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ANALYSING PERFORMANCE OF SUPER-CAPACITOR AND BATTERY IN LOW VOLTAGE ELECTRICAL DISTRIBUTION SYSTEMS

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ABSTRACT

The aim of this research project is to analyze and design of energy storages in electrical distribution system. The proposed energy storages consist of super-capacitor and battery based on MATLAB/SIMULINK software environment. These two types of energy storages is implemented to two level voltage source inverters (VSI). The controller d-q reference frame technique is used and applied to the two level inverters. In order to avoid high frequency ripple from inverters output, low pass filter is investigated. The various performances of simulation results between super-capacitor and battery have been investigated. The Total Harmonic Distortion (THDv) of the inverter output voltage is measured where two types of energy storages (battery and super capacitor) are applied to the inverter input. It can be observed that the THD voltage and current at load for the super capacitor is considerably lower than the battery.

Keywords: *Super capacitor (SC), Total Harmonic Distribution (THDv), Voltage Source Inverter (VSI).*

1. INTRODUCTION

The development of power electronics and increased powers involved and the flexibility of the use of semiconductors has electricians encouraged to undertake significant associations of static converters power to electric machines [1]. These devices are generally non-recurring charges linear, absorbing non-sinusoidal current and behave as harmonic generators. Moreover, they sometimes consume reactive power. Therefore, the waveform of the current sinusoidal source loses and gets also a deterioration of the power factor. Therefore, the electric power distributors obliged to impose standards and be protected against these disturbances [2]. The term harmonics can be defined as how pure the voltage is, how pure the current waveform is in its sinusoidal form. The objective of the electric power distributor is to provide its customers with electricity good quality [3]. The ideal voltage waveform used in power systems is a sine wave amplitude and constant frequency. In practice, the transmission of electricity and the use that is made user cause deformation of the sinusoid. This deformation or distortion the wave is called harmonic disturbance. The harmonic distortion is due in large part to the development of new uses (powered by electronic equipment) that spread both in industry and in households [3]& [4]. The need for harmonic studies was crucial when energy storage system like battery and super capacitor are applied. This paper illustrates the analyzing and design study of two different energy storages comprises of super capacitor and battery for reduction of the harmonic in the inverter output, the effects of harmonics at both energy storages systems are discussed and all results are displayed. Furthermore, method used to control the output voltage is based on synchronous dq reference frame technique that was applied to the three phase inverter systems. After that designing a new system is considered necessary to create a model of that system in order to test if it will work using computer simulations. Since the super-capacitor is still a rather new component, the development of appropriate models is still a subject which is being investigated. Recently super-capacitor has matured significantly over the last decade and emerged with the potential to facilitate major advances in energy storage [5]. However, there are many disadvantages associated with batteries such as high current total harmonic distortion, low power density and limited charge/discharge cycles. It provides a measure of the thermal influence of the harmonic, or it is the

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ratio of the RMS value of the harmonics to the fundamental [5] & [6]:

$$\mathrm{THD}\ (\%) = 100.\frac{\sqrt{\sum_{n=2}^{\infty}(G_n)^2}}{G_1} \qquad (1)$$

Total harmonic distortion for voltage (TDHv) is calculated as shown in the following formula [7]:

$$\mathrm{THD_v}\ (\%) = 100.\frac{\sqrt{\sum_{n=2}^{\infty}(V_n)^2}}{V_1} \qquad (2)$$

2. MODEL LAYOUT

Both super capacitor and battery's DC voltage is applied to an IGBT two-level inverter generating 50 Hz. The IGBT inverter uses PWM at a 20 kHz carrier frequency. The circuit is discretized at a sample time of 1 (sec) the load voltage is regulated at 1 pu (380 V rms) by a PI voltage regulator using abc to dq and dq to abc transformations. The first output of the voltage regulator is a vector containing the three modulating signals used by the PMW Generator to generate the 6 IGBT pulses. The second output returns the modulation index. The Discrete 3-Phase PWM Pulse Generator is used as shown in Figure 1.

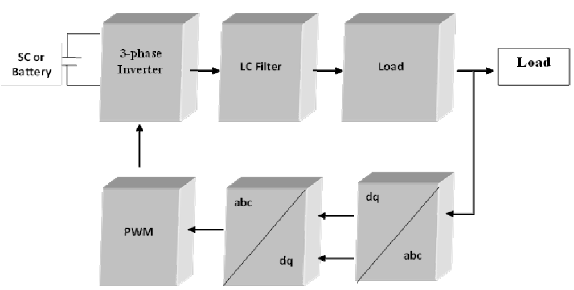

Figure 1: Model Layout Of Whole Proposed System

2.1 Super Capacitor Model

A super capacitor can be modeled by using some standard circuit components as shown in Figure 2. This circuit design is used because a similar circuit is presented in the data sheet for the super capacitor from EPCOS and because of recommendations from the project supervisor [8]. Simulink is used to create a first model of the super capacitor according to the basic circuit described in Figure 2. Initial model testing is done with a simple circuit consisting of a resistance in series with a capacitance and resistance in parallel. This base circuit manages to show the basic function of the super capacitor [9]. By adding more components until the circuit described in Figure 2 is achieved, the accuracy of the model is improved. The Simulink model that is used as the basic model of the super capacitor is shown in Figure 3. The relay block controls the switch that connects the balancing resistance R3 to the circuit [9].

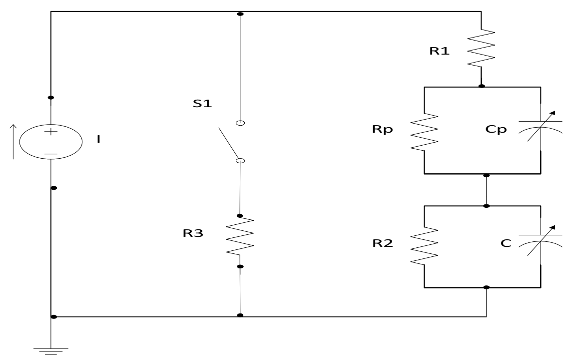

Figure 2: The Basic Circuit Model Of The Super Capacitor (EPOCS)

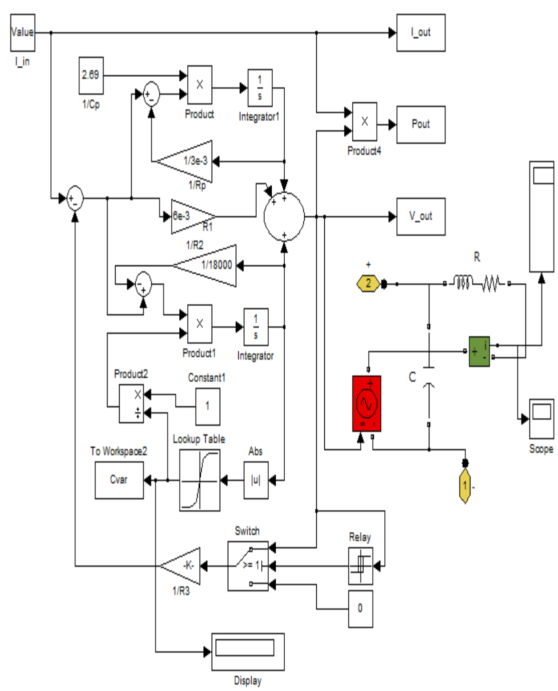

Figure 3: Simulink Model Of SC

2.1.1 Main capacitance

The capacitance value can be calculated in two different ways. The first method is to look at

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the voltage derivative during charging of the super capacitor. The relation between voltage derivative and the capacitance is

$$i(t) = C\frac{d}{dt}u(t) \quad (3)$$

Where;

C = the capacitance.

Using this relation the capacitance can be calculated for different parts of the voltage curve. When high currents are used, other effects than the capacitance can affect the voltage level. These effects can cause the calculated capacitance value to be incorrect

2.2 Battery Model

Battery model consists of two separate circuits that been linked by a voltage controlled voltage source and a current controlled current source. One circuit represents the overall capacity of the battery, while the other circuit models the internal resistance and transient behavior of the battery using a series resistance and two RC circuits [10]. Figure 4 illustrates the equivalent circuit of the model and then implemented by using Simulink Matlab as shown in Figure 5.

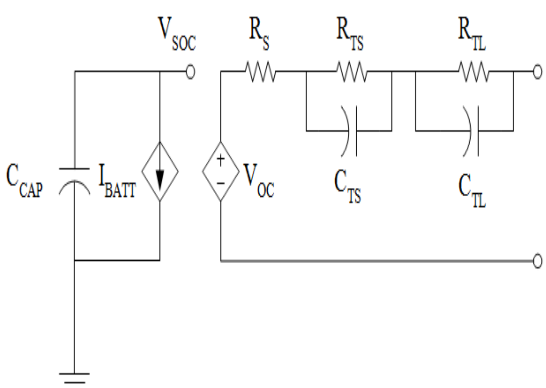

Figure 4: Circuit Model Of Battery

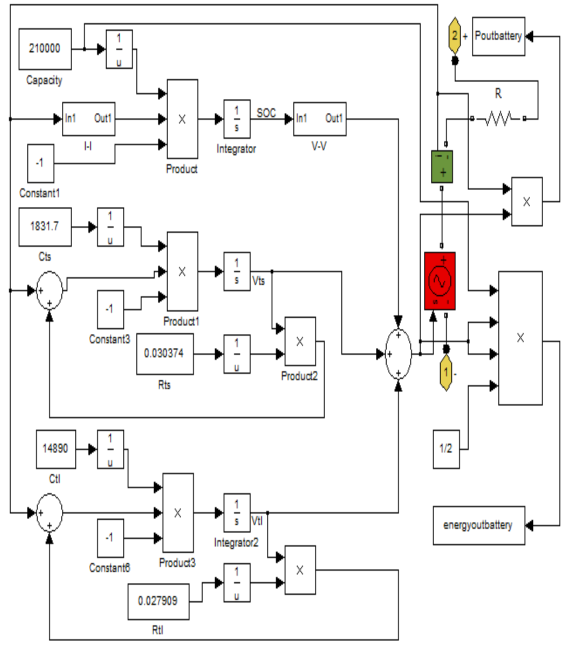

Figure 5: Simulink Model Of Battery

3. DISCRETE PULSE WIDTH MODULATION (PWM) GENERATOR

The three modulating signals used by the PMW Generator to generate the 6 IGBT pulses. The output pulses are a vector (with values=0 or 1). For a 3-arm bridge: Pulses 1, 3 and 5 are respectively for the upper switches of the first, second and third arm. Pulses 2, 4 and 6 are for the lower switches. External signals are used for pulse generation. The width of the input vector must be 3 for 3-phase bridges. It compares the modulating signal with carrier signal and generates pulses accordingly.

Table 1: Carrier Frequency Vs. Modulating Frequency

Parameters	Value
Fc (Carrier frequency in Hz)	20K
Fm (Modulating frequency in Hz)	50

4. VOLTAGE REGULATOR

The load voltage is regulated at 1 pu by a Proportional Integral (PI) voltage regulator using abc to dq and dq to abc transformations, The first

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output of the voltage regulator is a vector containing the three modulating signals used by the PMW Generator to generate the 6 IGBT pulses as shown in Figure 1. The second output returns the modulation index. The Discrete 3-Phase PWM Pulse Generator is used. One input is used as reference in per unit whose value is set as constant 1.Other input is 3 phase voltage in per unit refer as Vabc (pu).The conversion is done as below:

Vabc(pu)=Vabc(volts)/((VbaseLL/1.71)*1.41)

Where; Vbase Line to Line voltage in RMS.

Here, PI is used to remove steady state error in the model. Values are chosen carefully for the optimal operation of the circuit.

Table 2: Voltage Regulator Parameters.

Parameters	Value
Proportional Gain (Kp)	0.4
Integral Gain (Ki)	500

5. SIMULATION RESULTS

The whole system was designed to ensure that super capacitor and battery are applied to the three phase inverter designed as shown in Figure 10, the result of the simulation has revealed that voltage and current total harmonic distortion (THDv) at load in super capacitor storing system is lesser than battery. Which give a clear picture that super capacitor has more efficiency than other conventional storing system as battery.

5.1 Performance Analysis of Super capacitor and Battery Applied to the 3 phase Inverter

Super capacitor (SC) model is ensured to produce a fixed voltage value equals to 2.8 V and output current equals to 0.3 A as shown in Figure 6 and Figure 7, the same way battery design produces the same voltage SC produces with 2.8 V and current with 0.3 A as shown in Figure 8 and Figure 9.

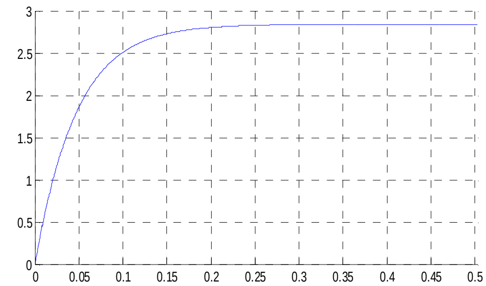

Figure 6: Super Capacitor DC Voltage

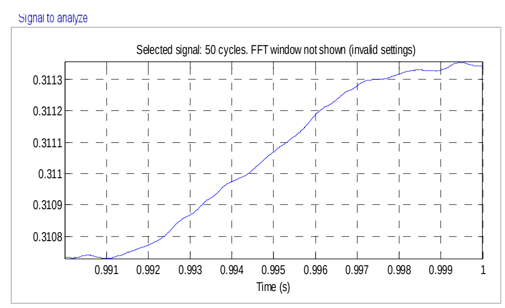

Figure 7: Super Capacitor Dc Current

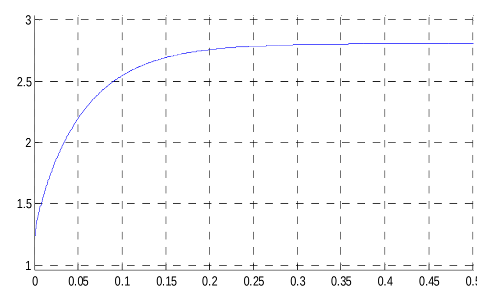

Figure 8: Battery DC Voltage

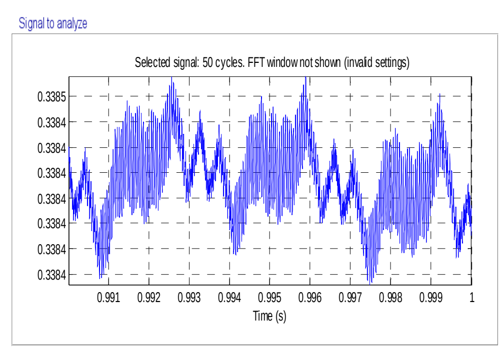

Figure 9: Battery Dc Current

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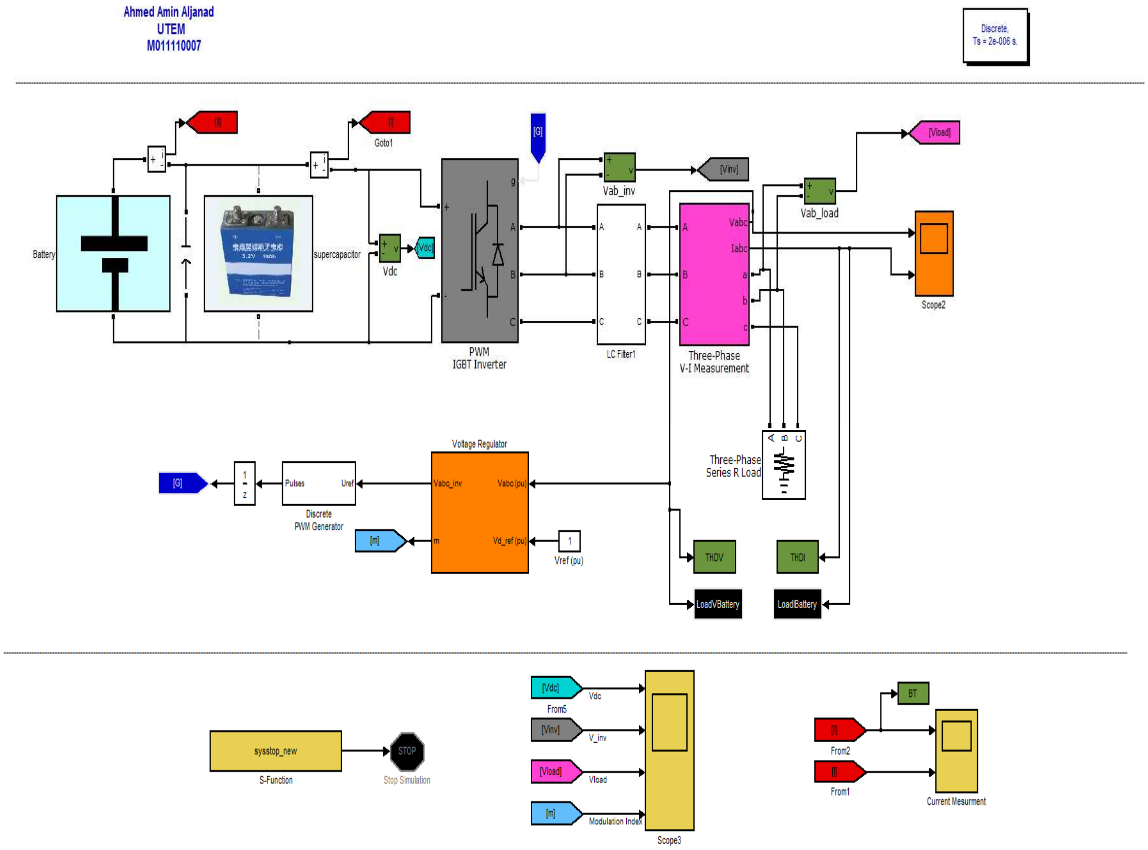

Figure 10: The Schematic Diagram Of The Whole System

The total harmonic distortion (THD) of Battery and super capacitor dc voltage is investigated after the time (Ts) is set from 0.5 to 0.6s as shown in Figure 11 and Figure 13. The result exposed out that THDv of battery dc voltage is much higher than super capacitor has with 101% and 80.4% as shown Figure 12 and Figure 14.

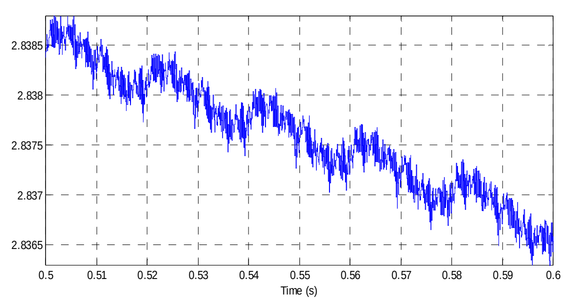

Figure 11: Battery dc Voltage (Ts= 0.5 to 0.6)

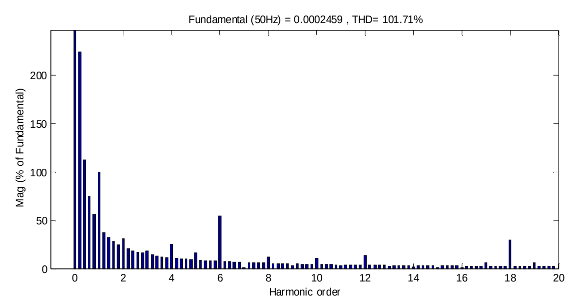

Figure 12: THDv of Battery dc Voltage (Ts= 0.5 to 0.6)

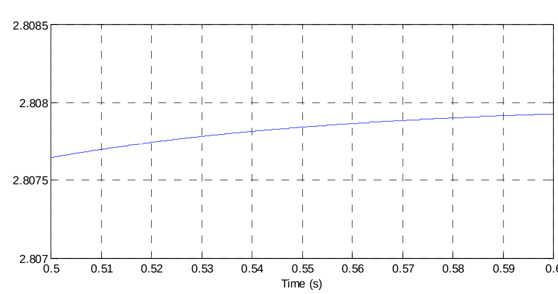

Figure 13: SC dc Voltage (Ts= 0.5 to 0.6)

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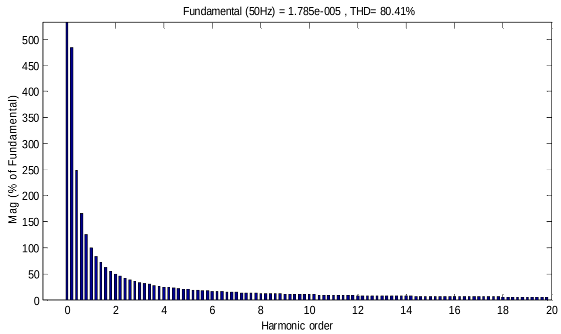

Figure 14: THDv of SC dc Voltage (Ts= 0.5 to 0.6)

5.2 Inverter results of Super capacitor and Battery

The circuit is discretized at a sample time of 2 us. The IGBT inverter uses PWM at a 20 kHz carrier frequency. After FFT performed on a 5-cycle window starting at t= 0.2 to 0.3 in both energy storages (Super-capacitor and Battery) inverters output as shown in Figure 15 and Figure 17, the THDv for super-capacitor is slightly reduced compared to battery with 53.08% and 68.26% as shown in Figure 16 and Figure 18 consecutively.

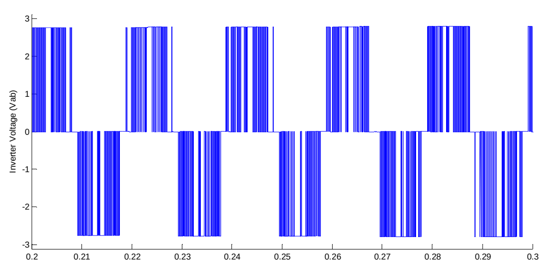

Figure 15: SC inverter Voltage (Vab)

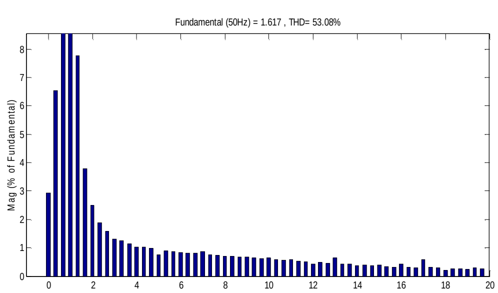

Figure 16: THDv of SC inverter Voltage (Vab)

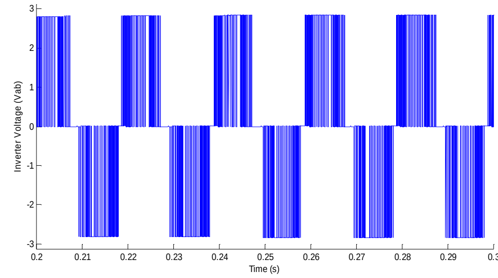

Figure 17: Battery Inverter Voltage (Vab)

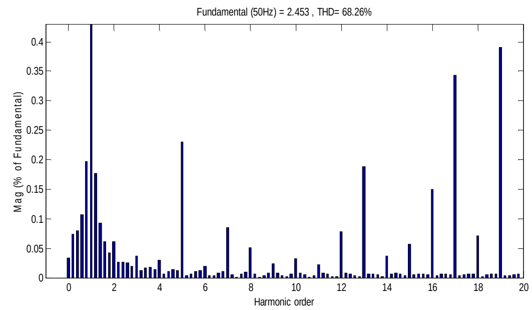

Figure 18: THDv of Battery inverter Voltage (Vab)

5.3 Load Voltage Result of Supercapacitor and Battery

The acquired results after simulation illustrate that super capacitor load in Figure 19 with approximately nominal voltage 2.1 V has less total harmonic distortion with 0.85% as shown in Figure 20 compared to battery load with the same nominal voltage 2.1 as shown in Figure 21; In contrast the THDv for voltage of battery has high total harmonic distortion with 10.29% as shown in Figure 22. The time was set for both energy systems from start point 0s to 0.2s.

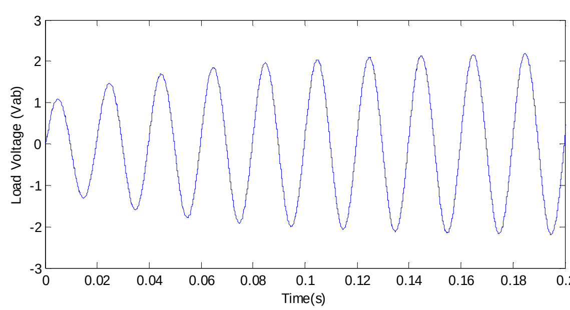

Figure 19: Super capacitor load voltage (Vab)

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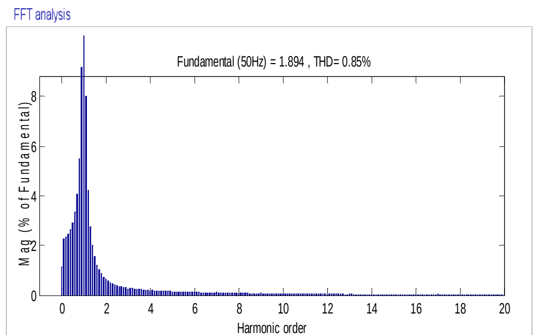

Figure 20: THDv of Super capacitor load voltage (Vab)

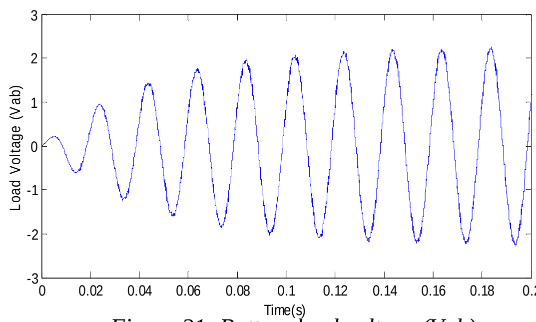

Figure 21: Battery load voltage (Vab)

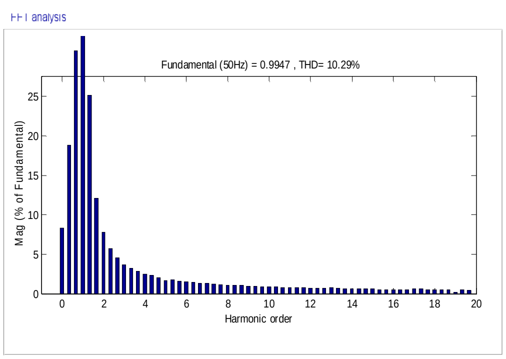

Figure 22: THDv of battery load voltage (Vab)

6. CONCLUSION

In this work the concept of Fast Fourier Transforms (FFT) is implemented to the three phases two level voltage source inverters (VSI). The results showed that the THDv for voltage of super-capacitor is slightly reduced compared to the battery. Future work will be implemented in the real prototype in order to validate simulation results through experimental work.

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