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RULES FOR ELECTRICITY EXCHANGE FOR PHOTOVOLTAIC RESIDENTIAL SYSTEMS

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A b s t r a c t: Decreased prices of photovoltaic system components in the last years have led to electricity generation cost reduction, obtained by photovoltaic systems to the level of electricity price offered to the distribution consumers. Still, compared to the other type of generators, the energy output from photovoltaic systems is generally low in amount and with varying power profile. Hence, they cannot reach adequate price at liberalized markets. One approach for supporting these systems is the introduction of rules for net metering within the distribution systems. In this paper, technical and economic aspects for installation of photovoltaic systems in households in the Republic of Macedonia, in cases with possibility for net metering, are analyzed. Several rules for net metering are elaborated, and using realistic examples, their influence to technical acceptability and cost effectiveness for the electricity consumers, the suppliers and the distribution grid, is estimated.

Key words: photovoltaic systems; residential electricity consumption; net metering

ПРАВИЛА ЗА РАЗМЕНА НА ЕЛЕКТРИЧНА ЕНЕРГИЈА ЗА ДОМАЌИНСТВА СО ИНСТАЛИРАН ФОТОВОЛТАИЧЕН СИСТЕМ

А п с т р а к т: Намалувањето на цените на компонентите кај фотоволтаичните системи во последниве години доведе до намалување на производната цена на електричната енергија од овие системи до ниво на цената што се нуди во електродистрибутивната мрежа. Сепак, во споредба со другите начини на производство на електрична енергија, од фотоволтаичните системи обично се добива помало количество енергија и тие имаат променлив дијаграм на производство. Поради тоа, тие не се во позиција да постигнат соодветна цена на електричната енергија во услови на либерализиран пазар. Еден од начините за поддршка на овие системи е обезбедување на т.н. размена на електричната енергија со снабдувачот. Во овој труд се разгледани техничките и економските аспекти за инсталирање на фотоволтаични системи во домаќинства во Р. Македонија, при овозможена размена на електричната енергија. Елаборирани се правила за размена на електричната енергија. Преку реални примери се оценети техничката прифатливост и исплатливоста за операторот на дистрибутивната мрежа, за снабдувачите и за домаќинствата.

Клучни зборови: фотоволтаичен систем; потрошувачка на електрична енергија во домаќинства; размена на електричната енергија

INTRODUCTION

During the last decade, installation of photovoltaic (PV) system continually expands. Worldwide, the total installed power of PV systems was around 5 GW by the end of 2005. By the end of 2014, the total installed power have reached 180 GW [1]. This increase is mainly a result of the support from numerous governments in form of feed-in tariffs for the electricity generated by PV systems. The continuous growth of electricity generation from PV systems has led to a decrease of costs for PV modules, resulting in decreased price of the electricity from PV systems [2, 3].

Starting from 2008, feed-in tariffs for electricity generated by PV systems in R. Macedonia have been introduced as well. Up to now, feed-in tariffs have been decreased several times. For PV plants with power lower than 50 kW, feed-in tariff has been decreased from 46 cent€/kWh to 16 cent€/kWh. For PV power plants from 51 kW to 1 MW the feed-in tariff has been decreased from 41 cent€/kWh to 12 cent€/kWh. The allowed period for usage of feed-in tariffs has been decreased as well from twenty to fifteen years. In the meanwhile the total installed power of PV plants in the country is limited to 18 MW [4]. Although feed-in tariffs were decreased, the quota for the total installed PV power in the country has been almost filled.

According to Energy Regulatory Commission (ERC) [5], the price of the consumed electricity for small commercial consumers connected to the distribution network is 0.14 (+ 18% VAT) €/kWh. For households it is 0.09 (+18% VAT) €/kWh in high tariff and 0.05 (+18 % VAT) €/kWh in low tariff. For households the average price of electricity during daily hours (six days high tariff and one day low tariff) is 9.95 cent€/kWh with included VAT. Following the tendency for installation of the PV systems and by considering the decreased prices of PV components and the potential of solar radiation in R. Macedonia, it can be easily concluded that, even without the feed-in tariffs for generated electricity, the payback of the PV systems is feasible. Still, as consequence of relatively low installed power of PV plants within the country, small amounts of generated electricity from them, variable diagram of electricity generation, the generated electricity has no real opportunity to reach the adequate price level at the liberalized electricity market. In spite of the achieved generation price, in cases when there are no other incentives for trading with this type of electricity, it cannot be expected that the increasing number of people who will install PV systems in their homes.

The problem with selling of the generated electricity from PV systems can be reduced or avoided, if this electricity is used for own consumption. Still, it is not realistic to expect that the household will consume all generated electricity in every moment of time completely. Namely, in certain periods there will be excess of electricity (Fig. 1). This electricity can be redirected to other consumers in the distribution network. For this to be feasible, it is essential to have a model for electricity exchange. In this paper, such model for electricity exchange from photovoltaic residential systems is presented and proposed for further evaluation, since up to now there is no applied methodology for electricity exchange from residential PV systems in R. Macedonia. Further, more experiences from other EU and non-EU countries, with respect to installation of PV systems at households and their connection to the grid, are analyzed.

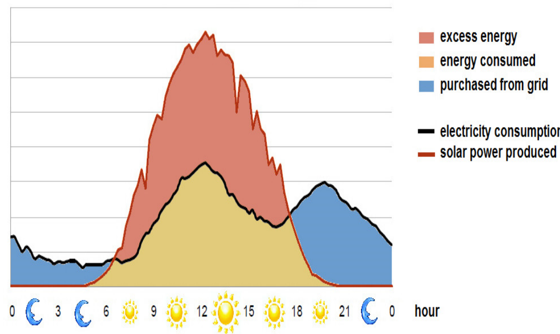

Fig. 1. Example daily diagram of electricity consumption and generation by a PV system

MODEL FOR ELECTRICITY EXCHANGE

Technical and economical aspects of electricity exchange (generated and consumed electricity) are complex and involve several aspects: distributed electricity generation, configuration of PV systems for residential use, as well as technical and economical conditions that will provide profitability for all participants in electricity distribution.

Backgrounds

Several examples of different models and rules for electricity exchange between PV systems, installed at households (roofs) and distribution network world-wide are presented and analyzed. Presented experiences from other countries may serve as guidelines for development of model for electricity exchange that should be implemented in the Republic of Macedonia as well.

Self-consumption of PV electricity is allowed in the Netherlands for all systems. Homeowners and tenants with their own solar panels are exempt from energy taxation for the electricity they have generated. They are allowed to deduct their private use from the generated electricity. This process is commonly known as netting or offset. An advantage of this process is that the value of the electricity that is fed back to the grid is determined by the price of electricity including tax and transport costs. For households this is about 23 euro cent per kWh, including a 11.65 euro cent per kWh energy tax component. Netting was limited to 5,000 kWh until the end of 2013. The over generation was calculated at a lower price. The electricity generated may be unlimitedly netted with the personal use from 1 January 2014 onwards [6]. In the U.S following metering arrangements are usually encountered [7]:

– Net purchase and sale

Under this arrangement, two uni-directional meters are installed: one records electricity drawn from the grid, and the other records excess electricity generated and fed back into the grid. Households pay retail rate for the electricity they use and the power provider purchases the excess generation at its avoided cost (wholesale rate). There may be a significant difference between the retail rate that is pied by the households and the power provider's avoided cost.

– Net metering

Net metering provides the greatest benefit to the household as a consumer. Under this arrangement, a single, bi-directional meter is used to record both electricity that is draw from the grid and the excess electricity that PV system feeds back into the grid. The meter spins forward as household draw electricity, and it spins backward as the excess is fed into the grid. If, at the end of the month, household used more electricity than the PV system has generated, the household pay retail price for that extra electricity. If the household generated more than have used, the power provider generally pays for the extra electricity at its avoided cost. The real benefit of net metering is that the power provider essentially pays to the household retail price for the electricity that is feed back into the grid.

All of the schemes currently operational in Australia (as of May 23, 2012) are net schemes, which pay only for surplus solar power exported to the power grid. The remaining programs come in essentially three forms: State government-backed Solar Feed-in Tariffs (SA, Victoria, and Queensland), 1-for-1 Solar Buybacks through electricity retailers (ACT, Tasmania, Northern Territory), and voluntary Solar Buyback schemes, which offer (often nominal) rates for exported solar power that are lower than retail electricity rates (New South Wales, West Australia) [8].

In Greece since July 1st 2009 a program has been in force for the installation of small PV systems (<10 kW) in the residential sector. In September 2010, the program was extended to cover all regions, and authorization procedures have been further simplified. Most barriers have now been lifted for this segment. Residential PV is one of the most dynamic segments of the market. A new self-consumption scheme (based on net-metering) has been decided and is being planned by the authorities in parallel with the existing support scheme which is based on feed-in-tariffs [9].

Distributed electricity generation

There are many definitions regarding "distributed generation of electricity" [10] most of them are related to distributed generators with small power ratings connected to the distribution network and located nearby consumers (households, industrial plants etc.). As distributed generators can be considered PV systems, wind generators, micro-gas-turbines, etc. Due to their simple construction, decreased prices of components, possibility for cogeneration, electricity tariffs, these generators are becoming very attractive source of electricity generation from economical point of view. Additionally, since the electricity generation is located nearby the consumers, electricity losses are decreased and quality of the power supply is improved. This paper will give an overview of technological and economical aspects of the PV systems application at households in R. Macedonia.

PV systems at households

The main components of a grid-connected PV system to distribution network are generator and inverter. In Figure 2 a PV system installed at residential house, is presented. Up to now, experience shows that such systems are easily constructed. In presented application, the generated electricity from PV system is primary aimed for own consumption, while the excess is feed in into the network. During night hours, or in cases when the generation is less than the consumption of household, the required energy is supplied by the distribution network.

In order such electricity exchanges to be carried out, a bidirectional meter should be installed. This meter registers the consumed and supplied electricity. Inverter is also important with respect to the power quality. It should also satisfy the distribution network requirements.

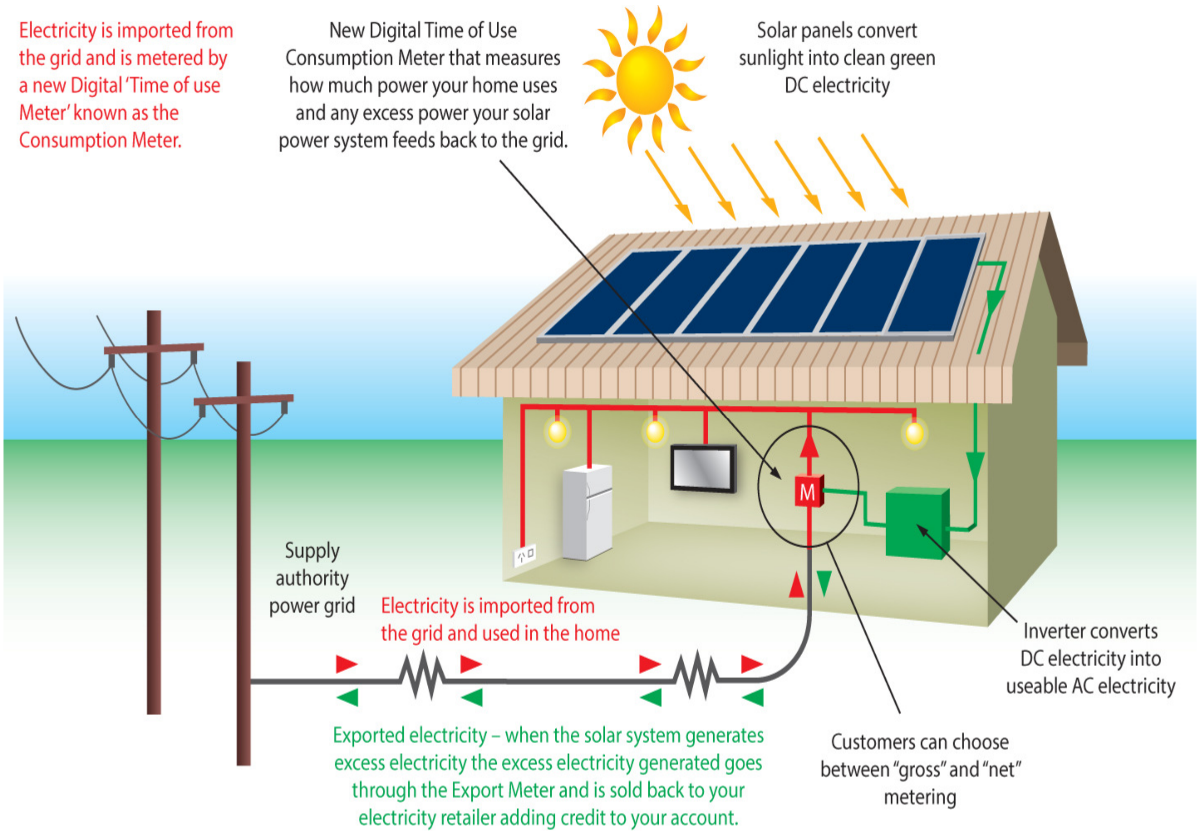

Fig. 2. PV system at households with possibility of electricity exchange

PV generators are consisted of a number of modules, which define their power rating. PV modules are connected in series and they form strings. These strings can be further connected in parallel connection [11].

In the past period, in R. Macedonia the total installed capacity is reaching PV systems with total capacity of 18 MW. Experiences from investors have shown that price of the investment in PV systems is about 1200€/kWh. This price covers expenses for equipment and its installation with included costs for land, connection to the distribution network, design and other expenses for obtaining necessary documentation. Operation and maintenance expenses of PV systems are relatively small, so in further analysis they will be neglected.

Calculations applied to this paper are using experiences from already installed PV systems in R. Macedonia. Consequently it is estimated that annual generation of electricity from PV system with fixed mounted modules is 1400 kWh/kWp. PV system of 6 kWp generates 8400 kWh/per year. In case when PV generator is consisted of modules with rated power of 250 Wp it is necessary to have 24 PV modules.

Prices of electricity

Currently all consumers of electricity in R. Macedonia are divided into two groups [5]. In the first group are households while in the second group are the commercial and industrial consumers. Both types of consumers are split into two tariffs. In this paper households with two tariffs are analyzed. Tariffs for households are: high tariff from 07:00 up to 22:00 o'clock and low tariff in the remaining part of the day. In Sunday during the whole 24 hours the tariff is low.

During the year, sun rises in interval from 4:58 to 7:02 o'clock and the sun set is from 16:03 to 20:14 [12]. Further more in the day when sun rises most early, solar radiation up to 7:00 o'clock is less than 3.5 % of total solar radiation if the day is clear (calculated for the area of city Skopje with software tool "Solar Calculator" [13]). In the remaining part of the year this percentage is too low and it is between 0 and 0.35 at clear days. Consequently if generated electricity from PV systems from sunrise up to 07:00 o'clock is neglected, the error in calculations is very small. This means that major part of electricity from PV systems is generated in high tariff (six days per week) except Sunday (one day per week) when the tariff is low. The average price of electricity from 07:00 to 22:00 o'clock is:

$$\frac{0.09 \cdot 6 + 0.05 \cdot 1}{7} = 0.0843 \text{ €/kWh.} \quad (1)$$

VAT of 18 % can be added to the obtained price and consequently, the average price is 9.95 cent€/kWh. Calculated average price of generated electricity from residential PV systems is still below the feed-in tariff (12 cent€/kWh and 16 cent€/kWh). But gaining the status of feed-in producer of electricity from renewable resources in R. Macedonia requires submission of extensive documentation. Sometimes to gain the status of feed-in producer, considering the power ratings of PV systems, it is necessary transformer station to be built as well as the associate cable or overhead distribution network. If these expenses are deducted, the investment in PV systems can be decreased. Still, in further calculations the worst scenario with price of 1200 €/kWh will be considered. Also it is assumed that electricity generation from PV system is 1400 kWh/kWp (for PV systems with fixed tilt of 30°, oriented toward south).

Regulations for electricity exchange

Electricity generated from residential PV systems is not always matching with its consumption. In certain periods there is an excess of generated electricity while in others the consumption exceeds the generated electricity. For example, PV system generates electricity during daytime while consumption is larger at night hours. One solution is the usage of battery. Negative sides are more elements in the system, possibility for faults, larger dimensions of the system. Other solution is changing the habits of the consumers. Still it can not be avoid consumption of electricity during night hours as it reflects on quality of living.

One measure to stimulate installation of large number of PV systems, is to create opportunity for electricity exchange with the distribution network. In order this to be feasible, it is necessary a set of regulations to be adopted. In this paper, such regulations are proposed and the influence of all participants in electricity exchange will be analyzed (consumer, electricity supplier and operator of distribution network). Model is developed based on following hypothetical rules for electricity exchange:

- The excess of generated electricity is taken over by the electricity supplier.
- The ratio of prices of taken over and consumed electricity is regulated on yearly basis. This ration can be smaller or bigger (i.e. 0.9 : 1 or 1.1 : 1). In this paper ratio of 1 : 1 is considered.
- If the generation of electricity from one household during one year is less than consumption, the household pays only the difference between consumed and generated electricity.
- If during one year more electricity is generated than it is consumed, then the excess of electricity is not paid. In such case the excess of electricity is transferred to the following year, decreased by a certain percentage, considering the variations of sun radiation. In this paper, the excess of electricity is transfer to the following year, decreased by 50 %.

In Table 1 is presented an example with few alternatives. Example is worked out in accordance to above set regulations. Exchange of electricity is between household with consumption of 4000 kWh per year with installed PV systems and electricity supplier.

Table 1

Example of electricity exchange (kWh)

Consumed EE–HT	Generated EE-LT	Consumed **EE-HT,**	Generated EE-LT	Balance
4000	5000	3000	1000	Payment of 1000 kWh – LT
4000	6000	3000	1000	Payment 0
4000	7000	3000	1000	Payment 0, transfer of 500 kWh in next year – HT

EE – Eleectricity, HT –high tariff, LT – low tariff

Additionally, following technical conditions must be fulfilled:

- Installation of meter, which register electricity in both directions (or two meters)
- Output power of the inverter should be limited in range of 5 kW to 10 kW. This limitation is necessary in order to stimulate installation of small PV systems and to avoid ineffective heating with electricity.

- Instantaneous power at the inverter output should not exceed in any moment the rated power of the inverter. In this way, the designer of the PV system defines the power of PV generator. Later on, depending on the meteorological conditions and regardless of the power of the generator, the output of the inverter is limited (rated output).
- Inverters should satisfy EN standards (high order harmonics, flicker and island operation).
- Three phase inverters should be used for the purpose of voltage symmetry.

DISCUSSION

In this section, the impact of rules for electricity exchange from PV residential systems on distribution network, electricity supplier and consumers with PV systems is analyzed.

Impact to the distribution network

There are several works addressing the issue of impact of PV systems on distribution network [14, 15]. Generally, PV systems are decreasing the losses in distribution network and are improving quality of the power supply. In [16] it is presented that quality of the power supply is improved if PV systems are distributed within feeders instead of PV systems connected in one of the distribution nodes. In cases when power of the PV systems is large, losses in distribution feeder are lower if the PV systems are connected to all nodes. Besides this, inverters in modern PV systems can generate reactive power, which can additionally decrease the losses in the network [17]. Further more, contemporary control strategies of PV systems enables dynamics of the PV system to be decoupled from those of the distribution network and, therefore, the PV system does not destabilize the distribution network [18]. Results in [19] indicate that the PV penetration level should not adversely affect the voltage on the grid when the distributed PV resources do not exceed 2.5 kW per household on average on a typical distribution grid. Results of the study in New Zeeland [20] have also proved that only minor overvoltage problems can be expected in the future, particularly in urban areas where PV systems are installed.

Impact to the electricity supplier

According to the above-described regulations for electricity exchange, is planned that the electricity supplier is obligated to take over the excess of electricity from PV systems (electricity that is not consumed by the household). As presented in Fig. 1 supplier takes over the electricity during day time, in high tariff (HT), and this electricity is compensated during night hours in low tariff (LT). Price difference in tariffs is the profit for the supplier.

In Table 2 is presented one example of a household with consumption of 7000 kWh per year, from which 3000 kWh per year are in high tariff and 4000 kWh per year are in low tariff. The household has PV system which generates 7000 kWh per year (6000 kWh per year in high tariff and 1000 kWh/per year in low tariff). Electricity, which is taken over by the electricity supplier, is sold to other consumers. In this case, the supplier has profit of 30 %.

Table 2

Calculation of profit for electricity supplier

Example	EE, kWh per year	Price of EE, €/kWh	Price of EE, €/year	Total price €/year	Price difference €
Consumed electricity – HT	3000	0.09	271.3	452.6	135.4 (30%)
Consumed electricity – LT	4000	0.05	181.2		
Generated electricity – HT	6000	0.09	542.7	588.0	
Generated electricity – LT	1000	0.05	45.3		

Impact to the consumers with PV systems

According to Table 2, household with monthly bill for electricity of 48.7 € (584.4 € per year), consumes annually 7000 kWh. This electricity can be generated by a PV system of 5 kW and cost of 6000 €. PV modules can be placed on roof and they occupy 35 m^2. The payback period of the investment is eight to ten years, in dependence of ratio high-low tariff, expected rise of electricity price, bank interest rates etc. In contrast, the operational life of the system is long event up to and may be expected to forty years.

CONCLUSION

Paper proposes a set of regulations for electricity exchange, which will enable installation of large number of PV systems in R. Macedonia. Presented analysis confirms that proposed regulations are well-balanced providing benefit for all participants (households, electricity supplier and operator of distribution network). These set of proposed regulations can be implemented by the aid of legislation, which anticipates quick and cheap procedure for obtaining all necessary documents for the installation of residential PV system.

From current point of view, payback period of the investment is eight to ten years. Considering that, it is expected that the price of electricity would rise and price of components of PV system to go down, this period for payback can be shortened. On that way, without any financial obligations for the state, the number of installed PV system will be increased and consequently the percentage of installed renewable resources in total energy balance of the state. Additionally, favorable conditions are created for lowering the emission of green house gasses.

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