CAPACITOR BANK BEHAVIOR OF CEMENT FACTORY IN PRESENCE OF SUPRA-HARMONICS RESULTED FROM SWITCHING FULL POWER FREQUENCY CONVERTER OF GENERATOR (PMSG)

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ABSTRACT

One of the major problems in optimal operation of the distribution networks is harmonic emission in the frequency range of 2-150 KHz or supra-harmonics. The emission of harmonics in the range of 2-150 KHz causes the capacitor banks burning, disruptions in power line communication (PLC) systems and loss of precision in the measurement devices. Additionally, the supra-harmonics has negative impact on the control system operation of the street lights, dimmers of household appliances, semiconductors used in medical equipment, scanners, security of control systems used in electrical transmission. Among the most important generation and emission factors of supra-harmonics, the converters used in the solar heating systems, wind power plants, fuel cells and batteries charge can be mentioned. Today, the use of power electronic devices in structure of the wind turbines is significantly increased. The use of full power frequency converters in type-4 wind turbines is an example for the use of power electronic devices in structure of DGs. The power factor correction capacitor banks are not capable of filtering the harmonics in the frequency range of 2-150 KHz, because the capacitor banks are usually used in the frequency of 50Hz or 60Hz. The capacitive impedance has an inverse relationship with the capacitor operation frequency, thus, the increase in the frequency harmonics reduces the capacitive impedance and increases the current drawn from the capacitor, which can cause the loss of capacitor, the protection system fail in detecting the ground fault circuit (GFCI) and decreased security in the capacitor. Some of the problems of the emission and harmonic immunity in the frequency range of 2-150 KHz are noted in IEC61000-4-19 standard. The testing and measurement methods of power quality are expressed in IEC61000-4-30 standard. In CISPR-16 standard, the measurement equipment and techniques of harmonic emission and immunity are presented in the frequency range of 9 KHz. However, very few studies have been performed on the impact of supra-harmonics resulted from switching the converters used in DGs on the behaviour of other network equipment and consumer. In this paper, the devastating effects of the harmonics in the frequency range of 2-150 KHz resulted from switching the full power frequency converter of the wind turbine (PMSG) on the capacitor banks of the cement factory are examined. The results include the spectrogram and periodgram diagrams of the current waveform. The results of simulation show that the harmonics generated by full power frequency converter of the wind turbine (PMSG) are in the range of 3-7 KHz. These harmonics can increase the current drawn from the capacitor bank current and the equipment burning.

INTRODUCTION

Development of power electronic devices in the distribution networks causes a new phenomenon in the power quality [1]. This phenomenon is known as the harmonic emission and immunity in the frequency range (2-150 KHz) or supra- harmonics [2, 3]. The harmonic emission in the frequency range (2-150 KHz) can reduce the precision of measurement in the energy recording equipment such as digital meters. The harmonics caused the increased current drawn from the capacitor banks, overheating, and finally burning of the capacitor banks. The majority of communication systems and power line communications (PLC) are used in the frequency range (2-150 KHz) [4], thus, another problem in the harmonic emission (2-150 KHz) is causing the interference in (PLC) system operation. However, no report has been presented on the major problem of the frequency interference in this frequency range [5]. The static converters used in solar systems, wind power plants, fuel cells, batteries charging, and some switching devices (DC-AC) cause the harmonic emission and generation in the frequency range of 2-150 KHz. The power supplies, variable-frequency drives, switching devices of converters (AC-DC) cause the emission of these harmonics in the distribution network. Power line communication (PLC) system also causes the generation and emission of these harmonics indirectly. The (PLC) systems are usually used for data transmission in the power networks to generate and transmit the signals with a frequency of 9-148.5 KHz. The frequency harmonics in the range of 2-150 KHz can be transmitted through the aviation networks, underground cables and buildings wiring. Although the distribution networks are designed for power transmission in the frequency of 50Hz or 60Hz, unfortunately, these networks have the transmission ability in the range of 2-150 KHz. In the frequency range of 100 KHz, the distribution network impedance is maximum, thus in this state the maximum harmonic emission in the frequency range of 2-150 KHz is conducted through the voltage and current waves.
The frequency range (2-150 KHz) has not been covered

enough in the international standards [6]. According to EN50065 and IEC61000-3-8 standards, the emission and immunity range for the frequencies (3- 9 KHZ) is almost 134dBV (2% of 230V) [7]. According to EN50065 standard in the frequency of 100 KHz, the emission and immunity range is almost (120dBV) or (0.5% of 230V) [7]. According to EN50065-2-3 standard, the immunity and security range of the power line communication (PLC) system equipment is expressed in the frequency range of 3- 95 KHz. According to EN50065-2-2 standard, a part of special tests of the PLC system is conducted in the frequency range of 9-148.5 KHz [7]. The major problems of the harmonic immunity and emission are expressed in the frequency range of 2-150 KHz in IEC6100-4-19 standard. In the IEC61000-4-30 standard, the test and measuring methods of harmonic emission are presented in this range [6].

A few studies have been performed on the harmonic emission and immunity in the frequency range of (2-150 KHz) resulted from switching the static converters used in DGs connected to the average pressure feeders. In this paper, the harmonic devastating effects in the frequency range (2-150 KHz) resulted from switching the full power frequency converter of the type-4 wind turbine (PMSG) connected to the medium voltage (MV) network on the capacitor banks in Matlab software have been simulated and analyzed in the real-time manner. The data of the distribution network and wind turbines have been taken from a real power system. The results show that the size of harmonics in the frequency range (2-150 KHz) was so big with the possibility to damage the capacitor banks equipment. The results also show that the harmonics in the frequency range (2-150 KHz) can reduce the capacitive impedance, and as a result, increase the output current drawn from the capacitor banks, which causes the insulation fault in the capacitor banks and increased reactive loss.

EFFECTS OF HARMONICSON THE CAPACITOR BANKS

The capacitors used in the input filters (LC) and power factor correction capacitor banks usually operate at frequency of 50Hz and 60Hz [5]. The capacitive impedance in the equipment is equal to $\frac{1}{2\pi fC}$, as can be seen, the capacitive impedance has an inverse relationship with system frequency. The increase in frequency reduces the capacitive impedance, and finally, enhances the current drawn from the capacitor. For instance, in a 50Hz- 230V filter, the earth current is almost 1mA. In this filter, with 2.3V voltage at a frequency of 50 KHz, the output current is ten times of the operation state at the frequency of 50Hz [6]. The capacitor banks are used to rectify the power factor correction of the industrial and commercial systems. The capacitors are designed in such a way to tolerate 110% of the nominal voltage and 135% of nominal Kvar. When these capacitors are exposed to the network harmonics, the voltage and reactive power values exceed the allowable values, and cause the damage. Since the capacitive reactance is a function of reverse frequency, thus, there is the possibility that the harmonics are flowed to the capacitor bank, and cause the insulation fault and capacitor burning by increasing the current. Another major issue is resonance that might be due to the presence of capacitor bank in the system. The series of capacitor banks and inductive impedance has a resonant frequency, if one of the harmonic frequencies of the network current is the equal to the resonant frequency; it caused the resonance in the system and damage to the equipment.

Resonant frequency is equal to:

$$f_R = \frac{1}{2\pi\sqrt{LC}} \tag{4}$$

where C is the capacitive reactance, L is the network reactance at the PCC point of capacitor banks.

In order to obtain the harmonic order of resonant frequency (R_n), the following equation can be used:

$$R_n = \sqrt{S_{sc}(MVA)/S_C(MVar)} \tag{5}$$

where S_{sc} is the three-phase short-circuit connection power at the PCC point of capacitor bank, and S_C is the nominal power of capacitor bank. For instance, in a cement manufacturing plant with capacitor bank of 1200Kvar, at the 20kV voltage, the resonance frequency is almost 235Hz. The harmonic order of resonance frequency will be 5th harmonic. The 5th harmonic is one of the notable frequencies in the distribution networks.

According to IEC871-1 standard, in the 20kV capacitors, the maximum current tolerated in the long term for each capacitive unit is 1.5 times of the nominal current. Also, in accordance to this standard, the maximum voltage tolerated in the long term (12 hours a day) is the nominal 1.1 voltage of the capacitor bank. The maximum tolerated capacitor bank voltage for the insulation capacitor fault is almost 125.5 kV. These requirements should be observed in all the present circumstances, meaning that at the same time with installation of DGs in distribution networks, observing the maximum current and voltage values are essential.

STUDY NETWORK

Figure (1) demonstrates the studied system in this paper. The system composed of a 1.5MW wind unit equipped with a permanent magnet synchronous generator. The generator is connected through a back to back full power frequency converter and coupling transformer (Δ/Y) to the medium voltage (MV) distribution network. The length of medium voltage (MV) network is 35Km. This feeder supplies the cement manufacturing plant with 18MW reactive charge. The reactive charge drawn from the medium pressure line is 8Mvar. For compensation of reactive power, a series of 1200Kvar capacitor bank is used on the 20kV network. The medium voltage (MV) model in the simulation is considered as the Distributed Parameter Line model. However for switching surge studies involving high- frequency transients in the kHz range, much shorter PI sections should be used. In fact, you can obtain the most accurate results by using a distributed parameters line model [8]. The frequency of distribution network is considered 50Hz. The distribution network alone is capable of supplying the plant energy, but due to the improved profile voltage and decreased network losses, the wind power unit is added. The distribution system characteristics are presented in table (1).

TABLE 1. MV feeder characteristics in distribution network

Parameter	Variable name	Value
Voltagegrid	v_{grid}	$20KV$
Frequencygrid	f_{Grid}	$50Hz$
LengthFeeder	l_{feeder}	$35km$
Equivalent resistance	R	$0.12\Omega/km$
Equivalentreactance	L	$1.05mH/km$
Switching frequency	f_{sw}	$3.3KHz$

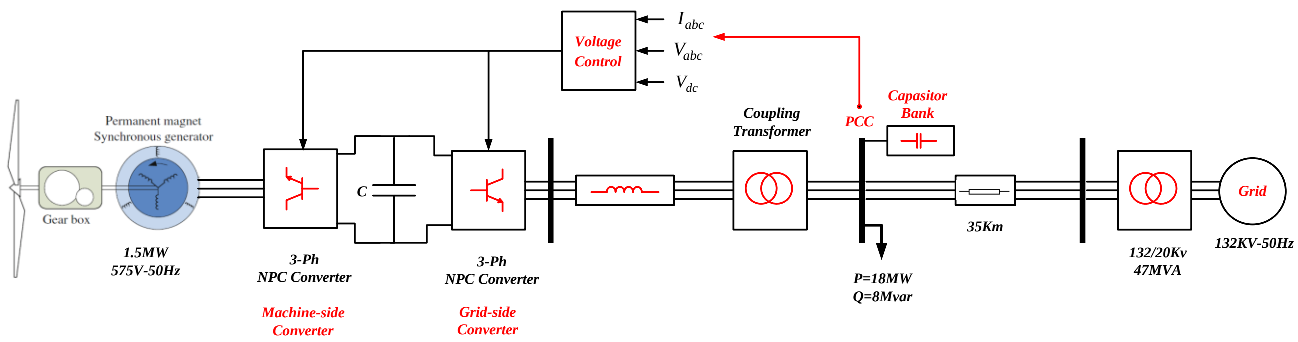

Figure. 1. Studied system

RESULTS OF SIMULATION

Simulation of the studied system is conducted Matlab/Simulink and during the simulation $t = 1s$ in real-time manner. The wind speed in this period is supposed to be constant, thus, the mechanical torque is practically assumed to be constant and equal to $T_m = -2.4\times10^5 N.m$ to transfer the highest power from the turbine to network. The simulation results include the diagrams spectrogram and periodgram of the network currents, charge, capacitor bank and wind turbine generator. The harmonic spectrum of the above-mentioned currents in range of 0-10 KHz is also evaluated. Figures (2) through (9) demonstrate the results of simulation of the capacitor bank behaviour in presence of the wind power plant and without the power plant.

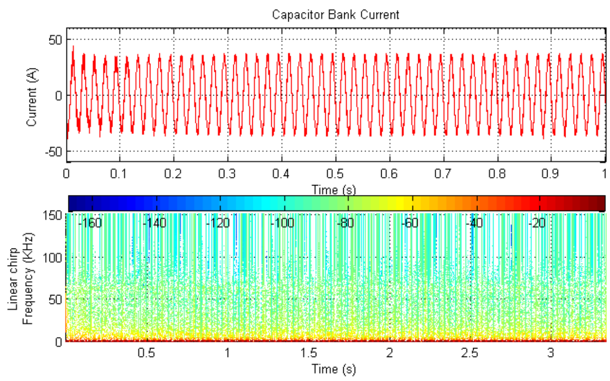

Figure. 2. Phase current a of the capacitor bank with wind power plant

According to the figures (2) and (3), the current drawn from a capacitor bank in the presence of harmonics in the range of 2-150 KHz is higher than the current in normal mode. According to Figure (4), the highest value of harmonic emission is in the range of 3500 Hz, and value of 0.5A. The emission value without the presence of wind power plant is almost 0.015A.

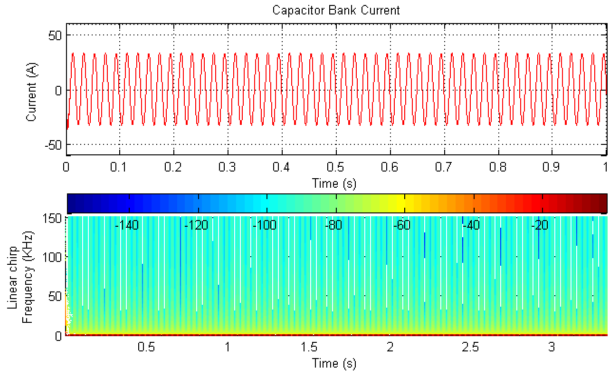

Figure. 3. Phase current a of the capacitor bank without wind power plant

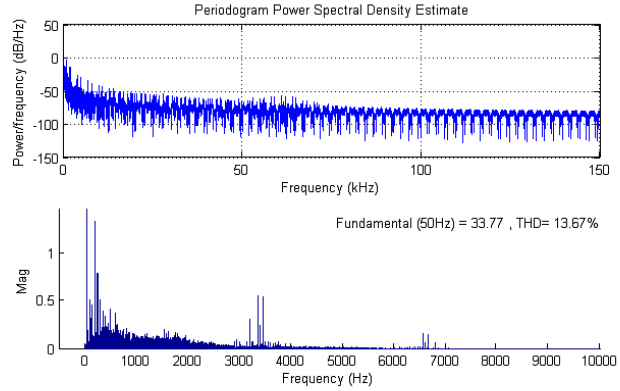

Figure. 4. Harmonic value of phase current a of the capacitor bank with wind power plant

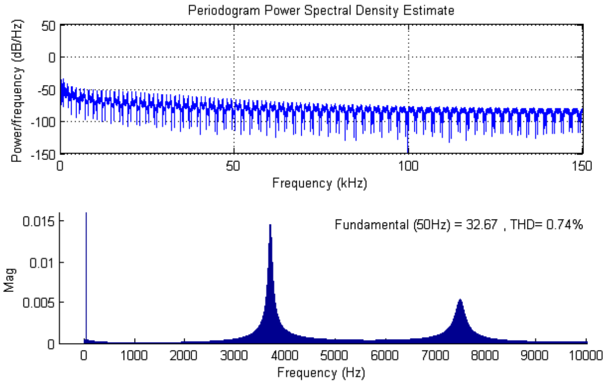

Figure. 5. Harmonic value of phase current a of the capacitor bank without wind power plant

In analyzing the complex alternative signals using Euler's Identity, such signals have both real and imaginary parts. So in the frequency spectrum of that the existence of each of the positive and negative spectrum (positive and negative frequencies) is necessary and frequency spectrum will be like Figure (6). Obviously, in this case, the negative part of the frequency spectrum always will have two same complex exponential components that will rotate with identical angular velocity in opposite directions [9].

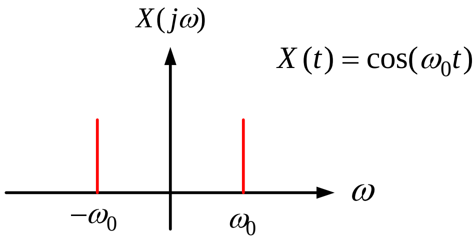

Figure. 6. Frequency spectrum of complex signal

Figures (7-10) show that the studied signals are a real symmetric signal that is not need to negative part of the frequency spectrum.

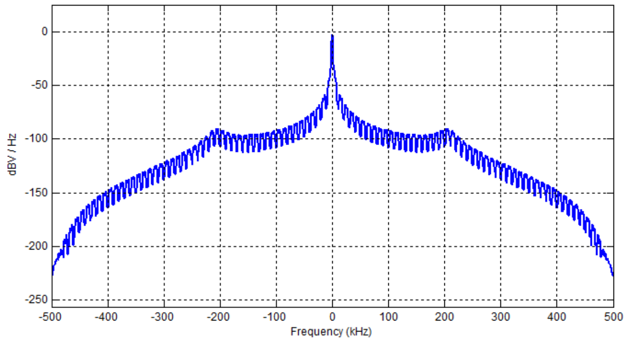

Figure. 7. Harmonic emission of phase current a of the capacitor bank with wind power plant

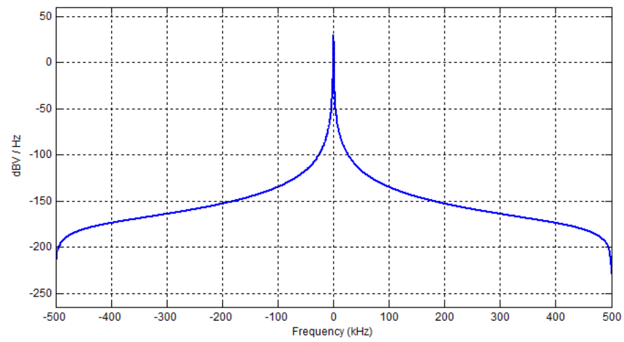

Figure. 8. Harmonic emission of phase current a of the capacitor bank without wind power plant

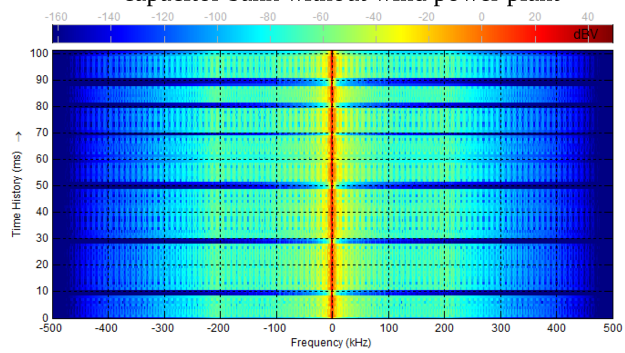

Figure. 9. Spectrogram curve of phase current a of the capacitor bank with wind power plant

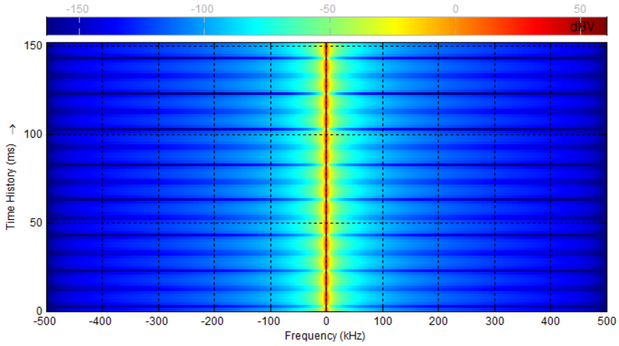

Figure. 10. Spectrogram curve of phase current *a* of the capacitor bank without the wind power plant

The overall harmonic distortion rate (THD%) of the capacitor bank current in the presence of wind power plants was 13.67%, while the overall harmonic distortion rate (THD%) of the capacitor bank current without the presence of wind power plant is equal to 0.74% as shown in table (2). The increased harmonic emission in capacitor bank in the presence of wind power plants is significant. However, increasing 13% in RMS value of current is in the range of the standard limit but it will cause overheating and reduce the life of the capacitor bank.

TABLE 2. Harmonic emission comparison with and without wind power plant

Component	THD%	
	With wind power plant	Without wind power plant
Network current	**4.66**	**0.04**
Capacitor bank current	**13.67**	**0.74**
Load current	**37.06**	**0.74**

CONCLUSION

In this paper, the harmonic emission and immunity in the frequency range (2-150 KHz) resulted from switching the full power frequency converter of the wind turbine connected to the medium voltage (MV) network was simulated and analyzed for a cement plant in the presence of capacitor banks. The results of real-time simulation in Matlab/Simulink show that the presence of wind power plant is caused the supra-harmonics in the frequency range of 2-10 KHz in the capacitor bank current. In the presence of wind power plant, the value of THD% of load currents and capacitor is superior to the allowable value defined in the standard, the maximum generated supra-harmonics value can be observed in the frequency of 3500 Hz and 6750 Hz. The harmonics will cause the severe heating of the capacitor bank. The overall results show that supra- harmonics emission in the studied system is occurred in the presence of wind power plant in the frequency range (3-7 KHz).

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