THE EFFECTS OF HARMONICS PRODUCED BY GRID CONNECTED PHOTOVOLTAIC SYSTEMS ON ELECTRICAL NETWORKS

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ABSTRACT

Photovoltaic (PV) systems use inverters to get connected to distribution networks that utilize alternative voltage. However, harmonic currents generated by PV systems may downgrade the quality of the electrical network and alter performance of other electrical equipment. In this paper, we investigate the effects of harmonic distortion on electrical networks, depending on the location and the number of the Photovoltaic systems, using Pspice simulation program.

I. INTRODUCTION

Nowadays, the use of grid connected Photovoltaic (PV) systems has become popular in many parts of the world. A large number of grid connected PV generators connected to a distribution network through PV inverters are potentially able to cause harmonic problems.

In general, a harmonic problem can be defined as a particular disturbance, which is created by the presence of non-linear components in the electrical system that determines a permanent modification of the voltage and current sinusoidal wave shapes in terms of sinusoidal components at a frequency different from the fundamental.

In this study, using real data and a simulation program on a computer, harmonic problems in grid connected PV systems have been investigated.

In a grid-interconnected photovoltaic power system, the direct current (DC) output power of the photovoltaic array should be converted into the alternating current (AC) power of the utility power system. Under this condition, an inverter to convert DC power into AC power is required. Various types of inverters are shown in Figure 1. A line commutated inverter uses a switching device like a commutating thyristor that can control the timing of turn-on but cannot control the timing of turn-off by itself. Turn-off should be performed by reducing circuit current to zero with the help of a supplemental circuit or a source. Conversely, a self-commutated inverter is characterized in that it uses a switching device that can freely control the ON-state and the OFF-state, such as an IGBT or a MOSFET. A self-commutated inverter can freely control the voltage and the current waveform at the AC side, adjust the power factor, and suppress the harmonic current, and is highly resistant to utility system disturbance. Due to advances in switching devices, most inverters for distributed power sources such as photovoltaic power generators now employ self-commutated inverters.

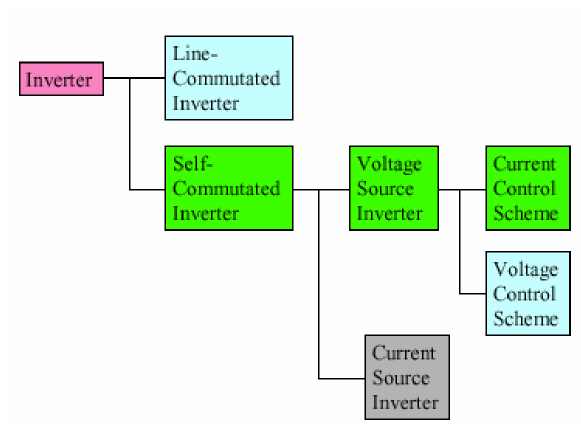

Figure 1 Classification of inverter types.

In a study to investigate the effects of harmonics on the electrical network in Braedstrup, Denmark [5], 60 PV panels have been installed on 29 houses. Each of panels had power of 1 kW_p and the composite capacity of the PV installations at the neighbourhood totaled 60 kWpeak which was 30% of the feeding transformer's rated capacity. The expected contribution to the voltage distortion from the neighbourhood was in the range of between 0.25-0.65%. However, the voltage distortion measured for the neighbourhood was 1-3%. Hence, it was concluded that the most important part of the voltage distortion in the neighbourhood came from external sources. At the same time the most significant part of the current harmonics produced in the neighbourhood was caused by TV sets and only to a limited extent by the PV installations. This conclusion is also confirmed by measurements realized at individual consumers with PV installations where no differences in the voltage distortion of phases with and without energy produced by the installations had been detected.

Another study about harmonics was done by IEA in Rokko Test Center, Kobe, Japan [2]. Five 2 kW PV systems were connected to the same phase of the secondary side (single-phase, three wires) of the 30 kVA pole transformer. The test was carried out under a no-load condition to remove the effects of a harmonic current from loads. The photovoltaic power generation systems were successively (at 1-second intervals) disconnected from the operating state, while the harmonic distortion at each location was measured continuously. When the measurements were done, it was observed that the rate of harmonic current increase was not necessarily proportional to the increase in the number of connected units.

Sydney Olympic Site, Australia was also an interesting site to study the effect of a large number of grid connected PV systems on the quality of supply of the utility systems [4]. The solar village consisted of up to 665 homes. Each of the 665 homes had 1 kW_p of photovoltaics on the roof connected to the local underground low voltage grid via an inverter. The results of the measurements from the Sydney Olympic Village showed that harmonic voltages (1.9%) at the Olympic Village were far below IEEE 519-1992 limits even after the operation of all PV inverter systems in the solar village.

Another study has been done in two small Greek islands (Arki and Antikythera) where Photovoltaic Stations (25 kW_p) were installed [6]. Inverters of Photovoltaic Stations were used to measure the harmonic voltages and currents. It was shown that the harmonics injected by the Photovoltaic Stations to the electric grid were not very high (1.25% - 1.99% for Antikythera and 1.85% - 5.30% for Arki) and at most cases they could not cause significant problems to the appliances of the customers.

II. SIMULATION

In the simulation of circuit, it is assumed that only house loads are present in the network. The number of the houses is chosen as twenty and they are fed with mono phase low voltage grid of a 50 kVA transformer. The houses are designed as a circuit of resistive and inductive components (R - L) which connected to the grid in parallel. The loads of houses in the circuit are presumed to be equal. Voltage, current, and power (active, reactive, and total) at a house in Gumuldur, in Izmir, Turkey have been measured at 10 a.m. in the morning since the PV systems inject the power into the grid during the daytime. From the measurements, the resistance (128 Ω) and inductance (243 mH) are calculated.

The transformer, which is used in the simulation circuit, is assumed to be linear. A 33/0.4 kV - 50 kVA transformer in the warehouse of Türkiye Elektrik Dağıtım Anonim Şirketi (TEDAS, Electricity Distribution Joint Stock Company of Turkey) Manisa branch has been measured to find the inductance value (to use in simulation program) of the windings (primer and seconder sides) of it with the help of a RLC meter.

The inverter [1], whose normalized harmonic spectrum and Total Harmonic Distortion values are given in Table 1, is used in the simulated circuit. Moreover, in the grid, there are not any other harmonic sources except the inverters of PV systems. In addition, it is assumed that inverters used in simulated circuit have the same harmonic values.

Table 1 Inverter current harmonics (Normalized to Fundamental) and its THD value.

Harmonic order (n)	% (In / I1)
1	100
3	1,5
5	0,6
7	0,3
9	0,4
11	0,21
13	0,2
THD	**1,7**

It is presumed that some houses have the PV systems of 2 kWp and so that the effective current of the inverter can be calculated as 9 Ampere. This value is adjusted to Table 1 and the result is shown in Table 2. Using the values in Table 2, each harmonic of the inverter is modelled as a current source. Thus, an inverter consists of seven current sources in the simulation circuit.

The wire used in the modelled circuit is a Rose aluminium conductor, which is used in overhead power lines in low voltage grid in Turkey. The wire is used to feed the group of houses in Figure 2. Each group consists of four houses and there are five groups of houses with distances among them as 40 meters. According to the distances, the resistance and inductance of the wire are found as 54 mΩ and 0.043 mH, respectively.

Table 2 Inverter current harmonics.

Harmonic order (n)	In (A)
1	9
3	0,135
5	0,054
7	0,027
9	0,036
11	0,019
13	0,018

Using values mentioned above, and changing location of inverters in the modelled system, fifteen different circuits are simulated and analyzed. The limit of total harmonic distortion is taken as 5 % in all circuits. The single line scheme of the modelled system is shown Figure 2.

III. SIMULATION RESULTS

When the circuit is examined from the point of view of harmonics, the total harmonic distortion of voltage is increased specifically when the inverter is close to the end of the line. However, these voltage harmonic distortions (0.075%) are far below the IEEE 519-1992 limits (5%) because the system chosen is close to the ideal electrical system in terms of the quality of energy. Increase in the number of PV systems causes voltage rise in the distribution line, particularly at the ends. In addition, current harmonic distortions increase when the number of inverters increases but do not exceed the limit of 5% (1.96%).

IV. CONCLUSION

According to the results of the simulation, the harmonic distortion generated by PV generators is below the standards in a distribution network which has only house loads. Moreover, if the Photovoltaic generators are located near the transformer, the harmonic distortion becomes even lower. In addition, installing Photovoltaic systems close to the transformer helps to control voltage rise in the distribution lines.

Inverters used in the simulation circuit affect the harmonic levels, so their quality properties are important for the grid. For example, using an inverter [3] whose harmonics are higher than the inverter we examined here, the current harmonic distortion changes between 7% - 16% in the simulation. This result shows that inverters to be used in PV systems should be chosen carefully.

In future work, we should investigate the effects of harmonics produced by grid connected Photovoltaic systems in the simulated circuits in which consist of different types of inverters, loads, and systems.

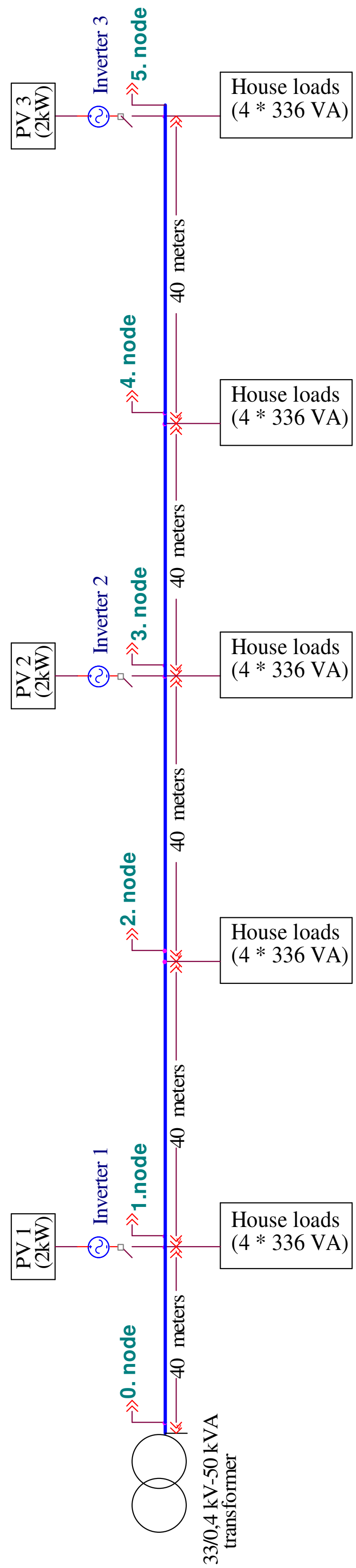

Figure 2 Single line scheme of the modelled system.

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