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The power quality improvement for an electric vehicle application

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Abstract-The electric vehicle Powertrain is designed to function in sinusoidal mode. On the other hand, the extensive use of power electronic and other types of a non-linear load within this system lead to disturb the prospective mode by the production of various perturbations. The latter affect the waveforms of the system current and voltage. In this paper, we tend to shed light on the harmonics perturbation and propose a solution to reduce it. The suggested system, for harmonics mitigation, is an active power filter (APF) based on evolving structure of the electronic power; the cascaded multilevel inverter. Moreover, a control circuit is designed to be adapted to the system variations. The entire model is implemented in Simulink Matlab to check its efficiency.

Keywords: Total Harmonic Distortion (THD), Active Power Filter (APF), Multilevel Cascaded Inverter (MCI), the synchronous reference frame theory, the phase-disposition PWM strategy, electric vehicle powertrain.

1. INTRODUCTION

In the recent years, the Power Quality (PQ) is a widespread term in the scientific and industrial field. However, the rising use of power electronics to upgrade process performance and controllability makes PQ problems such as harmonic perturbations and reactive absorption…Among the applications which are experienced the increasing development of the power electronics domain, we notice the electric vehicles. The Figure 1 presents the electric vehicle powertrain where the static converters are utilized as interface between the source; electric motor and the power system [1].

The use of a non-linear load; the AC/DC converter augment the harmonic distortion level into the system by the absorption of a non-sinusoidal current. Also, it leads to the creation of the harmonic voltage during the passage of these perturbed currents in the system impedances.

Some possible impacts of these PQ perturbations on the electric powertrain components are the overheating which affects the efficiency and the lifetime of motors and the transformers and the overvoltages and overcurrents caused by the resonance [2]. Because of these harmful effects, filtering systems appear to provide the means to satisfy the particular requirements of the PQ in the electric equipment. The aim of these new devices is to keep the level of the harmonic distortion inside accepted boundaries. Thus, many standard engineering recommendations such as EN 61000-3-2/EN61000-3-12, IEC 1000-3-2 and IEEE 519 are fixed the limits to respect [3]. The table 1 presents the IEEE 519-2014 which is the harmonic standard used in this paper to check the efficiency of the made work [4].

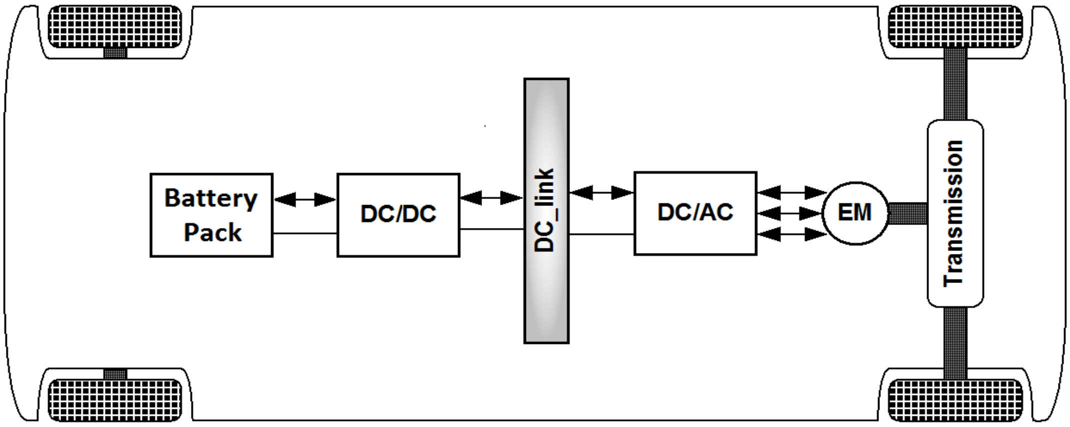


Figure 1. the use of static converters within the electric vehicle Powertrain

Table 1 Current Distortion Limits for system rated 120 kV through 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonic)[a,b]						
I_{sc}/I_L	$3\leq h\leq 11$	$11\leq h\leq 17$	$17\leq h\leq 23$	$23\leq h\leq 35$	$35\leq h\leq 50$	THD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

The Total Harmonic Distortion of the system current is calculated for the first fifty harmonics as follows:

$$THD = \sqrt{\sum_{2}^{50} \frac{I_h}{I_1}} \quad (1)$$

According to the depicted limits, a filtering solution is proposed and tested for the electric vehicle application. The work is divided as follows; first we present the different filtering solutions with precising our choice. Second, we present a detailed study of the power system of the selected harmonics filter. The filter control circuit is described in section 4. The checking of the made work is realized through a Matlab/Simulink simulation in the fifth section with a results description. Finally, we close with some concluding remarks.

2. SYSTEMS FOR HARMONIC CURRENT FILTERING

In order to mitigate harmonic currents into the electric systems, several solutions have been introduced in the literature such as passive filter and Parallel Active Filter (APF). But, the APF is the favourite one thanks to its adaptability to the variations of the load and source instead of passive filter. The goal of the APF consists of preventing disturbance currents (harmonics, reactive and unbalanced), produced by non-linear load, to flow through the system located upstream of the connection point of the filter. That is realized by the injection of the same current as the perturbed one but in opposite of phase at the Point of Common coupling (PCC). Thus, in order to have the best efficiency and reliability for this harmonic current generator, several topologies are created. It is to be noted that multilevel inverter is attracting more attention for it has many advantages. It is characterized by the ability to generate electric power with reduced harmonic distortion and lower electromagnetic interference (EMI). Among the multilevel topologies developed in the literature, we notice the neutral point clamped inverter, the flying capacitor inverter and the cascaded multilevel inverter. Among these three structures, the last one is the most used in the medium power applications and also in the active filtering systems. It is an interesting structure for various reasons:

- ✓ The extreme modularity: it consists of a certain number of identical H bridges.
- ✓ The simplicity: the less number of components without requirement of clamped diode and flying capacitors used for other multilevel topologies.
- ✓ Improved Electromagnetic compatibility
- ✓ A high output voltage with low harmonic distortion.

Thus, in this paper, the selected power system for APF application is a cascaded multilevel inverter which is introduced in the next section.

3. THE APF POWER SYSTEM MODEL

In this current article, the choice of the power system for the APF is a five-level cascaded multilevel implemented into the electric vehicle powertrain as shown in Figure.2.

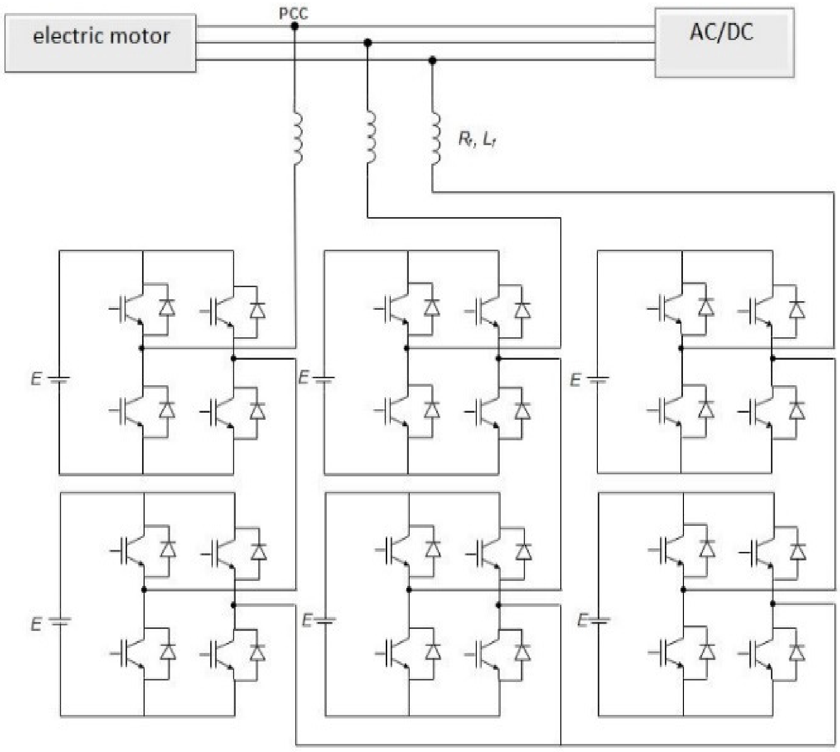


Figure 2. The cascaded multilevel inverter connected to the electric vehicle powertrain through smoothing inductance (R_f,L_f)

The structure of the cascaded inverter is based on separate DC sources E. Each one of them is associated a H-bridge cell. For each phase, the AC side of cells are connected in series to generate a phase output voltage with five levels: -2E, -E,0, E,2E.

In order to present the mathematical model of the five-level inverter, the Table 2 presents the different parameters of the system.

Table 2 the system parameters

Parameter	Description
L_f, Rf	Smoothing inductance parameters
E	H-Bridge source voltage
$Vcell1,2$	H-Bridge output voltage for each phase
$Vout$	Phase output voltage of the Cascaded inverter
Vm	Electric motor voltage
Im	Electric motor current
Il	The AC/DC current
I	Cascaded inverter current
δ_1, δ_2	Control signals for cell 1 and cell 2

For each phase, the five-level cascaded multilevel inverter can be presented by the following expressions:

$$\begin{cases} V_{out} = V_{cell1} + V_{cell2} \\ V_m = V_{out} + V_{on} + R_f I + L_f \dfrac{dI}{dt} \\ V_{on} = \dfrac{1}{3}(V_{out1} + V_{out2} + V_{out3}) \\ L_f \dfrac{dI_m}{dt} + R_f I_m = V_m - V_{out} - V_{on} + L_f \dfrac{dI_l}{dt} + R_f I_l \end{cases} \quad (2)$$

V_{on} is the voltage between the source neutral and the common point of the three cascaded inverter phases.

This mathematical analysis is necessary for the next step which is the determination of the parameters of the control block described in section 4.

4. THE DESCRIPTION OF THE CONTROL SYSTEM FOR THE APF

The control system plays an important role in the enhancement of the APF efficiency and reliability. As a matter of facts, to assure the best APF performance, the creation of this system is done by carrying out three fundamental tasks; to assess the harmonic currents, to extract a synchronized reference and to apply a closed loop control.

4.1 The identification strategy

The identification strategy principle consists of the detection and the estimation of the existing harmonic currents into the system. Various strategies are developed for this function where some of them use the source current as reference and others use the non-linear load current. In this paper, the used method is chosen to be one of the second type. The most popular strategies utilized this reference; the load current are the method of instantaneous active and reactive power and the synchronous reference frame theory. For this system, the proposed method is the last one which is characterized by simplicity in calculation, precision, robustness and efficiency in the transient and steady state.

4.2 The regulator model

In order to ensure that the APF current follows the identified current, the closed loop control is necessary. Thus, a Proportional Integral (PI) is designed to generate the reference signal for the control signals generator.

4.3 the modulation technique

The cascaded inverter response depends on the modulation technique used to control its switches. Among the popular control methods for the multilevel inverters, we mention the multicarrier Pulse Width Modulation (PWM) techniques which compare the output signal of the PI regulator and a certain number of triangular carriers. The disposition and the number of these carriers are defined by the type of the inverter (topology, number of levels) to control and the PWM strategy (Phase-Shifted PWM (PSPWM), Phase-Disposition PWM(PDPWM)…) to use. For the cascaded multilevel inverter with n levels, the most common used method is the PDPWM where we require 2*n carriers with the same amplitude and phase. This technique is selected due to the best waveform and harmonic spectrum of the cascaded inverter voltage relative to the ones of the PSPWM.

5. THE SIMULATION RESULTS

The implementation of the full model of the APF into the electric vehicle powertrain is done by a Matlab/Simulink simulation as shown in Figure.3.

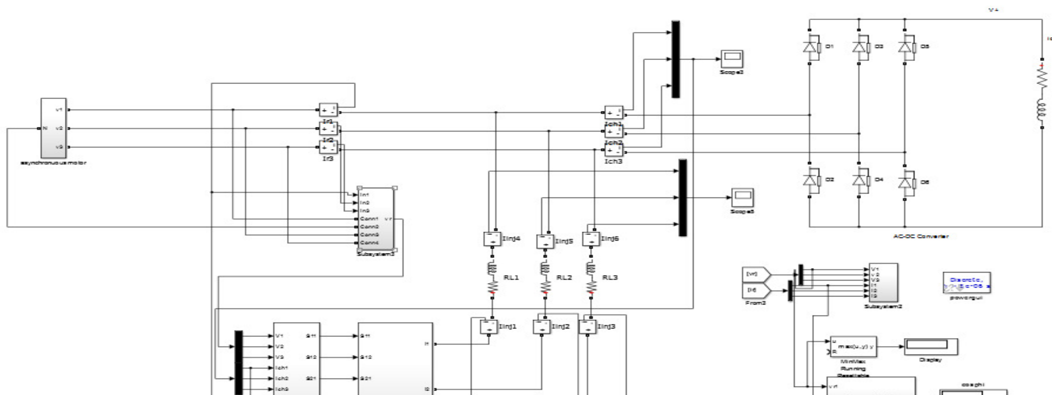


Figure 3. The APF model connected at the PCC between the electric motor and the AC/DC converter

The electric motor in this model is an asynchronous motor with vector control. Its speed is variable to achieve finally the nominal value; 1500 tr/min in the steady state as depicted in Figure 4.

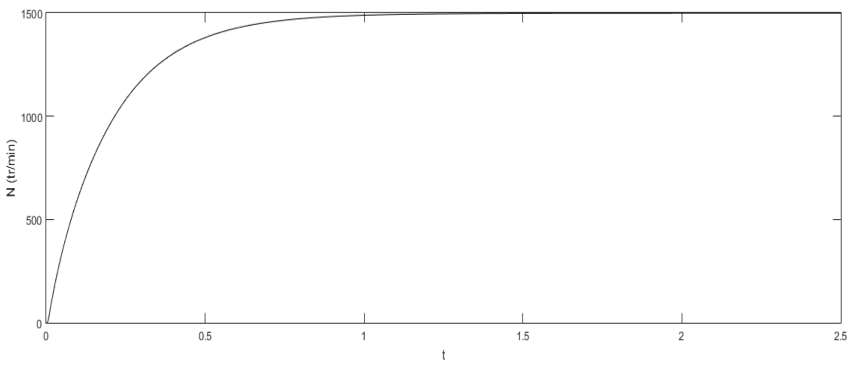
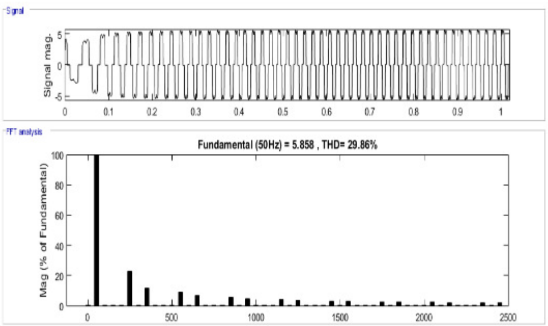


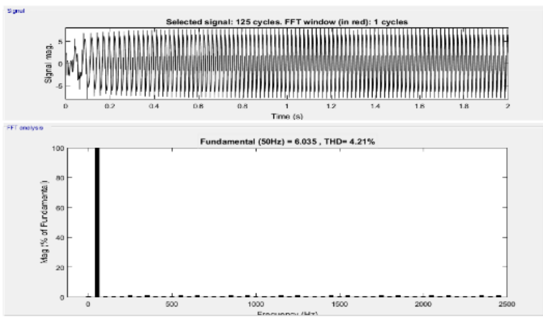
Figure 4. The electric motor speed

The motor speed variation must be taken into account for the APF model to have a fast and accurate system response.

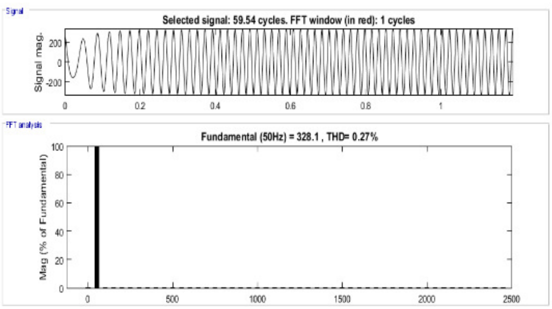
Moving to the verification of the efficiency of the filtering systems, the harmonic spectrums and the waveforms of the load and motor currents and the motor voltage are shown in Figure 5.



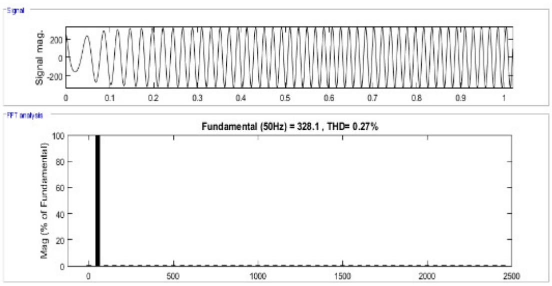
(a)the load current



(b) the motor current



(c) the motor voltage before filtering



(d) the motor voltage after filtering

Figure 5. The simulation results

The load current is a non-sinusoidal current with a THD value equal to 29.86%. that is the generated current by the motor before filtering. However, after the implementation of the APF, the motor keeps a sinusoidal waveform with a distortion harmonic level (THD=4.21%) respecting the fixed boundaries by the IEEE 519-2014 (THD =5%).

Despite the frequency variation of the system shown clearly in the motor current and voltage waveform, we reserve the sinusoidal mode required for the electric vehicle application.

As for the motor voltage, one can notice that there is no significant difference between the waveforms before and after filtering. That justify our choice of the cascaded multilevel inverter which generate an output voltage with a low distorion harmonic level.

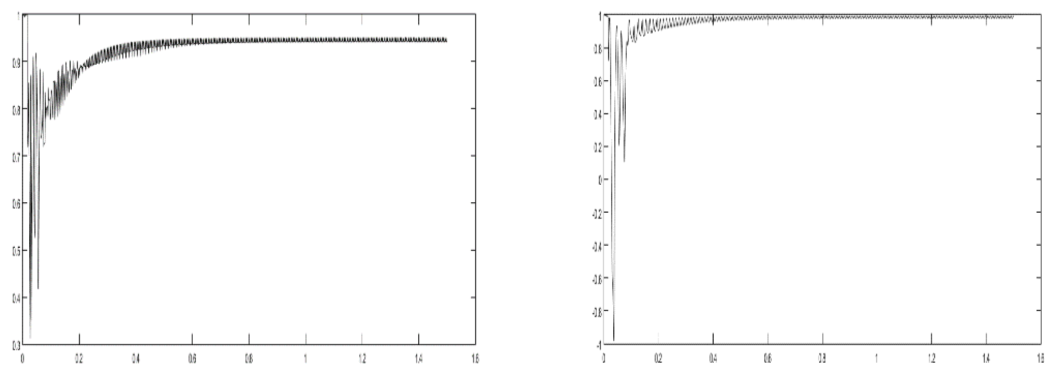
The validation of the APF filter for harmonic mitigation is proved. Other power quality factor can be calculated to show another advantage of the selecteted model. This is the system power factor f_p. The latter can be calculated by the following expression:

$$f_p = \frac{\cos\varphi}{\sqrt{1+THD_I^2}} \qquad (3)$$

Where THD_I is the total harmonic distortion of the current.

The more the waveform approaches of a perfect sinsoid, the more the THD_I tends to 0 by obtaining a power factor equal or near to the unit.

The calculation of the p_f for the simulated model before and after filtering indicate an improvement of this parameter value from 0.94 to 0.99 as shown in Figure.6.



(a) Before filtering (b) After filtering

Figure 6. Time evolution of the power factor

6. CONCLUSION

This current piece of research revealed the design of an active power filter for electric vehicle application. An analysis of classical and modern filtering systems has shown the superiority of the systems based on multilevel inverters. On other hand, particular interest has been given to the filtering system with cascaded inverter which proves its effectiveness of such applications. Then, a study of control techniques using for this multilevel inverter was conducted to understand the operation of this modular topology. The full APF model is implemented into the electric vehicle powertrain through Matlab/Simulnik platform. The simulation results validate the APF filter performance in the harmonic mitigation respecting the IEEE 519-2014 limits. Despite the frequency variation produced by the electric motor model, the system keeps a sinusoidal current waveform with a THD value equal to 4.21% w. For the system voltage, it is not affected by the adding of the power electronic device; the cascaded multilevel inverter. Also, another factor of the power quality is improved. It is the power factor which is increased from 0.94 to 0.99.

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