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Research Article

Smart Tariffs and Photovoltaic System Sizing

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Abstract The spread of smart metering to improve energy efficiency can be an important tool. One of the most related advantages is the possibility to achieve some demand response to a GHG emission reduction at system level. The spectacular decrease in the cost of solar small scale systems causes previously unthinkable levels of growth of the photovoltaic (PV) electricity production capacity. Therefore, the resulting distribution network problems and related higher costs hinder the further growth. Game theoretic approaches to the problems are still missing. Opportunities in the smart meters have not yet used to prevent the spread of difficulties. The smart tariffs have great potential to influence the deployment, so the grid problems can be reduced before the occurrence. In this paper it will be examined by net metering systems that a defined tariff structure which encourages a PV systems for sizing to winter maximum globally could be useful or not. Furthermore, the purpose of the investigation is bringing ideas to stimulate further thinking.

Keywords Small scale photovoltaic systems, tragedy of commons, grid integration, smart tariff, support strategy

1. Introduction

Preventing climate change is a noble goal. Our consumption electricity is still a major part of fossil fuel based energy, but the result of supports and intensive technological development, the renewable energies rapidly spread, including the photovoltaic technology. In fact more often there are projects without external supports. The EU in the 2010/31/Directive created the concept of the nearly zero energy buildings and the renewable energy usage will be compulsory integrated part with it from 2021 by every new buildings. Only a few years until 2021 and there will be an intense increase by the demands of installation of photovoltaic buildings with small scale systems, where the rate of growth is still low.

Fig. 1 shows the European Photovoltaic Industry Association details [1]. From the figure it can be seen that the 2/3 parts of the PV systems in the world was built only in the last three years [2]. This intensive growth is causes a big challenge for regulatory authorities and also the TSOs and DSOs. Moreover a new wave of growth could be expected because of the approaching of the grid parity and the stricter requirements connected to buildings renewable systems.

The International Energy Agency (IEA) Photovoltaic Power Systems Program in 2015 updated in the framework of the Trends 2015 series the solar photovoltaic publication [3]. This demonstrates that the growth rate of PV systems varied between nearly 30%/year and nearly 75%/year over the last five years, while the grid parity has not yet been fulfilled (Fig. 2).

The demand response measures could be easier when consumers also have their own electricity generating units, which basically could be a photovoltaic system. In the public grid the highest electricity demand occurs in winter. However, when positioning solar modules or sizing the system elements the target is the highest annual production. This effect in summer in some countries may even cause negative electricity prices because of regulatory difficulties by the basic power plants.

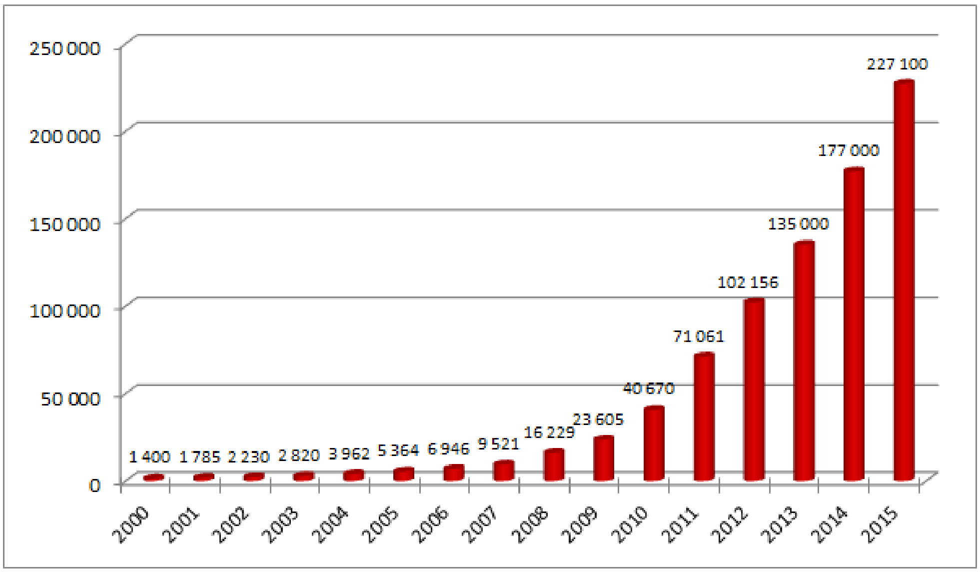

Figure 1: Evolution of the global installed PV capacities in MWP

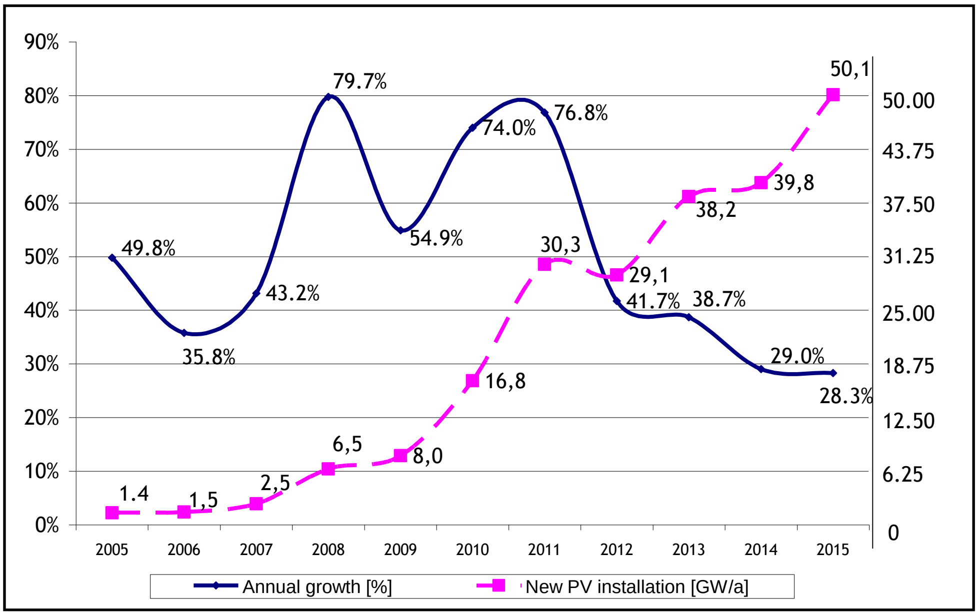

Figure 2: Global cumulative growth of PV capacity

The specific systems which based on rational decisions also could lead damaging or wasteful results. The human way of thinking is interest-based and this is shown in various trap-situations which are investigated by the game theory. Traps may occur even if these individual decisions are connected with some public supports programs and aims the public good or the climate change prevention. A classic example is the tragedy of the commons [4]. In this dilemma initially the cows are grazed in a freely available pasture by the owner farmers in equal proportions and optimal numbers. Rational behavior of the individual farmers to increase their number of grazing cows, so they can grow their own personal benefit even though if the common benefit gets a bit smaller. The cows are getting thinner and they worth are less and less money, eventually it develops an equilibrium position with a poor total income. If a new farmer also wanted to appear in this region, probably should chased away.

The tragedy of the commons by the environmentalists is a classic situation. Basically it could characterize a number of problems (overfishing, urban air quality degradation, etc.). However, in the energy sector is not usual to be thinking about taking any trap game theory situations. In particular, by political culture, which is trusting

in a liberalized and free market, the responsibility of the regulatory authorities and ministries increases to recognize in time the prisoner's dilemma-type situations. It is not always enough to protect the free market and the clear competition. The free competition, the system security and environmental protection requirements not obviously satisfied at the same time. In the tragedy of the commons it is decisive the ratio between the individual benefits - striving (deserters) and tradition admirers (co-operatives). The selfishness by deserters is more profitable individually. In case of cooperative behavior would be the largest total benefit, but if the number of deserters is low, the total benefit is only minimally reduced. Moreover, the deserters are in a better position during a dramatic drop in the total benefit, as the co-operatives. If you have already started a series of desertion there is takes a critical point, because the personal benefit potential by deserters remain better continuously to the final equilibrium position.
This paper is an overview of the options, which are used from the aspects of the integration and summarize some criteria which could be able to measure the PV systems from the system friendly aspects.

2. The network system suitability evaluation indicators for small scale PV plants

The PV GRID program has undertaken the exploration the grid problems caused by the small scale PV systems and develop solution proposals. The consortium explored details about the main technological opportunities, which the DSO or the electricity producer separately or together with each other in co-operation would be necessary to implement to safe the grid-operation and the grid could remain receiving. The main results are listed in Table 1. [5].

Table 1: Technical solutions enhancing distribution grid hosting capacity

No.	Technical Solutions	Categories
1	Network reinforcement	Opportunities only for DSO's
2	On load tap changer for MV/LV transformer	
3	Advanced voltage control for HV/MV transformer	
4	Static VAR control	
5	DSO storage	
6	Booster transformer	
7	Network reconfiguration	
8	Advanced closed-loop operation	
9	Producer storage	Opportunities only for electricity producer
10	Self-consumption by tariff incentives	
11	Curtailment of power feed in at PCC	
12	Active power control by PV inverter	
13	Reactive power control by PV inverter	
14	Demand response by local price	Opportunities only for cooperative behavior
15	Demand response by market price	
16	SCADA + direct load control	
17	SCADA + PV inverter control	
18	Wide area voltage control	

Therefore the proposed PV-Grid solutions could be divided into four main categories:

1. In the low voltage distribution grid the surplus produced electricity by small scale PVs forms to heat in the technical controls and increase the losses in public grid.
2. The small scale PV solar power can disconnect from the grid to ensure that the produced electricity could not causes difficulties in the grid (yoyo-effect).
3. Costly storage capacity building to ensure with the loss of a significant portion of the produced energy so the consumption could be later.

4. If too much producing PV electricity loads the low voltage grid, it can transform into a virtual power plant for a short period of time. Transformation and distribution losses escalate. This could cause negative pressured prices for the power plants. In view of competitiveness is not good option for the poorer countries.

The Hungarian Academy of Sciences Institute of Ecology and Botany in Vácrátót implemented within the framework of the Norwegian Financial Mechanism a complex renewable energy and energy efficiency project. A new visitor center was an important part of this development with a solar power system which from 80 to 100% of the own consumption. By this PV system the installing possibilities was influenced by a specific situation, so the solar panel placement is different from the usual way (Fig. 3).

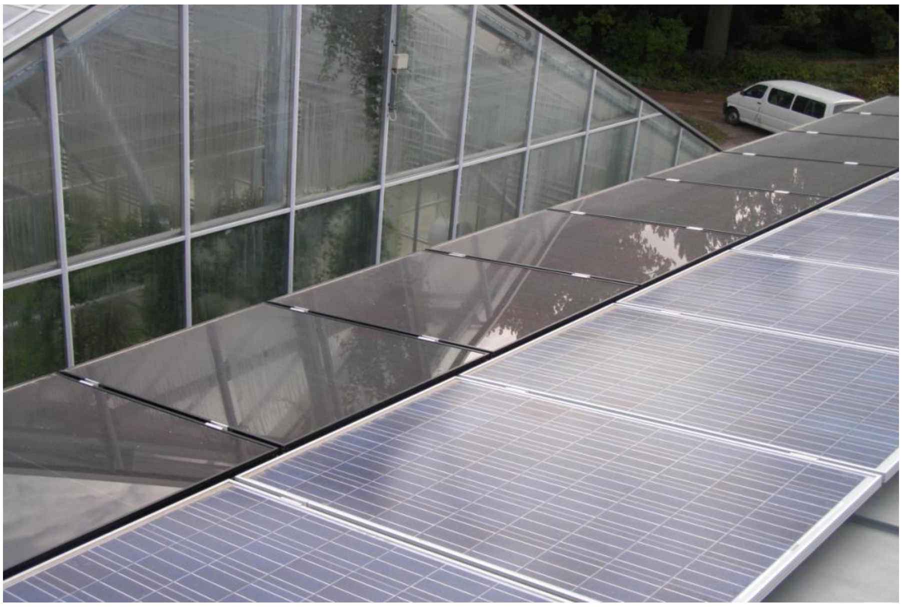

Figure 3: Solar panels on top of the visitor's center

Large part of the roof is green roof. There are only two remaining narrow parts, with a slight inclination to place the 1-1 line shadow-free solar installation. The orientations by these parts of roof are south-eastern and southwest. The south orientation of solar panels cannot be ensured. The highlight from the roof plane would have been technically feasible, but the 30-degree angle could provide only 2% additional electricity production. The main reason for this that the modules have been shown from behind some of the days because of the significant South West orientation, which is close to 70 degrees.

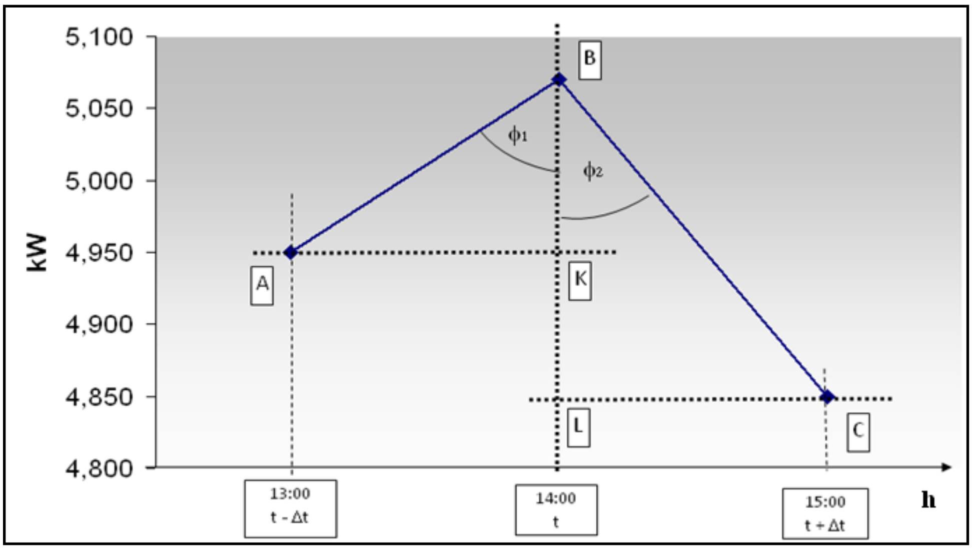

Figure 4: The peak angle

The visitor center was built on two sides linked in glass houses with significant shadow effect in winter. The specific productivity with the 7.75 kW_P rated output it is smaller than ideal case. However, the number of PV systems connected to the grid is less limited. So the less peak performance in the summer occurs in less annual production. The not produced electricity because of the network friendly installation can be considered as a cost of the co-operative behavior. The benefit from the integration perspective could be strengthened if the facade could have been built. However, without a shadow just the east and the north-west facade would have been suitable, but this was considered as an unreasonable option.

Evaluation indicators in aspect of system integration-friendly construction could be formed from publicly available data on the Internet (based on an hourly performance and electricity generation data). One such indicator is the peak angle (Fig. 4), which can be formed from data of the largest daily performance output and the one hour earlier and the one hour later outputs. The maximum theoretical approaches 180 degrees.

The peak angle is the amount Φ_1 and Φ_2 and from the right-angled triangles with two known clamping length (ABK and BCL triangles) can be calculated easily. The specific peak height in a given months, according to the Equation 1 can be determined in view only the clear day data in that months.

$$H = \left[\tan\left(\frac{\sum_{i=1}^{i=n} (\varphi_1(i) + \varphi_2(i))}{2} \right) \right]^{-1}, \qquad \text{(Eq. 1)}$$

where H is specific peak height in kW/kWP and the n is the serial number of the clear days in the month. The daily rated performance output per unit of electricity production in the power plant and a maximum annual production of reference established power plants are important parameters. The ratio of the daily electricity productions the nominal power is useful to compare a system friendly and a reference PV plants. The peak cut-off efficiency indicator (Eq. 2) gives the technical costs of the 1 kW/kWp peak performance reduction to fall in expected measurable electricity production [kWh/kW/d].

$$\Psi = \frac{\overline{E}_R - \overline{E}_{PV}}{H_R - H_{PV}}, \qquad \text{(Eq. 2)}$$

where R index marks the reference PV plan (placed and measured in Szentendre) and the PV index marks the system-friendly PV plan (placed and measured in Vácrátót).

3. Test method for system-wide cost-benefit evaluation

The grid for the households with small scale power stations is currently and generally free and opened "common pasture" for everyone. However, as a pasture, a distribution network also has its limitations. The expensive solution which has been applied in Germany to take some large amount export electricity with negative price because of the growth of PV systems, there cannot be good example to follow for poorer countries. Moreover the grid-balancing problems and fears could bring aversions, what some lobbies which interested in centralized energy development can also exploit. So managing the increasing expected demands could make some negative acts with more manmade barriers. The grid systems have become a new public service task to provide inclusive services for the domestic small power stations.

The grid systems were given a new public service task to provide inclusive services to domestic small scale power stations. This means that the grid would be ideal for lossless batteries behave, and the generated energy at other times would be available. In additional only the grid operators have to take the difficulties of the direct selling of the electricity production. So it is expected that the public grid to make common pasture behaving for the producers.

The main feature of the tragedy of the commons situation is that, if the individual players seek to maximize their benefits, they can launch a process, which leads a poorer result and poorer average individual benefit without cooperation and temperance. The operational support systems usually do not take into account the decreasing common benefit. This caused by the individual interests to establish small scale PV systems with maximum electricity production. So the subsidies reward the total RES production, not the consumable production.

The value of the H index is shown in Table 2 for both the test and reference PV systems. The recognized characteristic difference, which is lower with 23% by the test system shows the test system less strain on the network and thus the possibilities are less limited to establish new PV systems in the given grid or the PV produced, but not consumed electricity could be less by the test system than the reference system.

The Ψ indicator is measurable value, which is determined during the experiment by the Vácrátót PV Plan. The indicators examined in June to determine in the most sensitive period in view of the integration effects. The 7.7 kWh/d value means that, the technical cost of 1 KW peak power cut-off by the PV test system in Vácrátót is 7.7 kWh per day in clear weather in June. This amount of power cannot be produced, because the peak power is smaller with average 23%.

Table 2: Specific peak height by test and reference PV system

H, kW/kW$_p$	**Test PV system (Vácrátót)**			**Reference PV system (Szentendre)**		
	2014	**2015**	**Average**	**2014**	**2015**	**Average**
May	0,039	0,052	**0,045**	0,053	0,064	**0,059**
June	0,037	0,042	**0,039**	0,046	0,064	**0,055**
July	0,063	0,040	**0,051**	0,069	0,049	**0,059**
August	0,045	0,036	**0,040**	0,061	0,052	**0,056**
Average	**0,046**	**0,042**	**0,044**	**0,057**	**0,057**	**0,057**

Therefore this evaluation method is suitable for a variety of installation methods and knowing the particular conditions of the local distribution grid the system-wide cost-benefit evaluation of the options of the variable installations can be compared.

4. Integration problems handling in view of a game theory approach

In Fig. 5 it is also shown that the feed in tariff policy could help to reach the grid optimized storage activity, if the small scale producer storage is expected by producer storage. So, power peaks could be reduced with various feed-in tariffs and storage requirement [5].

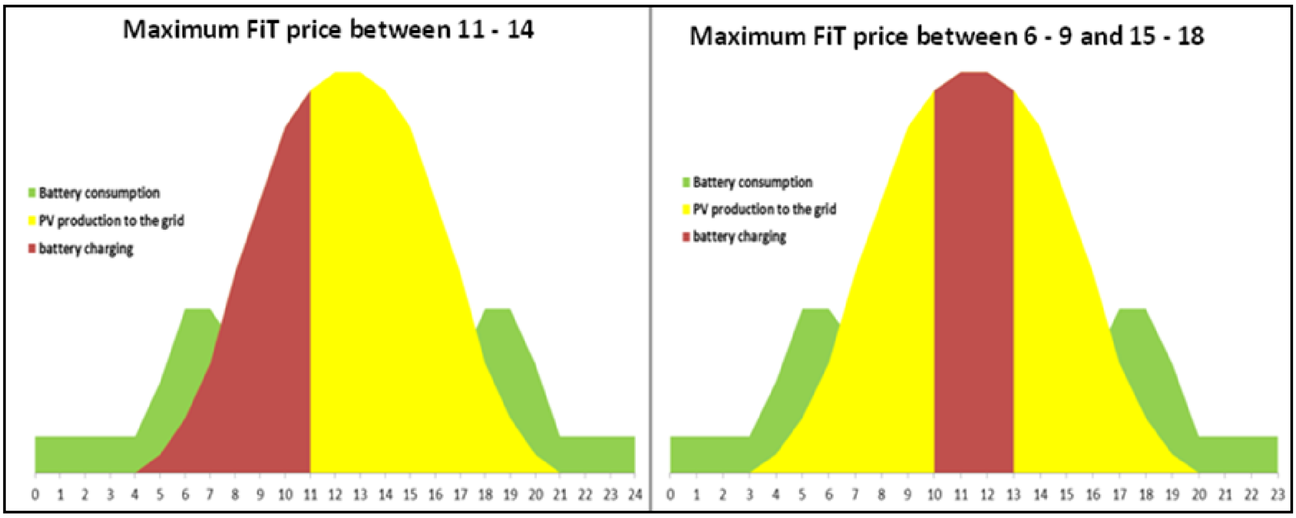

Figure 5: Feed in tariff (FiT) policy and battery strategy

The study from Fraunhofer Institute about the grid benefits says the power peak can be reduced by 40% without power losses. This means the grid could integrate 66% more small scale PV systems. Now problem is how to use installed small scale systems efficiently with grid connection. By a cost optimal control system in a grid connected systems with battery the total cost of electricity consumption mainly depends on the smart tariffs, the battery systems (initial capacity, charging efficiency, discharging efficiency) and the forecasting errors. The optimal control has a good robustness when forecasting errors are smaller than 10% [6].

So, the importance of short-term forecasts becomes determinant not only for the DSO but also for the achieving the cost optimal situation by the producer. In addition the tragedy of commons situation could be solved. For the short term forecast there are several directions of research and solution. Probably the most common is the satellite-based cloudiness monitoring models. However, new solutions could be based on error mythology between the expected and measured solar irradiation. In a rapid monitoring systems by the generated electricity from 6500 PV generators based on modeled and measured solar irradiation the difference between the expected error and the measured error reached only 8%, e.g. the yearly statistical error [7].

In Hungary a net metering system is operating, and it does not have yet any additional load fees, because the small scale PV systems' number is in the initial stage. But this idea has incurred and examined. In the case of an extra fee will be charged at only between 11 and 14 hours and small batteries will be required, the network cost can be reduced and the number of the grid-connected systems can be increased in the future.

If more and more small scale PV systems wish to connect to the distribution grid, they gradually exhaust the possibilities of the useful integration. In the first step the public grid operation costs grow and in the next these intentions increasingly strengthened, which would imposition unexpected new taxes or other fees for the PV. Therefore it could cause an unexpected decline by feed-in tariffs or premiums. Decline in installation costs of the PV systems could meet the more expensive grid costs, so the developments of new grid integration criteria by photo voltaic systems become necessary. So the expected economic return by the existing systems could be degraded while the establishment of new grid connected PV systems would be more difficult.

The situation is the same as saying by tragedy of common, in which if the number of cows to high, than would be optimal. The cows remain underweight and the social income is significantly lower than optimal. The peak load management of the distribution grid is one of the main directions of research, obviously it is suitable to reduce needlessly energy production and optimize the storage losses. The costly items extended system capacity can be increased to some point, but the situation is still remains the tragedy of common dilemma. The support schemes are basically given for all generated solar electricity without particular restriction. Therefore, the engineering design essentially become diversifying between the grid connected and autonomous PV systems (location, angle, installed a number of solar panels, etc.).

This is becoming less and less acceptable, as in the case of public utility grid systems is becoming understandable the term of the produced but not utilized energy. In case you are not at the system level thinking and designing, so the expectations based on non-complex logics the specific costs related to really useful PV produced electricity remain high or even increase further. If the produced, but not utilized electricity is high and increasing, then positive environmental sense and recognized benefits about the decentralized energy production could be compromised. Basically in context to the after 2021 nearly zero buildings obligations in European Union should approach the engineering design requirements each other between the autonomous and grid connected systems, even if it is reduced the amount of the individually producible renewable electricity.

The energy statistics often are misleading in the case of small scale systems. The produced but not utilized energy does not appear in the statistics, so the nation's political targets either. In the Hungarian energy statistics by net-metering systems only appears this production, which is more than the building's annual energy consumption. A similar mistake was in the Hungarian earlier regulation (2001-2011) by support of co-generations. The feed-in tariff was depend on a proper energy efficiency, but all produced heat, which was given to district heating network was recognized as a useful heat. So the annual network losses multiplied. This eventually led to the removal the CHP FiT support system and the share of co-generation fell by half from a high ratio. So, if the planning, legislation and support policy are not based on the really consumed energy and the regulation not look for the system-level optimum, the support policy will become unacceptable sooner or later.

The performance ratio is one of the most important variables for evaluating the efficiency of a PV plant. It is largely independent of the orientation of a PV plant and the incident solar irradiation on the PV plant. For this reason, the performance ratio can be used to compare PV plants supplying the grid. The performance ratio is a quality factor, which shows the relationship between the actual and theoretical energy production of the PV system.

The classic formula for calculation of the performance ratio is well known. This is the ratio of the Actual annual output of the system [kWh] and the calculated annual nominal output [kW/h]. On the other hand, if we design or regulate on a whole system level, it is recommended to use a modified PR (PRnet) factor instead of the classical PR factor, where the PRnet is the ratio the differences of the actual annual output of the system [kWh] and losses due to the distribution grid overload [kWh] and the calculated annual nominal output [kW/h].

In this case, the losses due to the distribution network overload consist of three factors:

- regulatory losses,
- storage losses (by together the producer and the DSO storage losses),
- not accepted energy production (DSO shutdown).

The solutions of the tragedy of the commons are based on the system level interpretation, so we should use the indicator of the electricity produced from grid connected PV systems, but not utilized energy. This is by the design of autonomous systems is already the case, because of the large amount of unnecessary, unutilized electricity production could give very high investment costs.

Integration of photovoltaic systems in distribution networks in two main ways: By the first way the conditions of the new PV connections become more rigorous and expensive. However, unique benefits of the existing systems can be reduced. Because of the increasing costs of the distribution network level the FiT reduction or new connection fee could be required sooner or later, so the expected returns would be not available. If the economic returns may be unstable, it will barrier to the further development.

By the alternative way the cooperative behavior to force by new grid connected small scale systems also by design, establishment and support policy. So some basic requirements may require by new installations

1. Regarding the tilt angle of installation it should not optimize to the maximum annual production, but should strive for greater tilt angles;
2. Greater promotion or support by the building integrated systems and support priority for the façade installed integrated systems.
3. Small scale demand-side solutions should be rewarded (coordinating between more consumers and small scale electricity producers).
4. For a small scale solar panel system can be maximized the allowed connected capacity which could depend on the consistency with the relevant low voltage distribution network consumption and the annual electricity consumption by the specific building or some small smart grid.

The calculated annual nominal output in Hungary by 30 tilt angles and a 1 kWp photovoltaic plant is generally about 1500 kWh/year. This value is 1390 kWh/year by 60 tilt angles. In the case where the produced energy is taken over unconditionally, obviously better choice the greater amount of energy production [8].

The greater amount of energy could be produced between March and October in the case of a 60 tilt angle. By 30 the summer surplus is significant. However, if the distribution network will be overloaded this surplus could be lost as a produced but not utilized energy. In system approach it is more important the greater energy production in winter and the balanced production in summer, so the 7,3% less annual production could mean more cheaper balancing cost and more useful production. The optimal tilt angel by grid connected PV systems also depends on the local grid conditions. In many situation is possible, but the variable electricity prices periodically change the optimal tilt angel [9].

To be a truly control for the really useful electricity productions rewards the continuous measurements required. The making studies and analyzes about the benefits of smart metering across the Europe are underway or completed based on cost-benefit methods. The main task is mainly the changing of consumer attitude, but less attention focused on the renewable energy integration. The data from 15 minutes smart measurements could allow to rethinking the basis of the feed-in or net metering policies.

Through the use of the possibility offered in Article 10c of the EU ETS Directive (hereinafter: “10c Support Mechanism”), Hungary establish a national smart grid pilot project. The main focus of the smart grid pilot project is to establish smart grid functions for the electricity and gas networks by creating and testing measurement solutions, data collection and other smart grid applications. The integration of small scale distributed generation and the finding the policy for sustainable and competitive support for renewable energy generation are one of the main tasks of this Pilot Project.

5. Conclusions

"The tragedy of the commons" could be interpreted by examining the long-term prospects of the low-voltage distribution systems and small scale solar panels. In view a long-term horizon and the entire decentralized system it can be examining to prevent or reduce more of the future grid-problems, so the network losses, the storage losses, or the losses because of the temporary shutdown systems and the necessary network development costs can be reduced. The development of decentralized energy production systems should be made in accordance with the decentralized energy consumption. This can provide the centralized and decentralized power plants long-term harmony, which could be regarded as a key factor of the competitiveness of the economy and the social well-being.

The installed smart meter by PV systems could allow the use of smart tariffs. This is important to produce a more balanced electrical energy and reach less distribution loss from the generated electricity. The local conditions and taking into account the local potential give systemic optimum. If the goal is not to maximize the electricity production, but also produce the more utilized electricity production, it should use the think the system-level optimum by the design of the PV system and the public should be motivated by incentives. The smart tariff is an essential tool for this

Difficulties and barriers could arise by the development of renewable energy due to game theory reasons. The responsibilities of finding of the solution are not only the engineers. Necessary to co-operate to other disciplines as well.

References

[1]. Masson, I. G. (2014): Overview of current market trends for PV systems, Solar Electricity Roadmap Workshop, Paris.

[2]. Masson, I. G. and Brunisholz, M. (eds) (2015): A Snapshot of Global PV (1992-2015), Report IEA PVPS T1-29:2016, ISBN 978-3-906042-42-8.

[3]. IEA International Energy Agency (2015): Trends 2015 in Photovoltaic applications executive summary, Report IEA-PVPS T1-27:2015, p. 7. http://www.iea-pvps.org/index.php?id=92 (downloaded: 05.07.2016)

[4]. Hardin G. (1968): The Tragedy of the Commons, Science, New Series, Vol. 162, pp. 1243-1248.

[5]. German Solar Industry Association (2014): PV GRID European advisory paper, Final report of the European Project PV GRID, p. 52. http://www.pvgrid.eu/news/news/news-details/article/pv-grid-final-report-is-now-available.html (downloaded: 04.06.2016).

[6]. Wu, Z and Xia, X. (2015): Optimal switching renewable energy system for demand side management, Solar Energy, 114, pp. 278-288.

[7]. Colantuono, G, Everard, A., Hall L. M. and Buckley, A. R. (2014): Monitoring nationwide ensembles of PV generators: Limitation and uncertainties. The case of the UK, Solar Energy 108, pp. 252-263.

[8]. Pálfy, M. (2006) The photovoltaic solar energy utilization in Hungary, Hungary renewable energy potential, Hungarian Academy of Sciences, Committee on Energy, Renewable Energy Subcommittee, pp. 32-52. http://fft.szie.hu/mnt/MO%20megujulo%20energia%20potencialja%202006.pdf (downloaded: 04.06.2016)

[9]. Rhodes, J. D., Upshaw, C. R., Cole, W. J., Holcomb, C. L. and Webber, M. E. (2014): A multi-objective assessment of the effect of solar PV array orientation and tilt on energy production and system economics, Solar Energy, 108, pp. 28-40.