

A NEW DESIGN METHOD OF OUTPUT FILTER FOR SPACE VECTOR PWM FED INDUCTION MOTOR

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Abstract

This paper proposes a new simplified method for design, simulation, implementation, and obtaining optimum value of ac output filter to the SVPWM inverter fed induction motor using the benefit of PSIM program is developed. Also a complex mathematical equations and transfer functions are not desirable.

The L-C filter cancels all harmonics and a real pure sinusoidal output voltage and current is obtained. Due to the flexibility of PSIM software, the values of L-C combination are obtained by trial and error method. The advantage of this method, it can vary the values of inductor and capacitor until the value of desired outcome is obtained.

Experimental and simulation results have verified the superior performance and the effectiveness in reduction the harmonics of the proposed filter.

Keywords: Filter, SVPWM, Harmonics Analysis, Induction Motor, THD.

طريقه تصميم جديده لمرشح خارجي لعاكس مضمن عرض النبضه للمتجه الفضائي يغذي محرك حتي ثلاثي الطور

الخلاصه

يقدم هذا البحث طريقه جديده ومبسطة قد طورت التصميم و التمثيل و التطبيق وللحصول على افضل وامثل قيمه للمرشح الخارجى (output filter) لعاكس مضمن عرض النبضه للمتجه الفضائي يغذي محرك حتي ثلاثي الطور باستخدام فائده البرنامج (PSIM). كذلك هذه الطريقه لا تحتاج الى معادلات رياضيه ودوال انتقاليه معقده. مرشح الترددات (L-C Filter) يقضى على كل التوافقيات ويحصل على موجة جيبيه نقيه وحقيقية للفولتية الخارجيه والتيار. من خلال مرونة البرنامج PSIM القيمة لمركبة LC ممكن الحصول عليها بواسطة طريقه التجربة والخطا (Trial and Error) من فوائد ذة الطريقه اذ يمكن تغير القيم لكل من الملف و المتسعة حتى تحصل على النتيجة المرغوب فيها. ان نتائج الاختبار العملي والتمثيل الرياضى اثبتت وبشكل واضح الاداء الفائق والفاعلية الكبيرة في تخفيض التوافقيات للمرشح المقدم.

NOMENCLATURE

L	Inductive
C	Capacitive
F	Frequency
X_m	Leakage reactance (ohm)
X_r	Rotor reactance (ohm)
X_s	Stator reactance (ohm)
R_r	Rotor resistance (ohm)
R_s	Stator resistance (ohm)
M	Modulation index
SVPWM	Space vector pulse width modulation
THD	Total harmonic distortion

1. INTRODUCTION:

The SVPWM technique has become a popular PWM drive three-phase voltage source inverter fed ac motors. These are widely used both in industrial and household applications [1].

To achieve excellent performance of SVPWM drive induction motor, fast switching devices are used. But this also brings disadvantage effects:

Firstly the waveform of output voltage and current contains a high amount of harmonic components, which increase additional losses, and lower performance for the motor.

Secondly, it causes higher switching losses in the inverter. The switching losses of the inverter are linearly proportional to the switching frequency and of course the efficiency of the system is decreased.

Consequently, the most important compromising and mitigating of the above disadvantages are the use of ac output filters for the SVPWM inverter.

There are several different types of output filters are given for PWM techniques [2,3,4,5]. But in the case of SVPWM technique is not found in literature any type of output filters, except a theoretical project for PH.D study [6]. The basic simple filter is a second order LC filter consisting of a series inductance and parallel capacitance. It has only two elements per phase that can be adjusted in this study figure (1).

2. PROPOSED MODEL:

The space vector pulse width modulation (SVPWM) inverter fed three-phase induction motor was built in last year. The model is designed by imitating the conception of TMS320 (DSP) Micro controller.

The step by step of the whole system was explained, analyzed, and studied using MATLAB SIMULINK without ac filter [7].

The overall drive system such study, design, implementation and simulation for prototype model are given in detail [8] using PSIM software.

PSIM program provides a powerful and efficient environment for power electronics and motor control simulation. PSIM's graphic user interface is intuitive and very easy to use. A circuit can be easily setup and edited. The simulation results can be analyzed easily using various post-processing function in the waveform display program.

The PSIM features are:

1. Simple use.
2. Fast simulation.
3. Flexible control representation.
4. Built-in modules.
5. Add-on modules.
6. Parameter sweep.
7. Runtime waveform display

PSIM's simulation environment is interactive. It allows users to change parameters and monitor simulation waveforms in the middle of a simulation run [9].

2.1 Structure and Building of the Proposed Model.

The blocks and their parameters of the system model are given in the following:

- 1- Space vector calculation.
- 2- Vector location
- 3- Time interval calculation.
- 4- Voltage source inverter motor drive system.
- 5- L-C output filter.

A single phase (full wave rectifier) is used as input power supply.

A rectifier circuit is one which links an a.c supply to d.c load; it converts an alternating voltage supply to direct voltage. The direct voltage so obtained is not normally level, as from battery, but are contains an alternating ripple component superimposed on the mean (d.c) level. Figure (2) shows the structure of whole system with LC output filter.

3. DESIGN AND IMPLEMENTATION:

The task of the filter design is not simple. Complex mathematical equations and transfer functions are needed. In addition, the filter size, cost, weight, and losses should be optimized. Besides that, it is constrained by the total harmonic distortion of the output voltage and current (THD_v , THD_i), the voltage drop in the filter inductor, and the filter resonance frequency [3]. Also the dynamic effect of the filter over all system must be considered.

Accordingly, new simplified method for design, implementation to get optimum value of LC output filter of the SVPWM drive induction motor using the benefits of characteristic of PSIM program is developed.

4. TRIAL AND ERROR METHOD USING PSIM PROGRAM:

The PSIM program is easily run to get the simulation results. In addition to that, all parameters in the following five parts of the SVPWM inverter drive system can be flexibly to be changed.

1. Rectifier and L-C dc link.
2. Three-phase MOSFET bridge SVPWM inverter switching frequency.
3. Modulation index and V/f ratio.
4. Three-phase induction motor.
5. A.C output filter.

The name plate of the motor: 3-phase I.M, 380volt(line), 1100watt, 2pole, 2800rpm, 50Hz. And the values $R_s=6\Omega$, $X_s=25.13\Omega$, $R_r=15\Omega$ (referred to stator), $X_r=12.5\Omega$ (referred to stator), and $X_m=300\Omega$.

The output parameters of full-wave rectifier are $C = 880\mu F$, $L = 16mH$ and AC supply voltage is (220) volt with respect to the rated frequency (50Hz).

The L & C of dc link is used to reduce the ripple content of the output voltage for the single phase bridge rectifier. Its values have been selected such that the ripple factor lower than 10% [10]. Then due to the flexibility of PSIM, the value of L-C combination is obtained by trials and errors. The advantage of this method, it can vary the values of inductor and capacitor until the desired outcome is obtained [11].

The optimum value of L-C combination has been obtained in PSIM as: $L_f = 8mH$, $C_f = 12.5\mu F$.

The trial and error method is run for different operating points, besides that all constrains and limitation points mentioned in section (3) are considered. Figure (2) shows the structure of SVPWM inverter with LC output filter.

5. SIMULATION AND EXPERIMENTAL RESULTS:

All parameter values of the proposed system are given in section four. Also the optimum value of L-C output ac filter is obtained using trial and errors method in PSIM program as: $L_f=8mH$, $C_f = 12.5\mu F$. The results at no load operation are performed because the total harmonic distortion THD is higher [7]. Two values of modulation index (90% and 50% of rated) is taken into calculation to give all possible ranges of THD variation.

The no load test of SVPWM inverter drive induction motor is obtained by applying the higher value of modulation index (90%) and the lower possible value (50%). The phase voltage and phase current SVPWM inverter are analyzed by using Fourier series. This analysis is done by using PSIM program to obtain the harmonic content, for complete switching frequency (i.e. the switching frequency of real building model which is equal to 2 KHz).

The simulation and experimental results of phase voltage and phase current are shown in figures (3....6) and figures (7....14) respectively, for two cases carried, without and with L-C output filter.

6. ANALYSIS OF THE RESULTS:

For the simulation results figures (3 and 5) show the frequency spectrum of phase voltage and current for two different modulation indexes (90%, 50%) large harmonic switching frequencies component are noted when no filter is installed

Figures (4 and 6) show the frequency spectrum of phase voltage and current for two different modulation indexes (90%, 50%) when LC filter is installed.

Significant reduction in high harmonic switching frequencies component are noted when a filter is applied as shown in table (3).

Also for the experimental results, the same conclusion can be made as shown in figures (7, 8....etc) (for the same operating points of the above simulation results). Comparison between simulation and experimental results for phase voltage and phase current are given in tables (1) and (2) respectively. By examining the above results (without filter and with filter) the following important points can be recorded.

1. The practical experimental tests have excellent performance parameters with respect to the theoretical results, and it can be seen clearly in the waveforms, fundamental component and total harmonic distortion for the voltage and current.
2. The L-C output filter attenuates high harmonic switching frequencies from the SVPWM inverter output voltage and current effectively.

7. STUDY AND DISCUSSION:

Table (3) shows the simulation and experimental results of important performance when the proposed filter is applied. The followings notes can be recorded:

1. The percentage reduction of total harmonic distortion for voltage (THD_v) and current (THD_i) for different operating points is very high in the simulation and experimental results as shown in table (3). Therefore, the proposed filter provides efficient and effective filtering, especially different operating points of the drive are typically chosen for filter design.
2. The voltage drop across the filter at fundamental frequency is very small for the simulation and experimental results (table 3). This must be kept within limits usually about (3%) because it reduces the available output voltage and thus the flux and torque in the machine [3].
3. The resonant frequency of the filter is defined as:

$$F_r = \frac{1}{2\pi\sqrt{L_f C_f}} \quad (1)$$

$F_r = 503.29\text{Hz}$ (in proposed filter)

This value of the resonant frequency (F_r) is normally excepted because the resonant frequency must be placed between the maximum fundamental frequency (50Hz+10%) and the lowest

switching frequency (i.e. 500Hz) [2]. According to the above studies all constrains motioned in the design procedure of the output ac filter are fulfilled.

8. CONCLUSION:

The following important points have been concluded:

1. The trial and error method using the flexibility of PSIM program is very simple, accurate, and effective for output filter design.
2. It can be easily applied for any type of filter.
3. It can be used for any different modulation technique, which produces different harmonic spectrum of inverter output.
4. Different switching frequencies can be achieved in order to make good compromise and optimize of the whole drive system.
5. This design method can be extended to any rating of similar drive system especially in industrial application.

The advantages of the output filter for SVPWM inverter fed induction motor are as the follows:

1. Harmonic switching frequency is canceled.
2. Total harmonic distortion of the output inverter (voltage and current) is reduced.
3. The output of the inverter is near sinusoidal power being applied to the motor. This means that:
 - No transient overvoltage occurs at the motor winding.
 - There are no additional motor losses.
 - Motor noise is low due to the absence of harmonics

9. REFERENCES:

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Table (1)

Modulation Index %	Simulation results		Experimental results		
	Fundamental V_{rms}	THD %	Fundamental V_{rms}	THD %	
90	540	9.1	538	10.2	Without filter
50	515	15.7	515.8	16.8	
90	495.4	4.6	496.9	4.2	With filter
50	437.6	4.4	435	4.3	

Table (2)

Modulation Index %	Simulation results		Experimental results		
	Fundamental V_{rms}	THD %	Fundamental V_{rms}	THD %	
90	107.5	23.8	107.8	25	Without filter
50	63.5	59.2	61.6	60	
90	105.6	15.6	106.7	15.3	With filter
50	62.2	4.6	60	4.9	

Table (3)

Modulation Index %	Simulation results			Experimental results		
	THD _v reduction %	THD _i reduction %	Voltage drop %	THD voltage reduction %	THD current reduction %	Voltage drop %
90	34.4	49.4	1.76	38.8	58.8	1
50	92.2	71.97	2	91.8	74.4	2.6

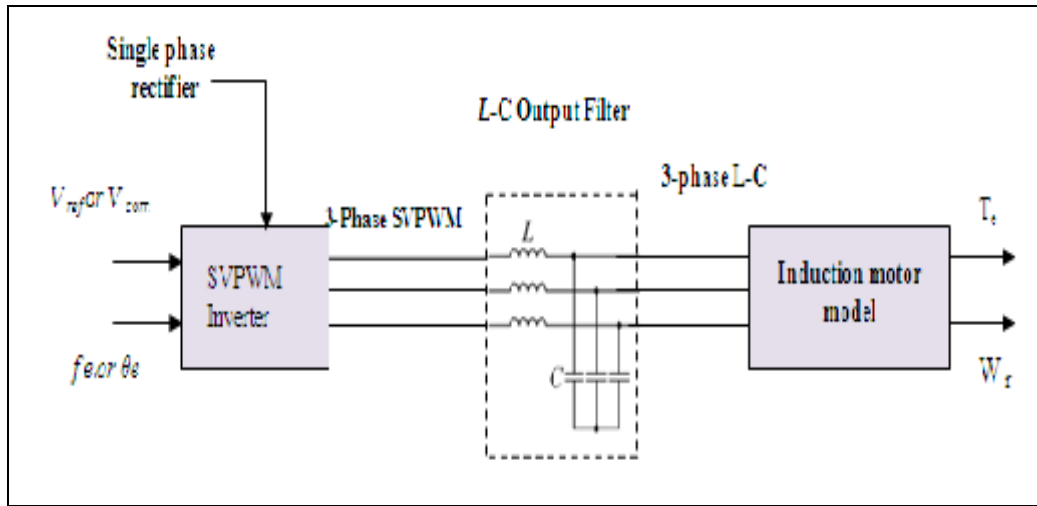


Figure (1) Block diagram of overall drive system

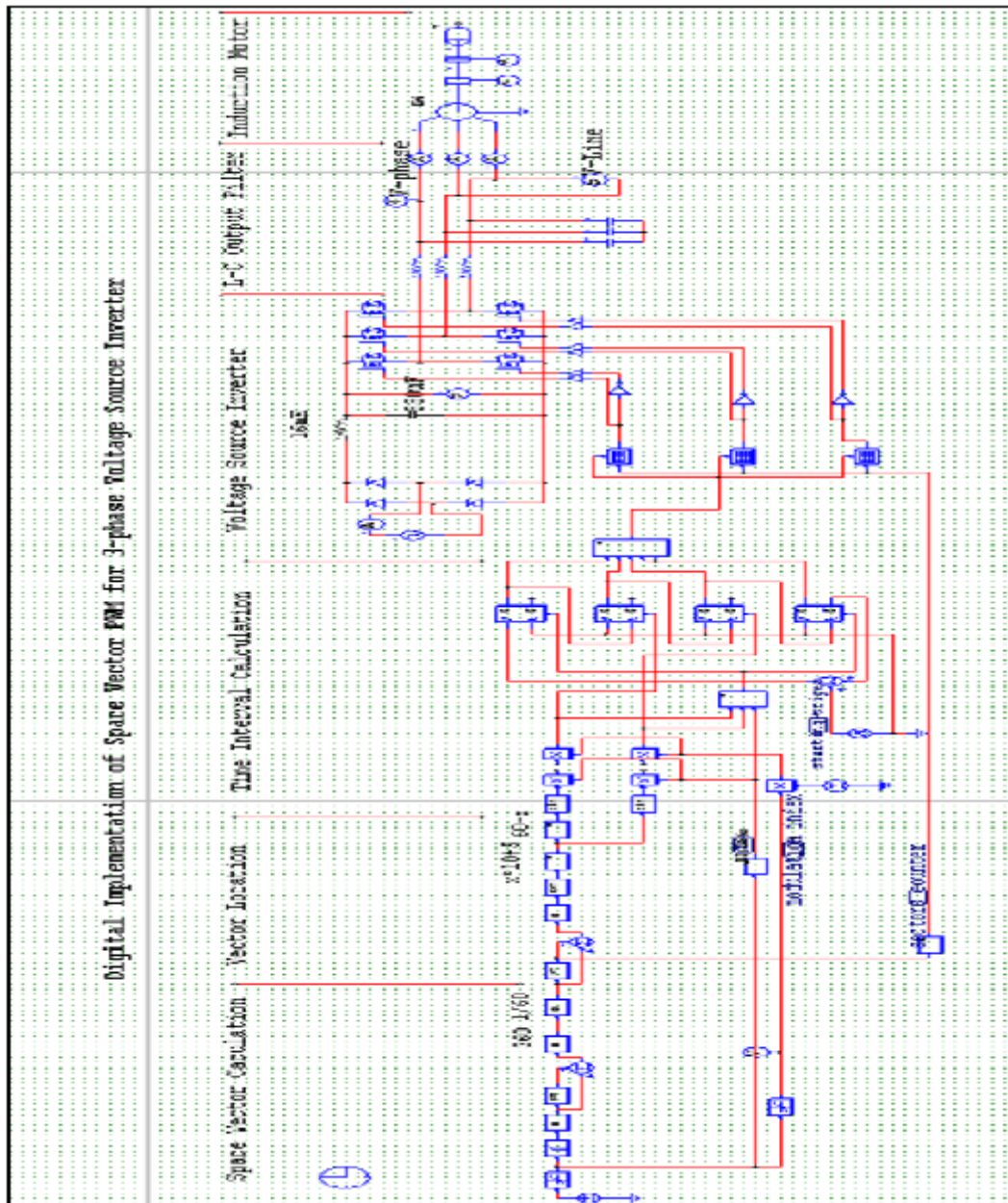


Figure (2) Structure of SVPWM inverter with LC filter

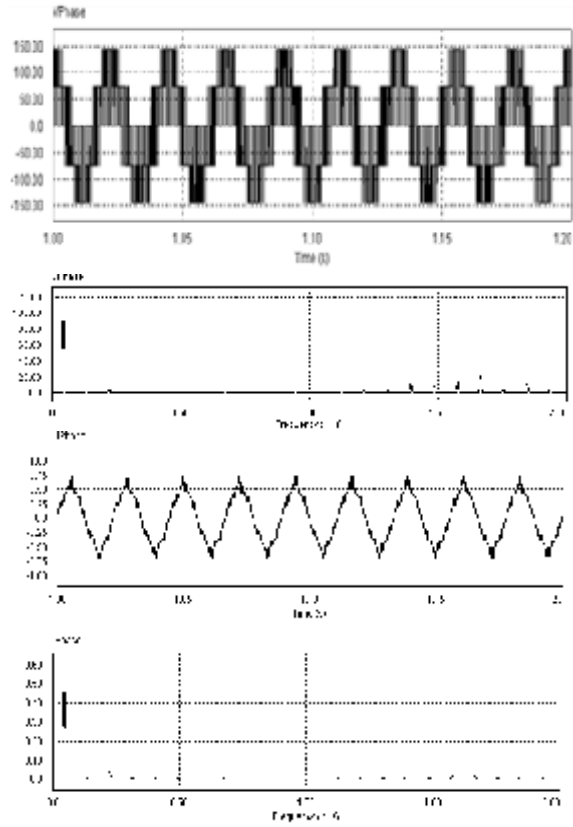


Figure (3) Voltage (v), Current (I) and harmonics of 90% rated (V&f) without filter

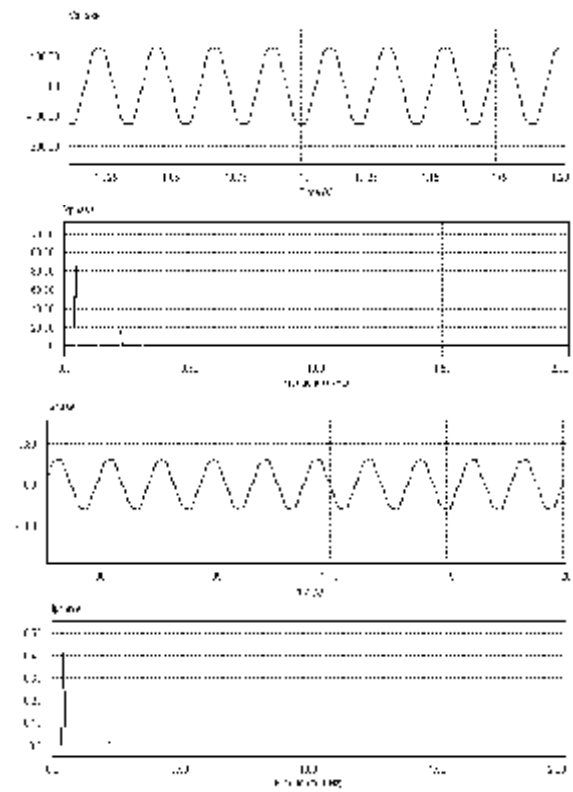


Figure (4) Voltage (V), Current (I) and harmonics of 90% rated (V&f) with filter

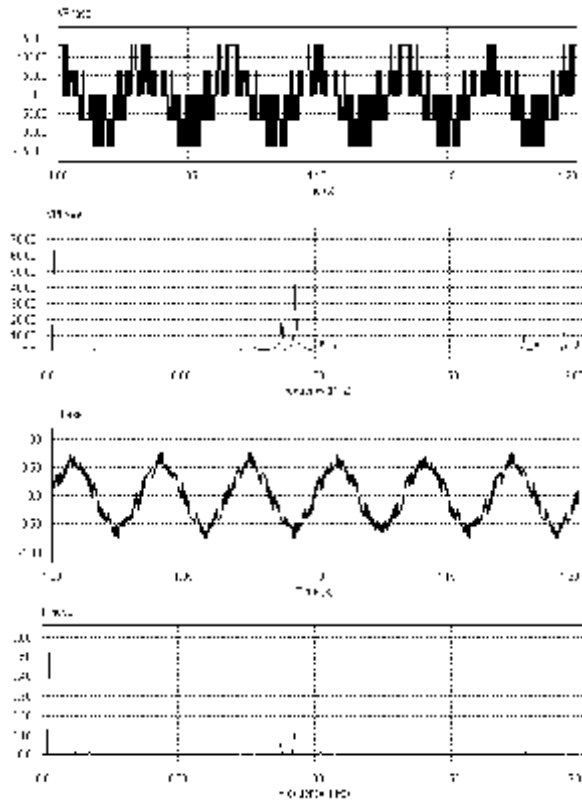


Figure (5) Voltage (V), Current (I) and harmonics of 50% rated (V&f) without filter.

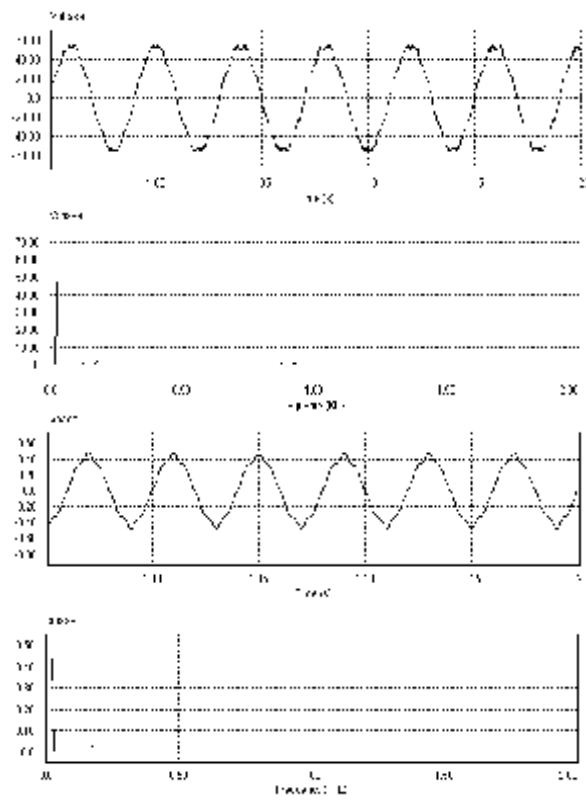


Figure (6) Voltage (V), Current (I) and harmonics of 50% rated (V&f) with filter.

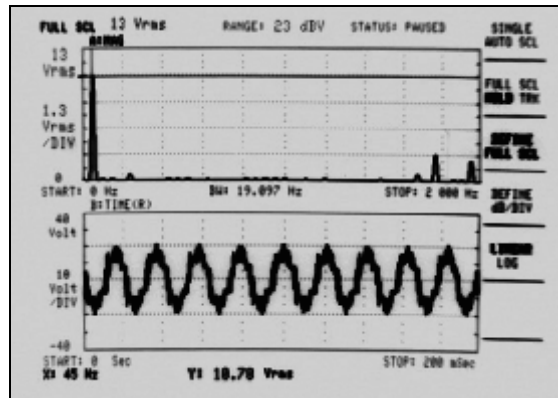


Figure (7) Voltage harmonic analysis of 90% rated without filter.

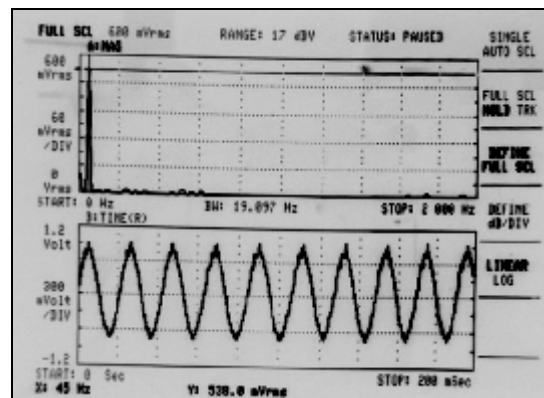


Figure (8) Current harmonic analysis of 90% rated without filter.

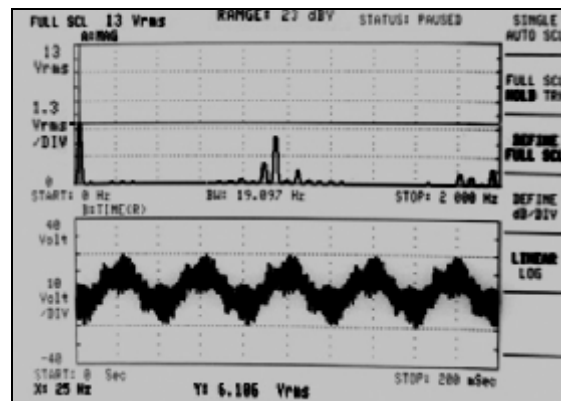


Figure (9) Voltage harmonic analysis of 50% rated without filter.

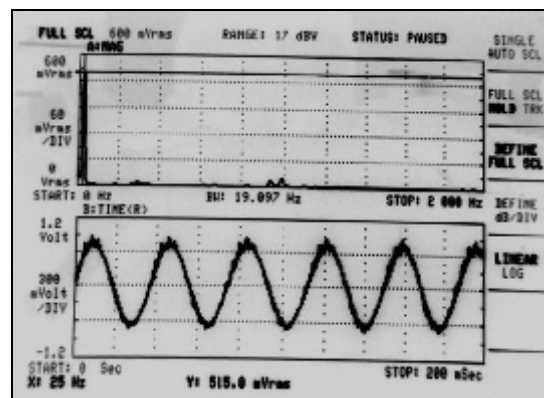


Figure (10) Current harmonic analysis of 50% rated without filter.

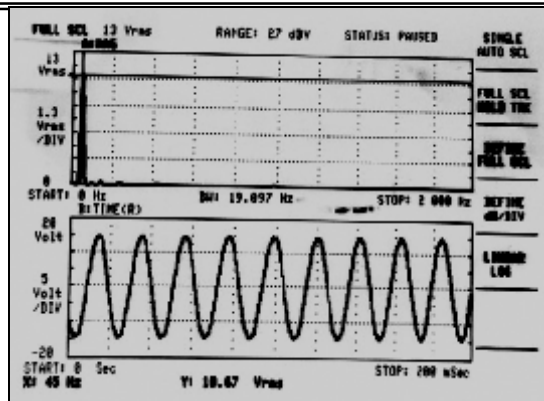


Figure (11) Voltage harmonic analysis of 90% rated with filter.

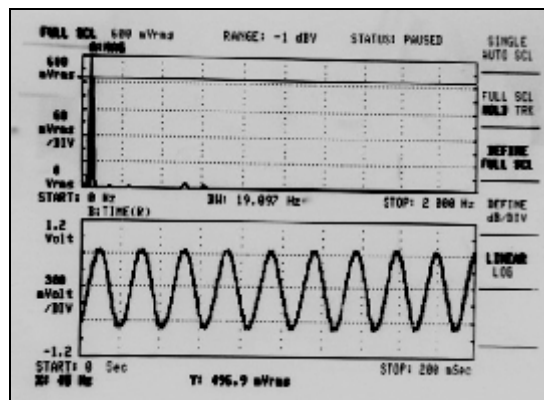


Figure (12) Current harmonic analysis of 90% rated with filter.

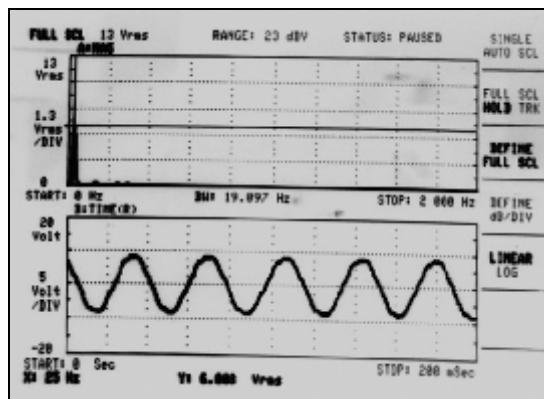


Figure (13) Voltage harmonic analysis of 50% rated with filter.

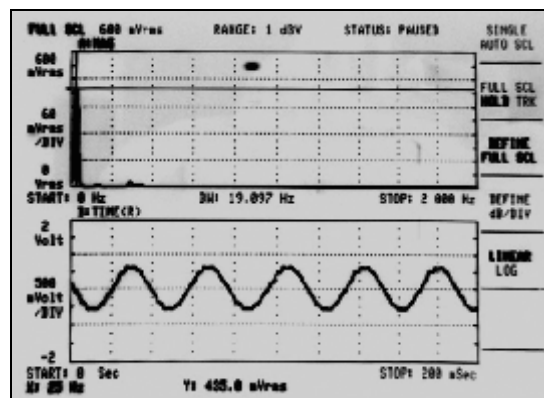


Figure (14) Current harmonic analysis of 50% rated with filter.



Picture of SVPWM drive system and L-C filter