

DOI: 10.5604/20830157.1201315

THEORETICAL ANALYSIS OF GENERATION AND COMPENSATION OF REACTIVE POWER IN PHOTOVOLTAIC POWER PLANTS

Michal Koniček, Boris Cintula

Slovak University of Technology in Bratislava, Faculty of Electrical Engineering and Information Technology, Institute of Power and Applied Electrical Engineering

Abstract. The paper is focused on the theoretical analysis of potential options of reactive power origin and its compensation in photovoltaic power plants. In the first part of paper parts of photovoltaic power plants, which can be a source of inductive or capacitive reactive power are described. The second part describes a compensation of reactive power and reasons of requirement of reactive power compensation. Further we describe the basic types of the presently most frequently used reactive power compensation equipment in photovoltaic power.

Keywords: photovoltaic power plants, compensation, reactive power, power factor

ANALIZA TEORETYCZNA POWSTAWANIA I KOMPENSACJI MOCY BIERNEJ W ELEKTROWNIACH FOTOWOLTAICZNYCH

Streszczenie. Artykuł poświęcony jest teoretycznej analizie potencjalnych możliwości powstawania mocy biernej w elektrowniach fotowoltaicznych i jej rekompensacji. W pierwszej części opisano elementy składowe elektrowni fotowoltaicznych, które mogą być źródłem indukcyjnej lub pojemnościowej mocy biernej. W drugiej części opisano kompensację mocy biernej i ze przyczyny wymogu kompensacji mocy biernej. Następnie analizowane są podstawowe typy najczęściej obecnie stosowanych urządzeń do kompensacji mocy biernej w elektrowniach fotowoltaicznych.

Słowa kluczowe: elektrownie fotowoltaiczne, kompensacja, moc bierna, współczynnik mocy

Introduction

Recently, in the energy mix of many countries has changed significantly the share of renewable energy sources. Rise installed capacity of these resources was also recorded in Slovakia, with the largest representation of photovoltaic power plants.

History in many cases showed that fast changes do not bring only the positives but also negative aspects. In the dynamic increase of photovoltaic power plants has shown that the operation of these sources provides a number of issues that need to be addressed.

The article aims to elucidate certain parts of photovoltaic power plants, which can be sources of reactive power and explain some methods of reactive power compensation in photovoltaic power plants. These methods are currently highly topical.

1. Reactive power generation in PVP

Reactive power is caused by the fact that electricity in one period of the capacitor creates an electric field and a magnetic field coil. In the second part of the period these fields disappear and return the same power to the circuit. Depending on whether load has inductive or capacitive character, the reactive power can take both signs: if the current delayed behind voltage reactive power have inductive character (positive) on the contrary it is a reactive performance capacitive character (negative) [8, 10]. Problem arises during operation PVP. Operators PVP must comply the required range of power factor ranging from 0.95 to 1 inductive character and must not cause unsolicited supply reactive power to the DS. In the design of many PVP was taken into account the fact that PVP inverters operate with unit power factor. Inverters work with this power factor only in certain power area. Also other components of PVP such as cable distribution (LV/MV) or transformer has a significant impact on this power [9].

1.1. Reactive power sources

Operator PVP is invoiced payment for unsolicited supply of reactive power or power factor failure. Unsolicited delivery of Q to the network is the particularly in mode where PVP not supply active power. It is at night. It is caused by elements of PVP which consists [2].

Transformer – From the perspective of reactive power it is a static inductive load. It consumes reactive power to create

a magnetic field. Transformer at no load status taken on small current from a network, which reactive component also magnetized iron. This situation is especially at night, and so PVP consume reactive power. No load transformer is solving by static individual compensation, which is determined by distribution network operator. Specific power transformers show the value of capacitors. Transformer creates a negative contribution to the total capacitance Q PVP [5].

Individual compensation transformer – From the perspective of reactive power it is a static load capacitance (capacitor installed). Static compensation transformer constitutes a positive contribution to the total capacitance Q PVP [3].

LV lines – From the perspective of reactive power is capacitive load that needs charging current to keep cables under voltage. LV line used for connects panels and strings have a minimal effect also as the outlet of power from one inverter. Significantly demonstrated in the case no central inverters and inverters which are very distant from transformers. LV line constitutes a positive contribution to the total capacitance Q [3].

Inverters – From the perspective of reactive power is a capacitive load that needs charging current to keep cables under voltage. It depends mostly on the manufacturer and type of inverter. Inverters make a positive contribution to the total capacitance Q PVP. Therefore, the smaller PVP inverters tend to shut down per night and thus also PVP [3].

HV lines – From the perspective of reactive power is capacitive load that needs charging current to keep cables under voltage. HV line constitutes a positive contribution to the total capacitance Q PVP. For large PVP with large lengths HV cables, it can be quite large value, which must be compensated. It compensates the static inductive compensation [3].

Individual compensation of capacitive Q – From the perspective of reactive power it is the static inductive load (choke installed). Static compensation of transformer creates a negative contribution to the total capacitance Q PVP [3].

A review of the individual parts of PVP is the clear that prevail capacitive loads and greater inductive loads are transformers. Cable charging currents are moving in very small values (units of amperes). On HV surface cannot be neglected. For example, at a voltage of 22 kV each one ampere is 38 kVar capacitive Q (three phase). When is excessive amount capacitive Q in PVP it can be reflected on the invoice for unsolicited delivery to the network. Also not forgetting on inductive load for which the operator PVP will pay penalties for failure to comply power factor [3].

2. Reactive power compensation

The main reason for the integration of compensation to the PVP is keeping power factor ($\cos \varphi$) at the point of connection to the distribution network or prevent unsolicited supply Q to DS. Keeping a neutral power factor are essential for voltage regulation in DS. In the current configuration and operation of the power system is paradoxically against the production from PVP and energy consumption, at a time when consumption is the smallest and is the largest production of PVP. The aim is generate as much active power at the time (thus energy), for which the operator gets paid. The ideal solution compensation can be designed to a particular functioning photovoltaic power plant [7].

Operating mode PVP counts in the range of 900 to 1,100 hours a year. This means that the plant is operated with the minimum active power (or none). In the case of small active power flows may not be neutral power factor (0.95 to 1 inductive) followed. Relatively small reactance performance compared to the large installed capacity of PVP cannot be underestimated and should be fitted appropriate compatible compensatory devices to PVP already in the project. Often the case, that reactive power

in PVP shows rather capacitive character due to long cable line which is the also undesirable. There is an unsolicited supply capacitive reactive power to the DS. This unsolicited supply is big taxes. This means that the operator PVP can pay significant amounts of time when the power does not produce [4].

PVP is the RLC circuit, which has a specific value of inductive and capacitive reactance. Thanks to the reactance is implemented supply or consumption of reactive power.

It should be noted that the point invoice of measurement DS registers reactance energy when PVP produce and at the time consume. Active power consumption is the time when the PVP does not produce any active power, so called "sleeping mode". Example of power flow in one day with changing cloud PVP is in the following Fig. 1 [1, 4].

The figure shows that unsolicited supply reactive power at a time when the power plant does not produce electricity, is almost constant. During of variable production (variable cloudiness) the supply of reactive power oscillate strongly. Regulation the size of Q according the prescribed power factor required value, when it proposal it must count for compensation or decompensation also with such waveforms [4].

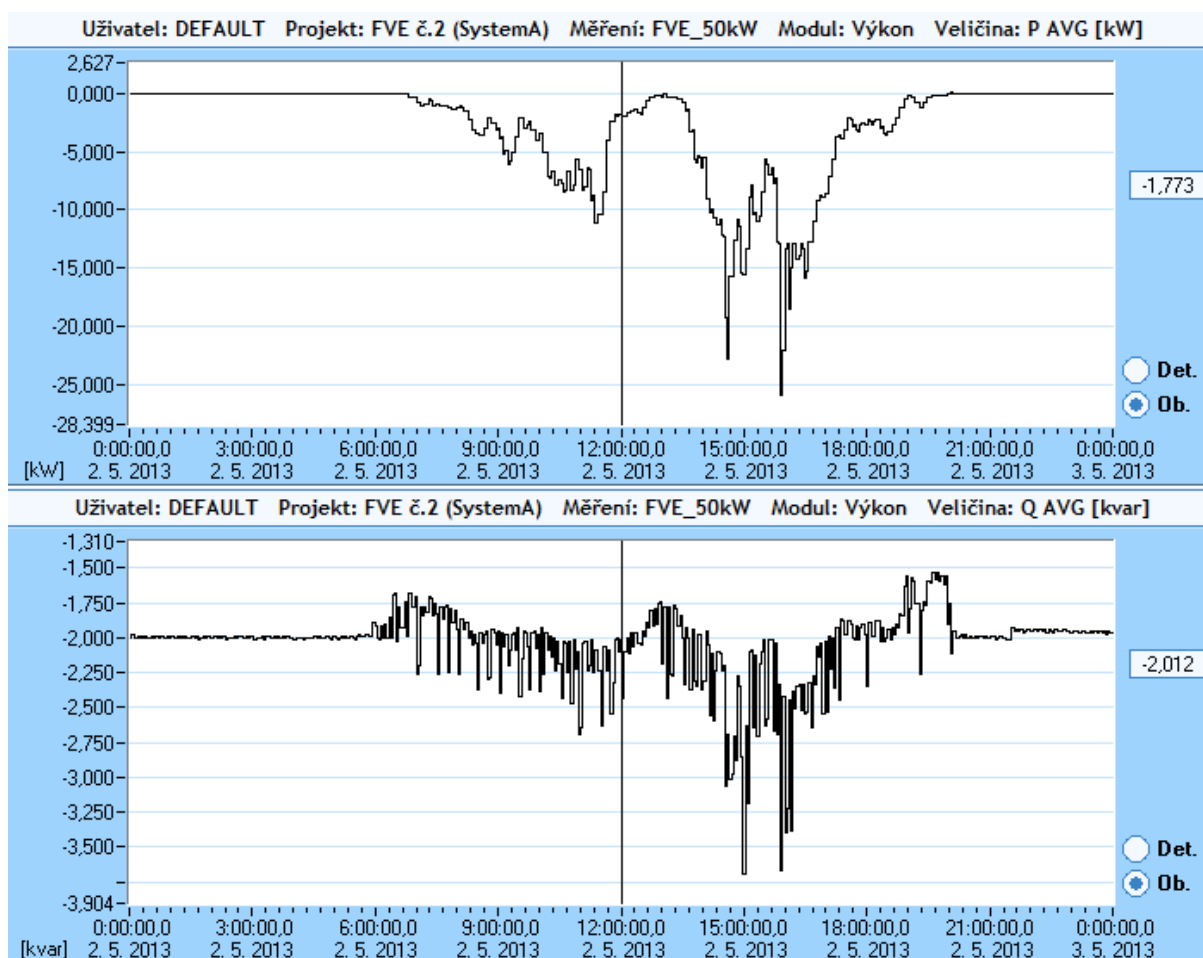


Fig. 1. The course of active and reactive power in point invoice measurements PVP in one day with variable cloud cover (is negative supply to the distribution network)

2.1. Existing inverters

Technically, the easiest way to regulate Q in PVP is used directly inverter already installed. For this purpose are not all satisfactory, and therefore depends on their construction. For most producers is value guaranteed reactive power regulation. I cannot do it always inverters themselves. They are conditional on additional technical modifications or installing software equipment. Such interventions represent an additional cost to the manufacturer. Consequently, that is necessary to supplement the control. The starting point for the control is invoice measurement. On some PVP is used stable setup simplified algorithms. Such

setting shall be based on manually calculated using need three reactive power. It's called alternative local solution [4].

The problem with regulation Q by inverters is reserve for current regulation. If were current-rated for maximum active power and thus are well operated so control is very difficult. Inverter control need 5% increase in current which is under full load active power is very difficult. It offers very few producers.

Compensation inverter does not solve all the states of PVP as "sleeping mode" or operating at low active power (possibly highly variable power).

2.2. Static compensation

Static compensation equipment shall be made in two ways. Static compensation by capacitor or inductor and a static compensation of stepped switching compensatory equipment (capacitors and inductors). These applications are mostly solved unsolicited delivery Q at night as well as management of Q on the required power factor. Switching can be made by contacts or contactless, but always only in steps. These compensation (decompensation) devices can be connected on HV and LV. The decisive factor place of connect is spatial possibilities, requirements for range and speed regulation and price of components (capacitors, inductors, switching elements, breakers, etc.) and technical connectivity options. In some cases, compensation devices need to install a transformer [4].

Addition of these devices sometimes requires new capacities which sometimes results to the construction work. In some applications, they cannot be replenished. Advantages are low loss in the capacitors. Losses in inductors and transformers can affect their dimensioning. Disadvantage is the already mentioned space requirements and regulatory principles. Regulation is always stepped what in respect of operating modes PVP is sometimes inconvenient. Because it is an supplement the capacities and inductances to the a power scheme PVP may be in some operating modes major problem driven harmonic resonance phenomena generated by inverters [4].

2.3. Active filters

An interesting solution is the use of parallel active filters. Meet all operating modes PVP. Their dimension is very small and is easy to space. They can be implemented on HV and LV level.

Disadvantage is the high price and low voltage variants and higher losses. Active compensation devices can continuous manages Q compared static which it manages stepwise. It can accurately to keep controlled power [4].

2.4. Hybrid reactive power controllers

Good technical solutions are hybrid reactive power regulators. Hybrid controller combines active and passive method of generating reactive power. Combination of static and active components did achieve a reduction of investment costs and also partly operational costs due to lower losses. From a technical point of view is achieved high dynamics and flow regulation. All disadvantages eliminate of a pure switching regulation of Q. Their main sections are few degrees of capacitors and inductors and parallel connected inverter. Economically advantageous is their application for the LV, either on LV side of the transformer sections of PVP, or a separate LV side of the transformer. Individual applications are shown in Fig. 4 [6].

Hybrid compensation devices are sized according to the power transformer sections PVP. Its price is comparable with static compensating devices. Advantage is full coverage of the reactive power necessary to achieve the requested values of power factor [1].

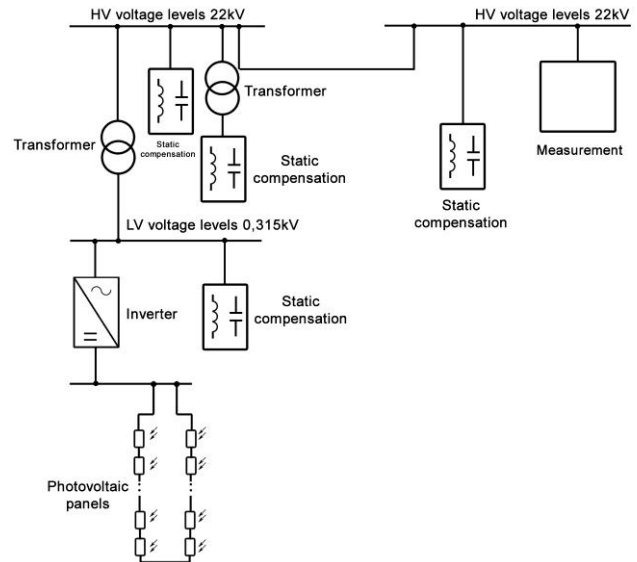


Fig. 2. Block diagram of PVP with various options connection static compensation

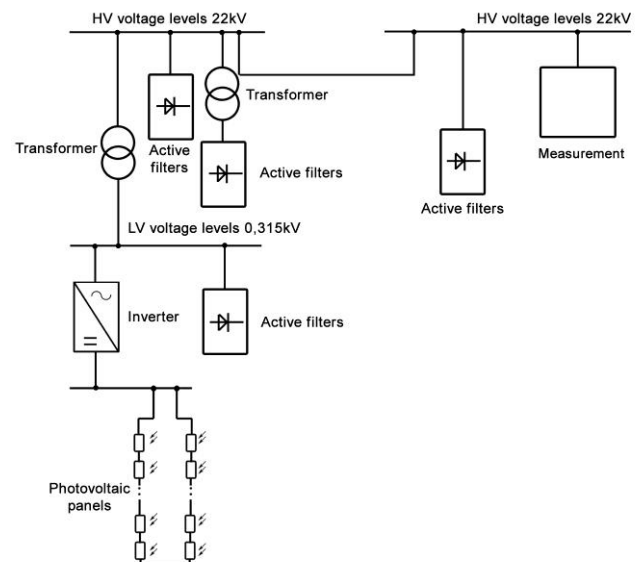


Fig. 3. Block diagram of PVP with various options connection using active filters

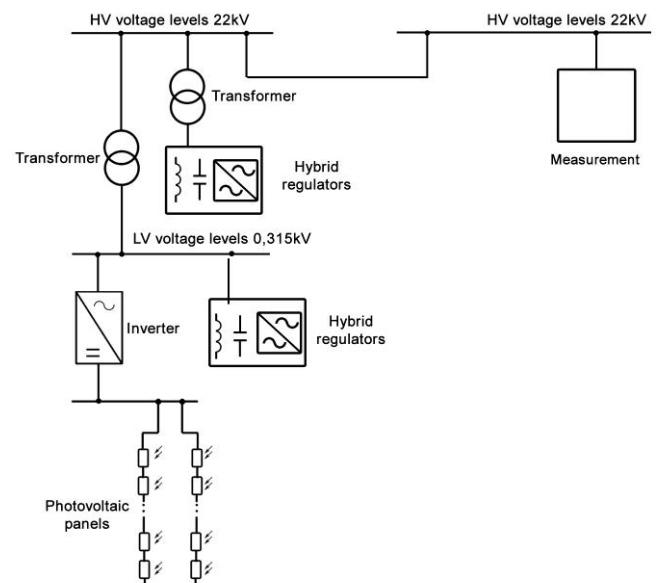


Fig. 4. Block diagram of PVP with various options connection compensation using hybrid regulators

3. Conclusion

In this paper attention is focused on theoretical analysis individual parts of PVP which are the source reactive power. These devices can be a source of capacitive or inductive reactive power describes the impacts on the operation of photovoltaic power plants.

The second part analyse methods of reactive power compensation, which are detail describes basic types of compensation and is currently the most widely used devices with the way they determined the advantages respectively disadvantages.

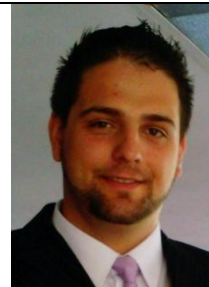
The interests an operator of photovoltaic plants is eliminate the excessive production of reactive power or consumption respectively. It certain conditions, operators can deliver savings of your finances.

References

- [1] Dixon J., Moran L., Rodriguez J., Domke R.: Reactive Power Compensation Technologies: State-of-the-Art Review. Proceedings of the IEEE 93 (12), 2005, 2144–2164.
- [2] Eid B. M., Rahim N. A., Selvaraj J.: Distributed photovoltaic generator performing reactive power compensation. In: Conference on Clean Energy and Technology (CEAT), 2013.
- [3] Gotz M.: Řízení účinniku a kompenzace jalového výkonu na FVE. <http://www.solartecnika.sk/solartecnika-12010/rizeni-uciniku-a-kompenzace-jaloveho-vykonu-na-fve.html>
- [4] Holoubek J.: Fotovoltaické elektrárny a jalový výkon. X Konference Energetické rušení v distribučních a průmyslových sítích, Brněnská přehrada, ELCOM, 2012.
- [5] Kaspírek M.: Dopad OZE na provoz distribučních NN sítí. 9th International Conference Control of Power Systems, Tatranské Matliare High Tatras: FEI STU, 2010, 1–7.
- [6] Korenc V., Bubela T.: Hybridní regulace jalového výkonu fotovoltaických elektráren. X Konference: Energetické rušení v distribučních a průmyslových sítích. Brněnská přehrada, ELCOM, 2012.
- [7] Korenc V., Bubela T.: Problematika regulace jalového výkonu u fotovoltaických elektráren. Odborný článek firmy ELCOM, 2012.
- [8] Principles for Efficient and Reliable Reactive Power Supply and Consumption, Federal Energy Regulatory Commission, Staff Report, Docket No. AD05-1-000, Washington. 2005, <http://www.ferc.gov/eventcalendar/files/20050310144430-02-04-05-reactive-power.pdf>
- [9] Reactive energy compensation, Industrial electrical network design guide, Schneider Electric, http://www.engineering.schneider-electric.se/Attachments/ed/guide/07_reactive%20energy%20compensation.pdf.
- [10] Tirpak A.: Elektromagnetizmus, Druhá upravená verzia, Bratislava: Katedra rádiofyziky, Fakulta matematiky, fyziky a informatiky, Univerzita Komenského, Bratislava, 2004.

M.Sc. Eng. Michal Koniček
e-mail: michal.konicek@stuba.sk

M. Koniček was born in Dubnica nad Váhom in 1988, SK. He graduated from the FEI at STU in Bratislava in 2013 and received the master degree in the Electrical Power Engineering. He is currently a Ph.D. student at the ÚEAE, FEI at STU. His research activities are in the area of distributed sources and renewable energy sources. He has experience of work in a project team on smaller projects. He presented the results of his work as author or co-author of 12 publications.



Eng. Boris Cintula
e-mail: boris.cintula@stuba.sk

B. Cintula was born in Levice in 1986, SK. He graduated from the FEI at STU in Bratislava in 2011 and received the master degree in the Electrical Power Engineering. He also graduated from the Institute of Life-Long Learning at STU. He is currently a Ph.D. student at the ÚEAE, FEI at STU. His research activities are in the area of power system control and power systems stability. He cooperates with transmission and distribution system operators in many scientific projects. He presented the results of his work as author or co-author of 48 publications.



otrzymano/received: 09.06.2014

przyjęto do druku/accepted: 18.01.2016