Voltage Problems Causes and Effects in Grid Connected Photovoltaic systems in Turkey

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***Abstract*—The usage of the Photovoltaic (PV) power systems has been increased dramatically, due to the abundant of the solar irradiation, and the government incentives everywhere. In most of the developed countries, the standards for connecting the PV systems to the grid has been set and is already applied. The incentives and regulations that supports PV systems are increasing day by day in Turkey. Because of this regulations more and more PV systems are connecting to the grid. Such high penetration of the PV systems in the distribution network leads to voltage disturbances. This paper studies the causes and effects of the voltage problem and proposes the best solutions to; mitigate the voltage disturbances and increase the distribution network stability.**

***Index Terms*—Grid connected Photovoltaic systems, Power electronics, Voltage problem, Feed in tariff, net metering.**

I. Introduction

The usage of PV Systems have increased greatly in the recent years due to it's advantages including; plenty of abundance, low operational costs, nil emission of carbon dioxide, as well as low maintenance costs [1]–[3]. Few years ago, in some European countries, the proportion of energy produced from PV Systems, reaches up to 50% during some seasons [4], [5]. Recently the sector of PV solar system is growing rapidly in Turkey [6]–[8]. The Feed in tariff mechanism introduced in 2010, was targeting to reach up to 30% share of the electrical grid covered from renewable energy by 2023 [6], [9]. However, after 10 years from that regulation Turkey have more than 46% of the grid covered from renewable energy resource as announced by the minister last year [10]. The portion of the solar energy is 3.4% nowadays and it is expected to grew due to the two solar regulations newly announced in Turkey. The first on is, the large and mini Renewable Energy Resources Zones (YEKA) [10] introduced in 2017, while the second one is, the grid connected rooftop net-metering systems [11] introduced in 2019.

The high penetration of the PV systems in the distribution network may leads to; frequency deviation, circulating reactive power, reverse power flow, and high voltage problem in transmission lines [3], [5], [12], [13]. These issues become more sever when the PV systems connected to the low voltage distribution network, which is the case for all rooftop PV system regulation introduced in 2019 [5], [11], [14]. This paper is studying the causes of high voltage problem in grid connected PV systems and analyzing the effects of such problem with proposing the best practices for Turkish energy market.

II. Grid Connected PV Systems

Most of the PV projects are connected to the low voltage distribution network in Turkey. The projects have to be connected to the grid to avoid the battery installation and to be able to get the government incentives. In order to investigate the feasibility of any PV solar project the return on investment (ROI) - as a financial indicator - has widely been used [15] for this purpose. The regulations introduced by the Turkish government in 2010 for the grid connected PV project are summarized in the table I [6], [9]. The FiT in Turkey is 0.133 USD per each kWh injected to the grid. And there is a distribution network usage fee which is about 0.028 USD/kWh. In addition to these FiT, the government is giving bonuses for each PV system using the local manufactured equipment shown in the table I. These amount of bonuses will be added to the basic FiT of 0.133 USD/kWh. The bonuses are valid for only the first 5 years of operation.

TABLE I
Feed in Tariff and bonuses from the government in Turkey For PV projects

Item	**Amount (USD)**
Payment from Government per kWh	0.133
Distribution network usage fees (19.38 kr/kWh)	0.028
Bonus of PV panel integration and solar structural mechanics production	0.008
Bonus of PV modules	0.013
Bonus of Cells forming the PV module	0.035
Bonus of Inverter	0.006
Bonus of Material focusing the solar ray	0.005

For the rooftop systems regulation introduced in May 2019 [11] the real persons or legal entities can install PV solar system up to 5 MW without any requirement to obtain a license. The installation can be rooftop, facade installations and ground-mounted with the condition not to exceed contract power of the consumption facilities. Due to these regulations, high amount of PV systems will be connected to the low voltage distribution network. This will lead to high voltage problem. The grid connected PV system shown in Fig. 1 illustrate the DC DC converter and DC AC inverter required to regulate the voltage at the connection point. The inverter and converter represent the power conversion system which is responsible for controlling the parameters and regulating the voltage and the frequency.

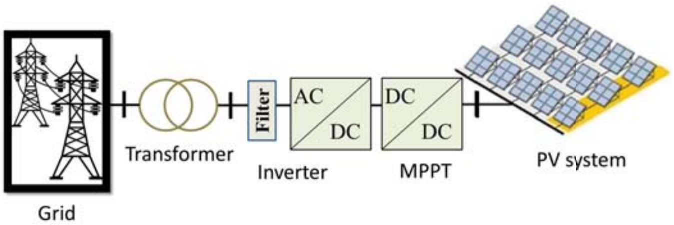

Fig. 1. Grid connected PV system with the power conversion system.

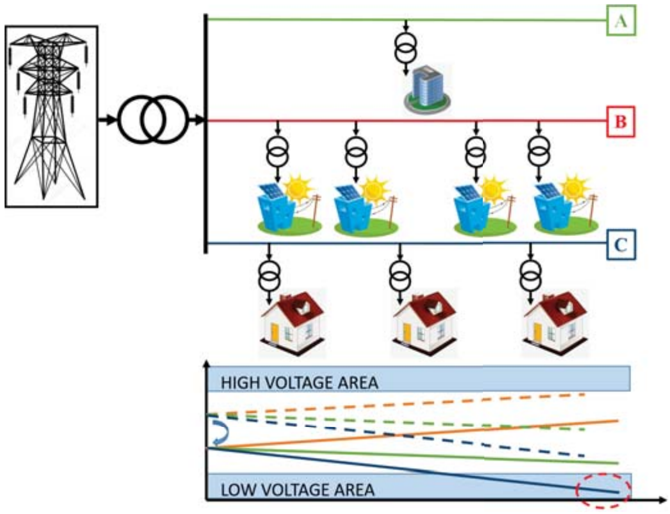

Fig. 2. Distribution network during high penetration of PV system at one of the phases.

III. Voltage issues causes, effects and solutions

An example for a high penetration of PV systems connected to the distribution network is shown in Fig. 2. In the low voltage side each phase is supplying a cluster of homes in the three phases A, B and C. Phase A the - green line - is in the acceptable zone of the voltage's value. However, for phase B a lot of homes installed PV systems which generates high voltage issue in this phase. On the other hand, in the phase C there are high consumption with no PV installations which will lead to low voltage problem. For the high voltage in phase B, when the generated active power injected to the grid the high voltage problem may lead to the tripping of the inverters and the loss of the income that may generate from the government incentives (such as FiT).

According to the regulation of grid connected PV solar system in Turkey, in case of the system's failure, it must be disconnected from the grid for the safety of the lives and property. When such problem occurred there are two types of solutions can be implemented:

1) Active Methods
   - Inject or absorb the reactive power,
   - Active power curtailment.
2) Passive Methods
   - Tap changer to increase or decrease the Voltage,
   - Adding local load,
   - Distribute the PV source over the phases.

In the active methods, the controller that inside the inverter of the PV system is changing the phase shift to generate/absorb reactive power. Or in case of the power curtailment the controller is cutting the injection of the active power that exceeding a preset level which will lead to the stabilization of the voltage. However in the passive methods, a physical changes in the systems have to be done to stabilize the voltage in the distribution network. This solution can be more difficult to implement.

In the cases above, the reactive power controller (Active Method) fixed the dc reference voltage (V_{ref}). To achieve robust voltage regulation via reactive power controlling strategy, the reactive power injected to the Point of common cabling (PCC) from the PV source has to be calculated carefully. The below equation shows the required amount of reactive power to regulate the voltage (1):

$$Q = V_{alcl} \frac{V_{af} - V_{bf}}{X_{\Delta}} \quad (1)$$

Where Q is the injected reactive power during voltage sag, V_{af} RMS line-to-ground voltage after the filter (see Fig. 1), V_{bf} RMS line-to-ground voltage before the filter and X_{Δ} is the reactance between V_{bf} and V_{af}. From (1) if V_{bf} is equal to V_{af}, reactive power generation is zero. In order to get the desired V_{bf} at the outputs of the inverter, the dc voltage V_{dc} is calculated based on the equation (2):

$$V_{dc} = \frac{V_{bf} * 2 * \sqrt{2}}{\sqrt{3}} \quad (2)$$

Where V_{dc} is the dc voltage at the DC side of the inverter which has to be higher than the peak value of the V_{af}.

Fig. 3 shows the voltage at phase B after connecting any disturbance such as extra load, the voltage became 208 v. This representing the case of implementing any of the passive methods mentioned above. However if an active method implemented the voltage drops for few (ms) as shown in Fig. 4, then the controller will be able to regulate it back to the rated values. Fig. 4 shows the voltage drops to 141 v at 0.1 s then return back to 220 v at 0.5 s.

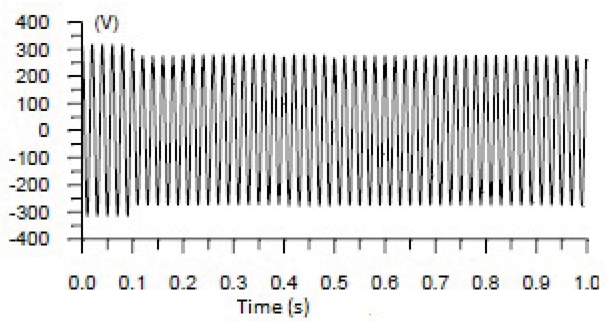

Fig. 3. Voltage at phase B after connecting a load.

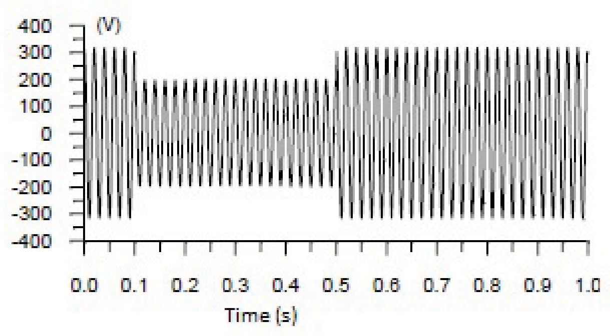

Fig. 4. Voltage at phase B after enabling active method.

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IV. CONCLUSION

This paper studied the PV solar projects incentives in the Turkish market. It explained the FiT mechanism and the net metering technique for rooftop PV system. The paper summarized the causes and effects of the voltages problem and the active and reactive methods that can be used to mitigate the voltage problems. The paper shows that the superiority of the active methods over the passive methods because of it's capability to regulate the voltage during different types of disturbances. For the growing PV market in Turkey, it is highly recommended to propose a new grid code that allows for the PV systems' owners to inject/absorb reactive power that contribute to the stability of the distribution network.

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