways to regulate the tension using transformers with taps or the known buster. Distributed generation may inject a reactive quantity, which improves the distribution network voltage levels.
- Flattening on the demand curve: distributed energy production may coincide with peak demand, avoiding the use of electrical power from distant power plants that operate only during those hours, at a very high price, compared with electricity of the

off-peak hours. For example, PV systems have their peak production in hours where consumption is increasing due to the use of air conditioning system in warm climates.

- It gives a choice of self-supply in areas where network infrastructure does not exist, or is very expensive which opens markets in remote areas without access to the mains or with high environmental restrictions.
- It increases the options of power supply for users.
- Its location is more flexible due to its small size.
- In case of contingency, it is possible to operate the system provisionally, giving a greater support to the affected region.
- It allows minimizing the risk and capital exposure due to its size, easiness of location and short installation time.
- It allows the risk and capital exposure due to its size, easiness of location and short installation time.
- It allows to use cheaper fuels that otherwise would be used as agricultural residues, biogas from landfills, waste heat, etc.
- Incentives from renewable energy sources: Many renewable generation technologies operate at scales of small generation and can be adapted by the smallest users. This opens a possibility for the use of resources that reduce environmental pollution. [9]

6. SHORT DESCRIPTION OF PV SYSTEM ANALYSED

The study is focused on the influences of connecting to the grid of a photovoltaic system with a rated power of 2.8 MW.

The type of solar modules used for the PV system is poly-crystalline solar modules with a nominal power of 230 W and a number of 12.172 of panels will be installed. The solar modules will delivery energy using 12 inverters with a power of 250 kW each.

A short list with technical specifications of solar panel is presented in table 1.

Table 1 Specifications of solar panel 230 W at Standard Test Conditions

Rated power	230 W
Type of cells	Poly crystal Si
Tolerance	±3%
Rated current	7,78 A
Rated voltage	29,8
Short circuit current	8.3 A
Open circuit voltage	37,3 V

Solar Panel manufacturers use what is called Standard Test Conditions (STC). This means they put the solar panels in a flash tester in their factory that has been calibrated to deliver the equivalent of 1000 watts per square meter of sunlight intensity, hold a cell temperature of 25'C (77'F), and assume an air mass of 1.5. This flash test gives them their STC ratings. Air mass is the optical path length through the Earth's atmosphere for light from a celestial source. As it passes through the atmosphere, light is attenuated by scattering and absorption; the more atmosphere through which it passes, the greater the attenuation. Consequently, celestial bodies at the horizon appear less bright than when at the zenith. An air mass of one is looking straight up from sea level at the sun when it is directly overhead [8].

Because of this, when utilities and municipalities are trying to calculate real available wattage on an average day (in order to issue tax credits, etc.) they use what is called Normal Operating Cell Temperature (NOCT) ratings. NOCT recognizes a bit of reality and assumes the following: 800 watts per square meter of Sunlight Irradiance, an average of 20'C (68'F) Air Temperature, an average wind velocity of 1 meter per second (2.24 miles per hour), with the back side of the solar panel open to that breeze (as opposed to being on a roof where heats builds up under the panels) [8].

The PV system will be connected to the distribution system, which has a nominal voltage of 20 KV. The inverters works at low voltage (0.4 KV) so two transformers with a power of 1600 kVA each will be required. From transformers will be created an electric line using a cable of medium voltage to connect the PV system to the electric line existing in the area.

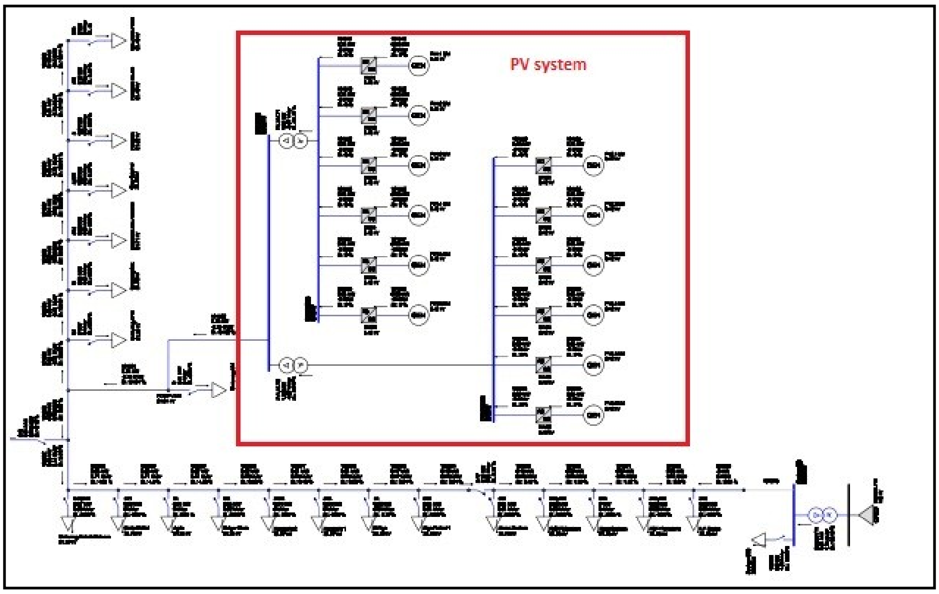

Fig. 4. PV system analyzed.

The system PV analyzed is presented in above figure (Figure 4) and local consumers connected to the distribution system, on the electric common line with the PV system. The local consumers connected on the same electric line with the PV system are influenced by the photovoltaics.

7. STUDY OF THE INFLUNECES OF CONNECTING THE PV SYSTEM TO THE GRID DISTRBUTION

To limit the influences and ensure the optimal conditions to produce and delivery all electric energy to the local consumers from the PV system, is necessary to analyze all operating modes of the grid and specially the grid distribution. The study is focused on the influences caused by connecting the PV system to the grid distribution.

To obtain the accurate results, all the local consumers have been identified with all electrical characteristics (installed power, absorbed power, electric line, protections).

The major problem required to be analyzed is the voltage levels. The new PV system changes the voltage profile of the local distribution network because of the change in the magnitudes of power flow. Usually the voltages profile will tend to rise, which is not a problem in congested networks with low voltage problems, as would be in the contrary. The design and configuration of the distributed network is to operate with the power flow in one direction. Connecting the PV system will cause the reverse of power direction, and it can cause malfunctions of protection circuits as they are configured. The installation of the PV system changes the flow into bidirectional.

The PV system analyzed is situated at a distance of 9 kilometers far from electric substation. An electric line of medium voltage cross the emplacement of the PV and the point of connection to the grid will be realized by building a new electric line using a cable with a length of 250 meters and connect it to the existing electric line.

Integration of the PV system into the medium voltage layer of the grid imposes to adapt the PV system to the distribution system. Here are few major conditions: voltage fluctuations, frequency, flow, and the reverse flow on the electric feeders used.

8. PROBLEMS REVEALED BY THE STUDY

Based on real measurement and characteristics of grid and respectively of local consumers the PV system power is limited by the electrical characteristics of the grid and especially by the electric line used to delivery the energy.

Creating a new electric line increases the cost of PV system. One of the biggest problems to create a new electric line is obtaining the permit to cross with the line all private properties to the transformer station for a length of 9 km.

Another problem revealed is the level of voltage. Generally, a simple distribution transformer, which is our case, has several feeder lines and the voltage for the line is adjusted in a block. The level of medium voltage for distribution system is set between values of 20.1 kV to 20.9 kV.

To produce energy the PV system require solar energy, which means that night the system is unable to produce energy so the scenario of the grid working night is not necessary to be analyzed.

In distribution system are two severe conditions: working with maximum load and minimum load. For an accurate analysis has been used information from the grid owner for the maximum load of the grid, and also the minimum load connected to the grid, and the level of voltage used to work the distribution in this two situations in safe electrical parameters.

For scenario with the PV system connected and producing at rated power with distribution system at maximum load at the local consumers, the drop voltage is situated at value of 5 % of nominal voltage at the point of connection of PV system. In this scenario a part of local consumers are sustained by the PV system and the difference of power required is covered by the electrical substation. The loss on feeders rises with 48% by loses in scenario without system PV, and the direction flow is changed. The value of fault current rises only with 6%.

The worst scenario for the PV system is the minimum load at local consumers (e.g. summer weekend) when as is well known that the level of voltage in substation increases and the PV is generating at maximum power create also a bigger value of drop voltage on the electric line, a value which is situated at 5.3 % of nominal voltage. The loss on feeders rises with 71% by loses in scenario without system PV, and the direction flow is changed.

It is possible by fluctuations to the locally voltage to achieve bigger values than 7.5% over nominal voltage and cause disconnection of the PV system through an overvoltage protection required by the grid owner.

Distribution utilities have reported challenges in regulating voltage in areas with high penetration of solar PV [5]. Locally, the voltage can fluctuate as a response to fluctuating solar irradiance, ass well as other factors such as load transients or the existence of multiple solar PV inverters (12 inverters in this case) on a distribution circuit. When the PV system is grid-connected, the connection impedance between that system and the grid naturally drives up the nominal voltage at the point of interconnection. This voltage rises is, among other things, proportional to the amount of current generated by the PV system and this current it itself proportional to the solar irradiance fluctuations throughout the day directly create grid voltage fluctuations [6].

The owner of the grid required a recloser integrated in SCADA (Supervisory Control and Data Acquisition) and a network analyzer for harmonics in the point of grid connection.

The recloser will have installed overvoltage and undervoltage protection required by the grid owner to protect the local consumers. A solution to avoid overvoltage protection and disconnect the PV system is to limit the power in the moments when a set value is reached in timing steps and if is necessary by restricting the power by stopping one or two inverters by case until system became stable.

9. CONCLUSIONS

Concerns about voltage variations and reverse power flow are expected to rise as PV systems installations are increasing. With the existing technologies and best practices for managing those technologies, can minimize voltage fluctuation and reverse power flow effectively.

REFERENCES

1. *www.transelectrica.ro/pdf/piata/unitatiproductie.pdf* accesed on 27 March 2013.

2. Antonello Gaviano, Karl Weber, Christian Dirmeier, *Challenges and Integration of PV and Wind Energy Facilities from a Smart Grid Point of View*, Energy Procedia, Volume 25, Pages 118-125, 2012.

3. Rajkumar Viral, D.K. Khatod, *Optimal planning of distributed generation systems in distribution system: A review,* Renewable and Sustainable Energy Reviews, Volume 16, Issue 7, Pages 5146-5165, September 2012.

4. Markrides G, Norton Matthew, Schubert Markus, Werner Hj, *Potential of photovoltaic systems in countries with a solar irradiation. Renewable and Sustenable Reviews,* Renewable and Sustainable Energy Reviews, Volume 14, Issue 2, Pages 754-762, February 2010.

5. J. Bebic, *Power System Planning: Emerging Practices Suitable for Evaluating the Impact of High-Penetration Photovoltaics,* Subcontract Report, NREL/SR-581-42297, February 2008

6. Mohamed A. Eltawil, Zhenming Zhao, *Grid-connected photovoltaic power system: Technical and potential problems- A review,* Renewable and Sustainable Energy Reviews 14, pp.112–129, 2010.

7. Samuel Wolfe, Adje Mensah, *Overcoming Challenges to High Penetration of Solar PV: Using Optimized Energy Storage and Distribution Grid Controls,* The Electricity Journal, Volume 25, Issue 9, Pages 43-47, November 2012.

8. *http://www.amsolar.com/home/amr/page_164* accesed on 28 March 2013.

9. J.A Hernandez, D. Velasco, C.L Trujillo, *Analysis of the effect of the implementation of photovoltaic systems like option of distributed generation in Colombia,* Renewable and Sustainable Energy Reviews, Volume 15, Issue 5, Pages 2290-2298, June 2011.

10. *http://science.yourdictionary.com/solar-cell.* accesed on 29 March 2013.

11. Vatra Fanica, Postolache Petru, Vatra Cristiana Andreea, Poida Ana, *Intergrarea si functionarea centralelor eoliene si a instalatiilor fotovoltaice in sistemul electroenergetic*, Ed SIER, 2012.