EVALUATING EMISSION AND IMMUNITY OF HARMONICS IN FREQUENCY RANGE OF 2-150 KHZ CAUSED BY SWITCHING OF STATIC CONVERTOR IN SOLAR POWER PLANT

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ABSTRACT

By increasing spread of DGs connected to the distribution networks, the use of power electronic devices and static converters for integration of these types of resources to low voltage feeders has been significantly grown. The static convertors are the new technology for efficient and flexible connection of DGs to the networks. Due to the switching frequency of the static converters used in DGs, an increase in supra-harmonic emission is caused. The static converters of DGs are an important resource to generate harmonic distortion in the network current and voltage waveforms. The spread of harmonic emission in the frequency range of 2-150 KHz (frequency range used in power line communication) is different from sub-harmonic and intermediate-harmonic emissions. Today, with spread of smart grids, the emission and immunity in the frequency range of 2-150 KHz has become very important. Usually in the restructured low and medium voltage distribution networks, for the protection applications, remote measurement of energy consumption (AMI smart meters) and distribution network automation, the PLC telecom platform used with 2400bps velocity to transfer data and information. The electromagnetic disturbances caused by the directed emission in the frequency range of 2-150 KHz causes frequency interference in PLC behaviour. Thus, the smart grids function might be at risk. In this article, the harmonic emission and immunity in the frequency range of 2-150 KHz caused by the switching frequency of the static convertor in a 100KW solar power plant connected to the low voltage feeder have been studied and analysed. The low voltage feeder and solar power plant information has been taken from a real network. First, the spread and emission of harmonics in the frequency range of 2-150 KHz from the static converter to the network throughout the low voltage network in a high switching frequency will be investigated, then, by calculating the optimum switching frequency, the switching effects of the convertor will be analysed with optimum frequency on the supraharmonics generation. The simulation results in Matlab show that in the switching with optimum and low frequency of 2.5 KHz, the highest emission of supra-harmonics was in the frequency range of 2-20 KHz, and in the switching with frequency of 20 KHz, the highest emission of supraharmonics was in the range of 20-150 KHz. These harmonics are also damped and decreased from the static converter to the distribution network.

INTRODUCTION

In evaluating the low voltage modern networks, a new type of power quality phenomenon is discussed [1]. In addition to the injection of medium harmonics and sub-harmonics with non-linear loads, some harmonics were also injected to the network in the frequency range of 2-150 KHz resulted from the switching frequency power electronic devices used in DGs known as supra-harmonics [2, 3]. The emission and interference of these harmonics with communication signals of PLC transmission lines are not yet completely specified [4]. No report has been provided yet of the main problem of frequency interference in this frequency range, however, there are two main reasons to consider this range, one is the use of a portion of the frequency range (2-150KHz) in the PLC system structure and the other is to increase the use of modern equipment such as power electronic devices in distributed generation resources of low-power capacitive lamps, LEDs … in the distribution networks [5, 6]. In recent years with the spread of DGs, particularly the solar system connected to the low voltage networks, there is the possibility that harmonics emission in the frequency range of 2-150 KHz causes interference in the communication lines signals of distribution networks. The frequency range (2-150 KHz) is not covered enough in international standards. Considering the standards EN50065 and IEC61000-3-8, the emission and safety limit for the frequencies (3-9KHZ) is almost 134dBV (2% of 230V) [5]. According to standard EN50065, in the frequency of 100 KHz, the emission and safety limit is almost (120dBV) or (0.5% of 230V) [5, 6]. According to EN50065-2-3, the immunity and safety range of power line communication (PLC) equipment is expressed in the frequency range of 3-95 KHz. According to EN50065-2-2, a part of specific tests on PLC performed in range of 9-148.5 KHz [6].

The GPRS, PLC telecom platforms and the optical fibers are the most widely used communication platforms in the information and data exchange in the distribution networks. By starting the restructure in the electricity industry and establishment of competitive market, and also the need for online measurement of the energy consumption, the participation of consumers in the electricity market, energy consumption management and distribution networks automation has spread the use of PLC communication platform in the communication system of distributed networks [4]. Since based on EN50065 and IEC61000 standards, the frequency range of PLC systems in the low voltage networks is 9-148.5 KHz, therefore, the probability of interference of the signals with harmonics in the range of 2-150 KHz is very high. In the studies in recent years, the influence of the harmonics in the frequency range of 2-150 KHz caused by the switching frequency in the single-phase and three-phase low-power solar systems have been provided in accordance to Table (1) [7].

TABLE 1. Influence of supra-harmonic

	1-PH 1.5KW With MPPT	1-PH 2.5KW Without MPPT	3-PH 20KW Without MPPT	3-PH 20KW With MPPT
Dominating supraharmonic frequency	16.7KHz	16KHz	4Khz	3.8KHz

Therefore, there is a need for analysis of the harmonic emission and immunity in the frequency range of 2-150 KHz resulted from the static converters switching used in DGs connected to the low voltage feeders. This study aimed to simulate the harmonic emission in the frequency range of 2-150 KHz caused by the static convertor switching of the 100KW solar system connected to a low voltage feeder in Matlab software. All the information related to the low voltage feeder, network loads and solar power plant have been obtained from a real system. First, the emission of supra-harmonics throughout the low voltage feeder will be investigated from the static convertor, then the effect of convertor switching frequency on the emission of supra-harmonics will be analysed. The simulation results in Matlab show that in the switching with low and optimum frequency of 2.5 KHz, the highest emission of supra-harmonics is in the range of 20-150 KHz. These harmonics are also damped and decreased from the static convertor to the distribution network.

SOLAR SYSTEMS IN SMART GRID

In Figure (1), the solar system diagram block connected to the three-phase distribution network has been shown. The solar system structure includes the solar panels which are connected to the DC-DC boost converter. The voltage DC of the solar panels increased to an acceptable level with the use of boost convertor.

The static converter in addition to convert the voltage DC to AC is responsible to maintain the power factor. The solar system in the coupling common point (PCC) is connected to the three-phase distribution network through a NPC three-level convertor [8]. The convertors have low $\frac{dv}{dt}$ and switching stress compared to the multi-level bridge converters.

The communication frequency of static convertors used in the solar system is in the range of 15-20 KHz. In the conditions with frequency of 20 KHz, the highest amount of harmonics will be obtained for a three-level static convertor of $m=3$ in the level of $n_h=1199$ that is $59.95KHz$, and this harmonic is located in the frequency range of 9-148.5 KHz. The most optimum switching frequency for the m-level convertor is calculated as following [6]:

$$m_f = \frac{f_m}{m-1} \tag{1}$$

$$f_{cr} = m_f \times f_m \tag{2}$$

$$f_{sw} = (m-1) \times f_{cr} \tag{3}$$

where m_f is modulation index, f_m is modulating wave frequency, f_{cr} is carrier wave frequency and f_{sw} is the optimum switching frequency of static converter [6].

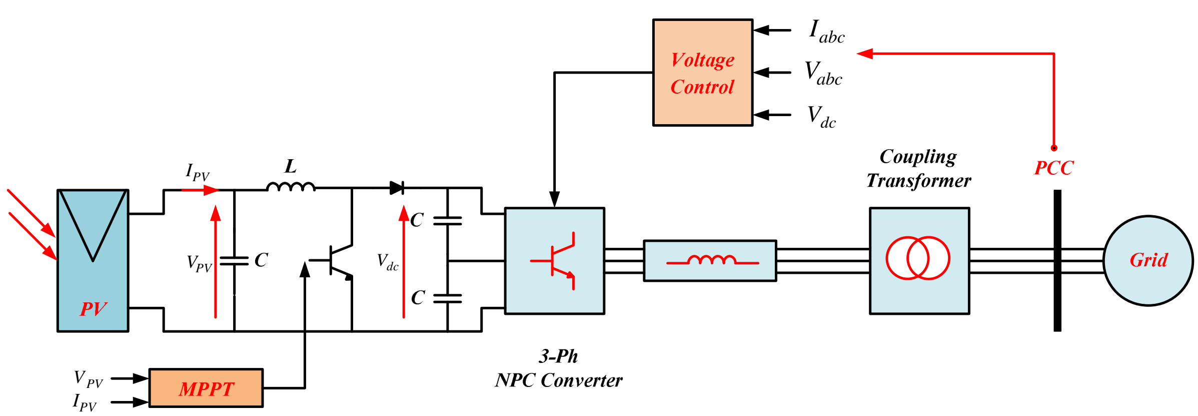

Figure. 1. Structure of the solar power plant in smart grids

STUDIED SYSTEM

Figure (2) shows the studied system in this article. In this system, a 100KW power plant is connected to the distribution network through a low voltage feeder. In the simulation of low voltage line, the PI model of line has been used [9]. The power electronic devices used in static converter are IGBT/Diode. Characteristics of these switches are presented in Table (2). The six harmonic measurement devices of (power analyzer) are located in each bus. The distribution system characteristics are presented in table (3). The static converter control system is designed in such a way that the induction reactive power of the solar power plant to the distribution network is almost negligible to the extent of 0Var. A RC filter with power of 10Kvar is embedded for compensation along with the solar power plant. The distribution network frequency is considered 50 Hz. The switching frequency of the static converters is considered 20 KHz. In order to ensure the maximum power extraction in the solar power plant, the increased conductivity (INC) algorithm has been used. The low voltage network is designed in such a way to have the power transfer capability of the solar power plant.

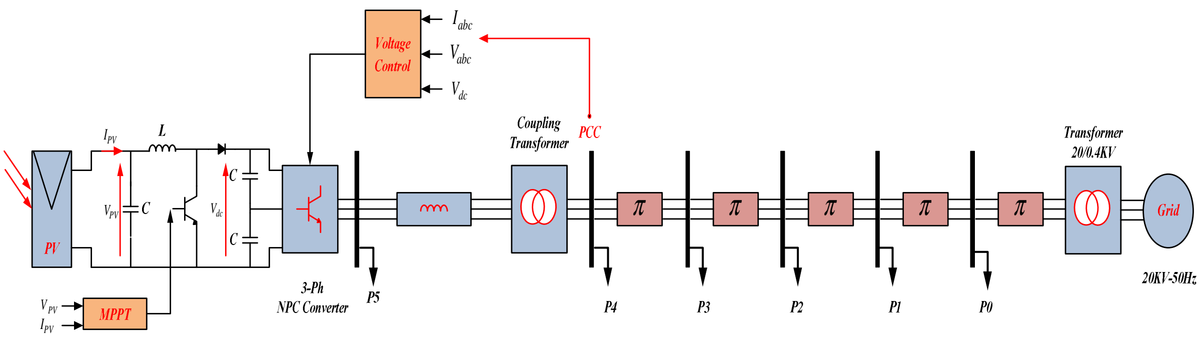

Figure. 2. Studied system

TABLE 2. Characteristics of power electronic devices (IGBT/Diode switch)

Parameter	Value
R_{on}	$0.2^{-3}\Omega$
C_s	$0.1\mu f$
R_s	$10^6\Omega$

TABLE 3. Low voltage feeder characteristics in distribution network

Parameter	Variable name	Value
Voltage grid	v_{grid}	$400v$
Frequency grid	f_{Grid}	$50Hz$
Length Feeder	l_{feeder}	$1000m$
Equivalent resistance	R	0.005Ω
Equivalent reactance	L	$0.17H$
Filter	$filter$	$0.1Kw-10K\,\mathrm{var}$
Switching frequency	f_{sw}	$20KHz$

SIMULATION RESULTS

The simulation of the studied system has been done in Matlab and at the constant temperature of $T = 25^{\circ}c$. The solar radiation at $t = 1s$ is supposed to be constant at $Irr = 1000W/m^2$. The simulation results including the harmonic analysis of the buses voltage waveform. The bus (P5) is related to the output voltage of static convertor. For power analyzers (P4-P0), the harmonic analysis (FFT) have been performed in the basic frequency (50Hz) and effective voltage of $V_{rms} = 400v$.

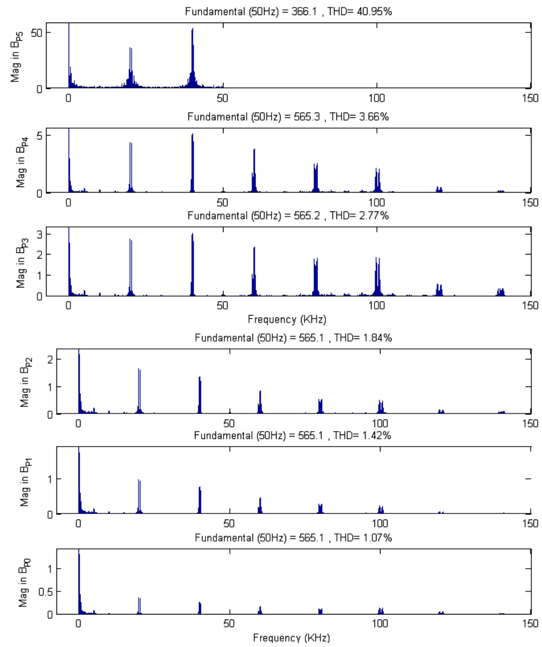

Figure. 3. Harmonic emission value in the buses of BP0 to BP5 with switching frequency of 20 KHz

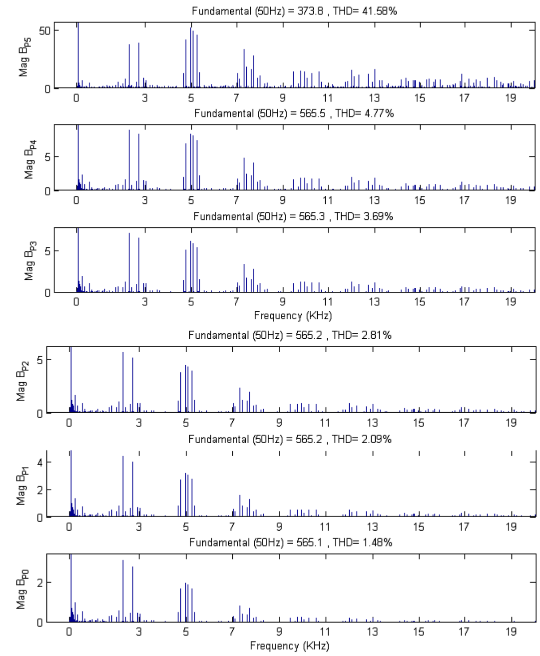

Figure. 4. Harmonic emission value in the buses of BP0 to BP5 with switching frequency of 2.5 KHz

TABLE 4. Harmonic emission value in the frequency range of 2-150 KHz of voltage waveform with switching frequency of 20 KHz

Bus.Num	THD%	20KHz	40KHz	60KHz	80KHz	100KHz	120KHz
P0	1.07	0.4	0.35	0.2	0.15	0.15	0.1
P1	1.42	1	0.85	0.5	0.35	0.2	0.1
P2	1.84	1.8	1.5	1	0.8	0.5	0.2
P3	2.77	2.8	3.2	2.5	2	2	0.8
P4	3.66	4.8	5.1	4.3	3	2	0.5
P5	40.95	40	50	0	0	0	0

TABLE 5. Harmonic emission value in the frequency range of 2-150 KHz of voltage waveform with switching frequency of 2.5 KHz

Bus.Num	THD%	3KHz	5KHz	7KHz	9KHz	11KHz	13KHz
P0	1.48	3	2	1	0.5	0.2	0
P1	2.09	4.5	3.5	1.5	1	1	0.2
P2	2.81	5.5	4.7	3	1	1	0.5
P3	3.69	7	6	3.5	2	2	1
P4	4.77	9	8.5	5	2	2	1
P5	41.58	40	50	35	18	18	10

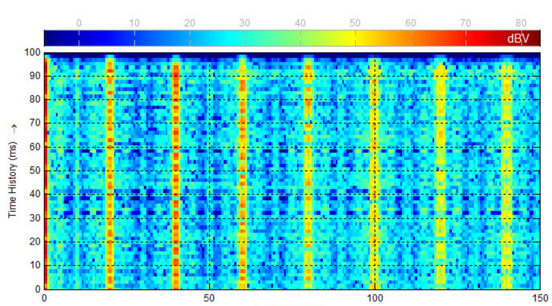

Figure. 5. Voltage spectrogram curve in converter terminal with switching frequency of 20 KHz

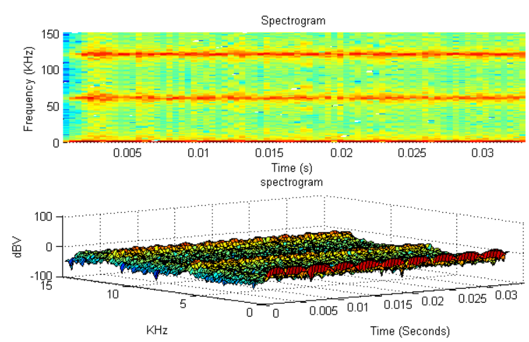

Figure. 6. Voltage 3-D spectrogram curve in converter terminal with switching frequency of 20 KHz

Figures (7) and (8) show damping of harmonics in the frequency range of 2-150 KHz throughout the low voltage feeder for the switching frequency of 2.5 KHz and 20 KHz.

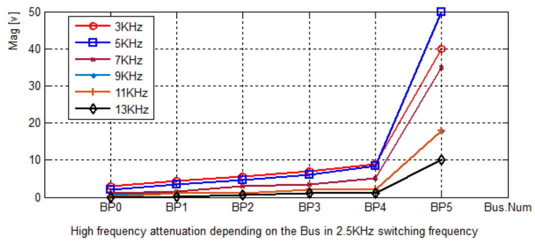

Figure. 7. Damping of harmonics in the range of 2-150 KHZ throughout the feeder with switching frequency of 2.5 KHz

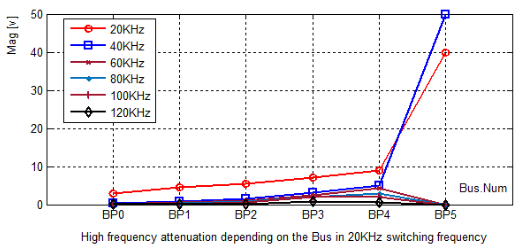

Figure. 8. Damping of harmonics in the range of 2-150 KHZ throughout the feeder with switching frequency of 20 KHz

According to the simulation results in Figures (7) and (8), the highest emission of supra-harmonics in the optimum switching frequency of 2.5 KHz was in the range of 2-20 KHz, and in the switching frequency of 20 KHz, it was in the range of 20-150 KHz.

However, in the optimum switching frequency of 2.5 KHz, the amount of THD% is increased compared to the switching frequency of 20 KHz, but the amount of harmonic distortion in the worst conditions was lower than 5%, which is standard in the determined permitted range.

Additionally, the results show that due to the resonance of low voltage lines and the use of coupling transformer, the frequencies damped and decreased throughout the network. The results provided in the Tables (4) and (5) also show that the harmonic distortion in the output bus of the static convertor was so high and there is a need to use the filter in its output.

CONCLUSION

In this article, the emission and immunity of the harmonics in the frequency range of 2-150KHz resulted from the switching frequency of the static convertor of a 100KW solar power plant connected to the low voltage feeder in Simulink/Matlab software was simulated with use of the PI model of low voltage line. By using the mathematical equations for the three-level converter used in this study, the optimum switching frequency was determined. The simulation was performed in the optimum frequency and high frequency and the results were analyzed. The results show that in the optimum switching frequency, the spread of supra-harmonics was in the frequency range of 2-20 KHz with great amplitude. In the switching frequency of 20 KHz, the spread of supra-harmonics was in the frequency range of 20-150 KHz with low amplitude, although the decrease in the switching frequency increases the amount of voltage waveform THD%, but its value has not surpassed the standard permitted limit.

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