Impact of PV Type Dispersed Generation on Harmonic Distortion on Distribution Networks

Martina Korlevska[1], Metodija Atanasovski[2], Mitko Kostov[2], Ljupcho Trpezanovski[2]

Abstract – **This paper investigates PV power plants impact on harmonic distortion in distribution network. Namely, the paper summarizes the problems with harmonics introduced in the network from inverter-based generation units, especially PV dispersed generation units mostly connected on distribution networks. The problem of filter dimensioning is also addressed in the paper. Real case study of distribution network feeder is analysed with two scenarios with and without filtering of inverter unit. PV power plant of 1 MW is connected on the feeder. Total harmonic distortion is calculated for each node in the network with and without filtering. Filter dimensioning calculation is elaborated and results for two scenarios are presented.**

Keywords – **PV, Harmonics, Distribution systems.**

I. Introduction

The increased presence of renewable energy sources (RES) in distribution systems as part of dispersed generation (DG), changes the overall concept of network operational and planning issues. Nowadays, distribution system operators and planers are challenged with a great number of requests for network integration and connection of different RES, especially photovoltaic (PV) units. Namely, total distribution management technical and economic functions are affected from increased presence of RES. PV units are especially challengeable for power quality issues. One of the problems with power quality caused by PV units are harmonics. Inverters used in PV power plants are main source of harmonics. The harmonic distortion is phenomena that occurs when the shape of current and voltage exceeds the standard sinusoidal form. This type of distortion generates existence of current and voltage components with higher frequencies than the basic one. This phenomenon produces overheating of distribution transformers, operational interruptions of electronics devices and appliances and resonance of capacitor banks for reactive power compensation. The amplitude and the level of current harmonics depends from the type of the inverter and its operational state. There are filters that reduce the impact of harmonics and the harmonic distortion level on acceptable level for the distribution network. The acceptable level of harmonic distortion is defined in specific power quality standards as in [1]. The filters for harmonics reduction and elimination can be active and passive.

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This paper summarizes the problems with harmonics introduced in the network from inverter-based generation units, especially PV dispersed generation units mostly connected on distribution networks. The problem of filter dimensioning is also addressed in the paper.

Real case study of distribution network feeder is analyzed with two scenarios with and without filtering of inverter unit. PV power plant of 1 MW is connected on the feeder. Total harmonic distortion is calculated for each node in the network with and without filtering. Filter dimensioning calculation is elaborated and results for two scenarios are presented.

II. Problem of Harmonics and Filter Dimensioning

Basic sources of harmonics are computers and electronic devices, converters, inverters, PV grid inverters, arc furnace, switching equipment etc. The harmonic characteristics depend on the type of the source equipment. Fig. 1 depicts current distortion caused by presence of variable resistance (nonlinear resistor) in the circuit. It is obvious that the voltage and current wave shape are different. The input voltage is with regular sinusoidal wave shape, while the current is distorted from the regular wave shape. The increase of voltage in few percent can produce double increase of the current and different wave distortions different from regular sinusoidal shape. This phenomenon represent harmonic distortion in power systems [2].

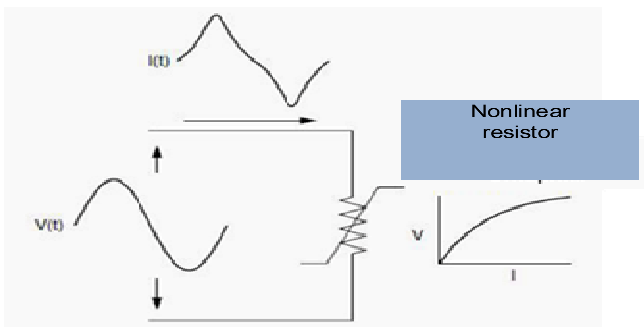

Figure 1. Current distortion caused by nonlinear resistor

Fig. 2 illustrates that any periodic (distorted) waveform can be expressed as a sum of sinusoids. This is a case, when the distorted waveform is identical from one cycle to the next and it can be decomposed as a sum of pure sine waves with integer multiple frequency of the fundamental frequency of the source-distorted waveform. The decomposed outputs form a new Fourier series in which only magnitudes of the

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harmonics are of interest. The Fourier series is a sum only of odd harmonics, if the positive and negative half-cycle of a wave shape are identical.

Harmonic presence in a waveform is commonly represented with a single number called total harmonic distortion (THD) [2]:

$$THD = \frac{\sqrt{\sum_{h=1}^{h_{max}} M_h^2}}{M_1} \quad (1)$$

where M_h is the rms value of harmonic order h of the quantity M.

Three phase inverters have found wide usage in applications where amplitude and frequency regulation of output sine voltage is necessary. The mostly used method of amplitude and frequency regulation of inverter output voltage is with application of sinusoidal pulse wide modulation [3].

Three phase inverters are mostly used as network interface device at PV power plants. The connection of PV modules with the inverters can be realized in four configurations: with central inverter, inverter in each string (series), combination of chopper at each string with central inverter, or smaller individual inverter on each module. The mostly used configuration in practice is with central inverter [3].

Fig. 3 depicts the current waveform in p.u. of 4x250 kW inverters in 1.0 MW PV power plant without filtering. Fig. 4 summarizes the presence of harmonics currents of the grid inverter in percentage of its rated current.

Passive harmonic filters are elements constructed of inductance, capacitance and resistance. They are relatively inexpensive compared to other means for elimination of harmonic distortion, but they have the disadvantages of potential adverse interactions with the power system. With appropriate tuning of elements to create resonance at selected harmonic frequency, passive filters can eliminate harmonics or block harmonic flow between power system parts [2].

Basic passive filter configuration is depicted on Fig. 5. Filter dimensioning and tuning is performed slightly below the harmonic frequency of concern. Filter on Fig. 5 will be designed for the fifth harmonic, since this harmonic in harmonic spectra presented in Fig. 4 is dominant. The capacitor power bank will be with rated power of Q_c=500 kvar. Since, the rated voltage of grid inverter is U_n=400 V, the capacitor reactance in the filter will be calculated as follows:

$$X_c = \frac{U_n^2}{Q_c} = \frac{400^2}{0.5} = 0.32\ \Omega \quad (2)$$

Filters are tuned lower than the frequency of harmonic to be filtered to provide a margin of safety in case there is some change in system parameters. Fifth harmonic filter will be tuned with factor 4.7 or frequency 4.7x50=235 Hz (250 Hz is frequency of the fifth harmonic). Filter reactor reactance will be:

$$X_R = \frac{X_c}{n^2} = \frac{0.32}{4.7^2} = 0.0145\ \Omega \quad (3)$$

The tuning performance of the filter is measured with quality factor, which is a measure for sharpness of tuning and for series resistance of the reactor can be calculated as:

$$Q = \frac{n \cdot X_L}{R} \quad (4)$$

where n is the tuning factor of the harmonic, X_L is the reactance of reactor at fundamental frequency and R is series resistance of the reactor.

The THD of the supply voltage, according to [1] (including all harmonic up to order 40), shall be less than or equal to 8%.

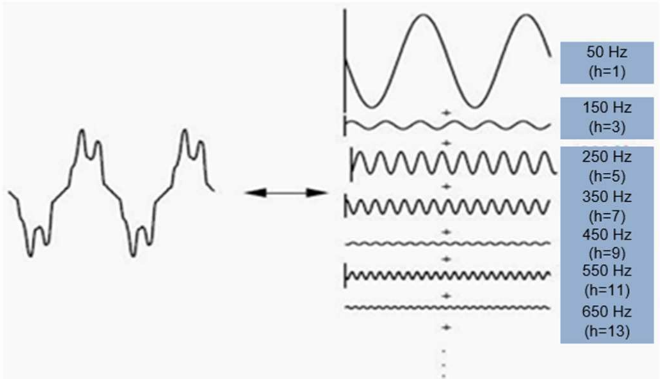

Figure 2. Fourier series decomposition of a waveform

Figure 3. Output current in p.u. waveform of 4x250 kW inverter in 1 MW PV power plant without filtering

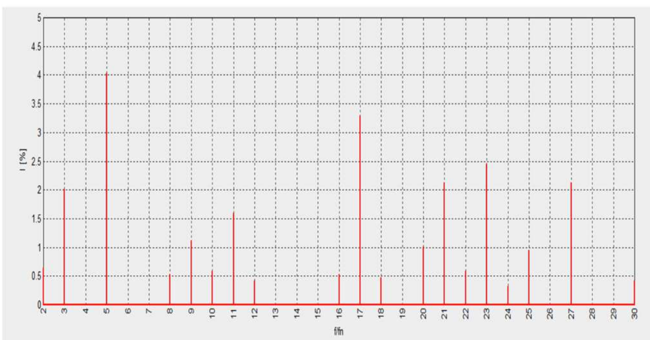

Figure 4. Harmonics presence as a % of rated current of 4x250 kW inverter in 1 MW PV power plant without filtering

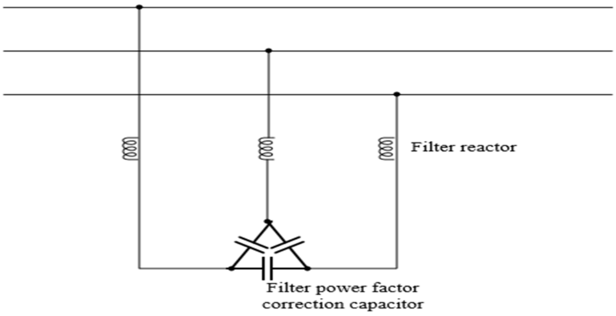

Figure 5. Basic filter configuration

III. CASE STUDY

Analyzed distribution network (Fig. 6) is radial and network model is developed in NEPLAN 5.3.5 (Faculty of Technical Sciences Bitola has educational and research license of NEPLAN 5.3.5). The distribution network is supplied from power station 35/10 kV/kV with one transformer 4 MVA. The distribution feeder is consisted of 11 nodes with 6 transformers 10/0.4 kV/kV. PV power plant (PV low voltage node) is connected on 10 kV node J4. Total installed power of the PV is 992 kW. PV is consisted of 4 central inverters with 250 kW rated power each, connected with 2 transformers 10/0.4 kV/kV of 500 kVA [4, 5].

Simulations are performed for two scenarios:

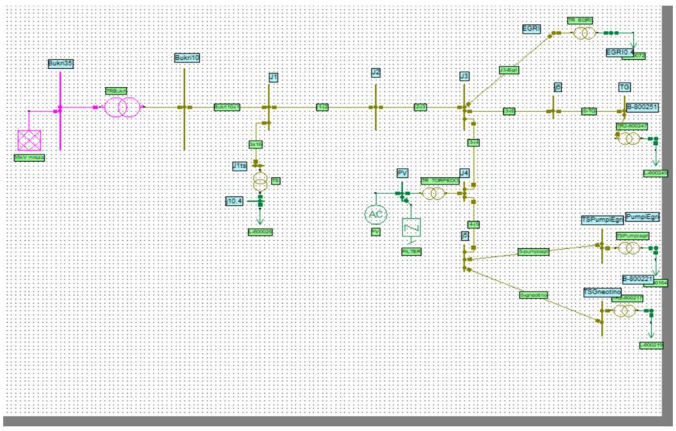

Fig. 6 Analyzed distribution network with PV power plant

1) Calculation of THD per node and harmonic voltages as a percentage of nominal voltage when the filter (Fig. 6) is not connected;

2) Calculation of THD per node and harmonic voltages as a percentage of nominal voltage when the filter (Fig. 6) is connected. The scenario with filter is simulated with filter for 3rd harmonic, 5th harmonic and 7th harmonic, separately.

Table I summarizes calculated THD for some of the nodes in the network for the analyzed scenarios. The improvement in THD is evident as the order of the filter harmonic is increased. THD is higher at nodes close to the PV and lower at nodes electrically far from PV. It is obvious that harmonics problem is not exported to 35 kV network, since the THD for node Bukri35 even without filter is 2.81%. It is evident that application of filter for 5th harmonic resolves the problem with harmonic distortion in the network and THD in all nodes is lower than the acceptable limit of 8% according to [1].

TABLE I

THD IN % FOR NETWORK NODES

Scenario / Node	Without Filter	With Filter 3rd harmonic	With Filter 5th harmonic	With Filter 7th harmonic
	THD (%)	THD (%)	THD (%)	THD (%)
PV	21.04	15.44	6.44	3.00
J4	17.26	13.06	4.94	2.09
TG	18.15	13.84	5.15	2.13
J1	11.13	8.45	3.17	1.32
Bukri10	10.68	8.11	3.04	1.27
Bukri35	2.81	2.14	0.80	0.33

Figures 7-9 depict the current waveform for one full period (20 ms) of the PV (or transformer TR_TORPEDO) after filtering. This current sinusoidal waveform with filtering from Figs. 7-9 can be compared with PV current without filter depicted on Fig. 3. It is obvious that when a higher harmonic filter order is used the current waveform distortion is eliminated. Practically ideal sinusoidal waveform is achieved with a filter of 7th harmonic.

Figure 7 Current of the transformer TR_TORPEDO (2x500 kW) with filter of 3rd harmonic

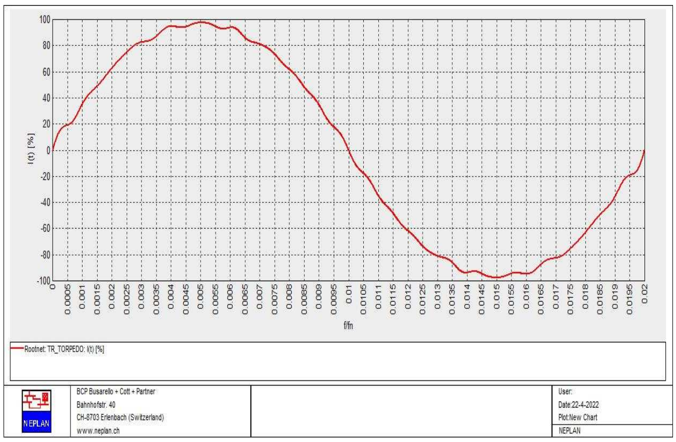

Figure 8 Current of the transformer TR_TORPEDO (2x500 kW) with filter of 5th harmonic

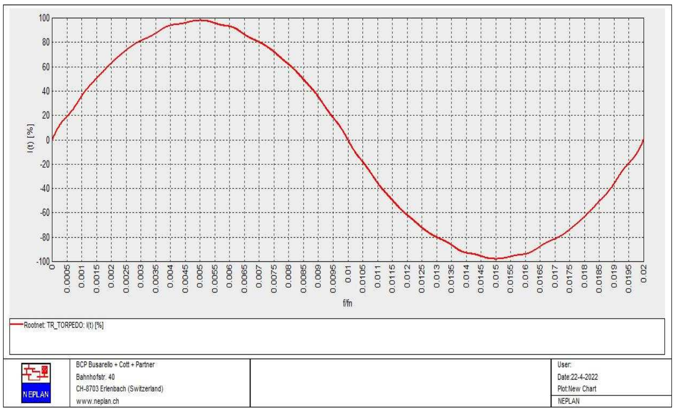

Figure 9 Current of the transformer TR_TORPEDO (2x500 kW) with filter of 7th harmonic

Figures 10-12 illustrate the harmonics voltage in (%) of nominal voltage for PV node with 3rd, 5th and 7th harmonic filter appropriately. They can be compared with Fig. 4 for the scenario without filtering. It is obvious that with higher harmonic filter the harmonic presence in (%) at the voltage decreases.

IV. Conclusion

The paper presents useful detailed analysis of PV type dispersed generation impact on harmonic power quality problem in distribution network. Sinusoidal PWM offers a technique called selective harmonic elimination, meaning that the power electronic pulses can be configured as to avoid certain harmonics generation. Passive filter dimensioning process is well elaborated, as one of the most simple and economic efficient measures for harmonic elimination. Passive harmonic filters are not tuned deliberately exactly to the harmonic frequency of interest to offset for system parameter change and to offset for aging of the filter components. The case study has shown that for achieving standard limits fifth order harmonic filter is sufficient.

Acknowledgement

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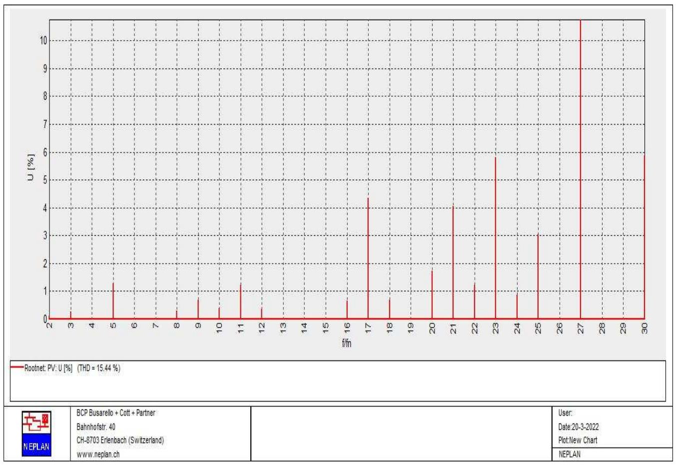

Figure 10. Harmonic voltages in (%) of nominal voltage for PV node with 3rd harmonic filter

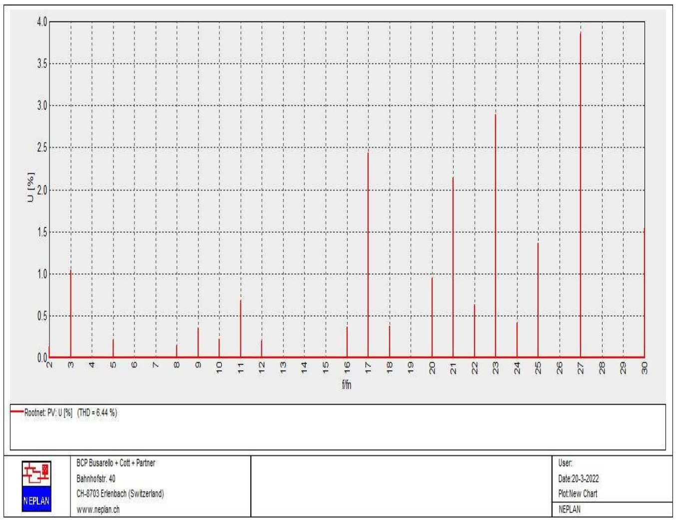

Figure 11 Figure 10. Harmonic voltages in (%) of nominal voltage for PV node with 5th harmonic filter

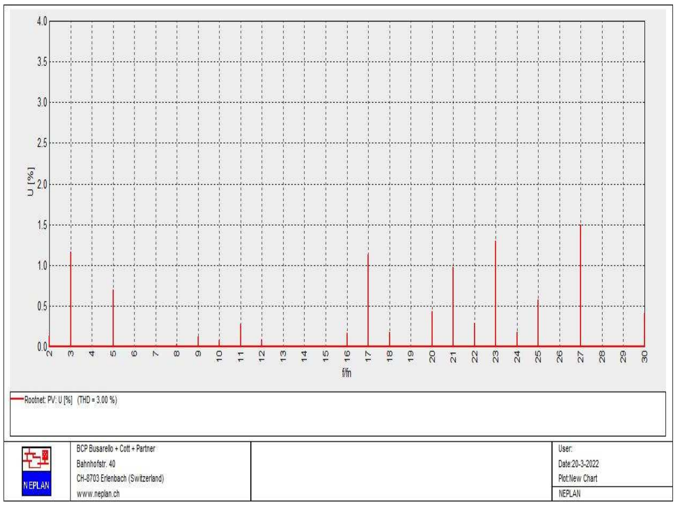

Figure 12 Figure 10. Harmonic voltages in (%) of nominal voltage for PV node with 7th harmonic filter

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