Power Quality Enhancement in ASD Systems Using Genetic Algorithms

B. Justus Rabi, S. S. Darly, and R. Arumugam

Abstract—**In traditional Adjustable Speed Drives (ASDs) voltage controller low power factor and high-energy are some of the major drawbacks. These can be eliminated using Genetic Algorithm based PWM optimization. This Genetic Algorithm optimization eliminates the harmonics in the inverter output and provides power factor close to unity. The increased use of power electronics-based loads, (adjustable speed drives, switch mode power supplies (SMPS), etc.) for improving system efficiency and controllability results in increase in the harmonic distortion levels in end use facilities and overall power system. In this paper, the harmonic contents and distortion factor are less in the output of Genetic Algorithm optimized pulse width Modulated impedance source inverter when compared to standard PWM and random PWM based inverters. It is the most economic methodology to improve the power quality of inverters.**

Index Terms—**Harmonic distortion, impedance source inverter(ZSI), pulse width modulation (PWM), genetic algorithm(GA).**

I. Introduction

In RECENT years, a variety of power electronics equipment with voltage-fed pulse width modulation (VSI-PWM) inverters are used widely in industrial applications. These power network systems have caused significant problems, such as generation of reactive current, as well as higher harmonic distortion in the utility power sources. To reduce the harmonic distortion it is advantageous to have a complete inverter system that uses an efficient method to suppress the harmonic distortion. In many previous papers random pulse width modulation techniques have been presented [1]. However these methods have been mainly concerned with an active reduction policy for all harmonic components based on PWM pattern generations [2]. There are two issues in random PWM method, first, output harmonic distortion have not been alternatively improved and second, the output harmonic intensity of the inverter may is randomly changed with various random sources. These random harmonic distributions may be different at every sinusoidal cycle, which may be observed from a spectrum analyzer [3]. Hence the random modulation may not ensure that the power quality of the inverter output is optimum at all times.

In this paper a method based on Genetic Algorithm is proposed to suppress harmonic distortion. Compared with standard PWM and random PWM methods, the genetic algorithm-based inverter has smaller harmonic distortion and spread of harmonic energy that will result in less loss and lower acoustic noise. In research an investigation is done by simulation and experimental studies on a voltage controlled inverter with various output frequencies. The proposed strategy can improve the power quality of variable frequency dc-ac inverters, uninterruptible power supplies (UPSs) and scalar-controlled low performance ac drives.

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II. Genetic Algorithm Based PWM Optimization

GAs have recently recently been applied to optimize the performance of the electrical drive systems [4]. In order to find the best triangular carrier sequence for a DSP based sinusoidal PWM inverter, a real-valued GA is employed with minimum harmonic distortion as the objective function [5]. In a GA, the objective function is used to provide a measure of performance valuation. For the proposed optimized PWM inverter, the fit individuals should have a minimum harmonic distortion value [6], [7]. Hence, total harmonic distortion (THD), weighted total harmonic distortion (WTHD), and distortion factor (DF) of output line voltage may be separately selected as an objective function according to customer requirements. The GA procedure for optimizing PWM with the following operations [8]:

1) initial generation;
2) performance evaluating;
3) fitness calculation;
4) Selection;
5) recombination (crossover);
6) mutation;
7) reinsertion.

The Genetic Algorithm uses objective functions based on some performance criterion to calculate an error. However, the Genetic Algorithm is based on natural selection using random numbers and does not require a good initial estimate. Genetic algorithms manipulate strings of binary digits and measure each string's strength with a fitness value. The stronger strings advance and mate with other strong strings to produce offspring. Eventually, one string emerges as the best. One of the most important advantages of the Genetic Algorithm over the Newton–Raphson technique is that it is able to find the global minimum, instead of a local minimum, and that the initial estimate need not be close to the actual values as shown in Fig. 1. Another advantage is that it does not require the use of the derivative of the function, which is not always easily obtainable or may not even exist, for example, when dealing with real measurements involving noisy data. Reproduction is a process in which individual strings are selected according to their fitness. The fitness is determined by calculating how well each string fits an objective function. Copying strings according to their

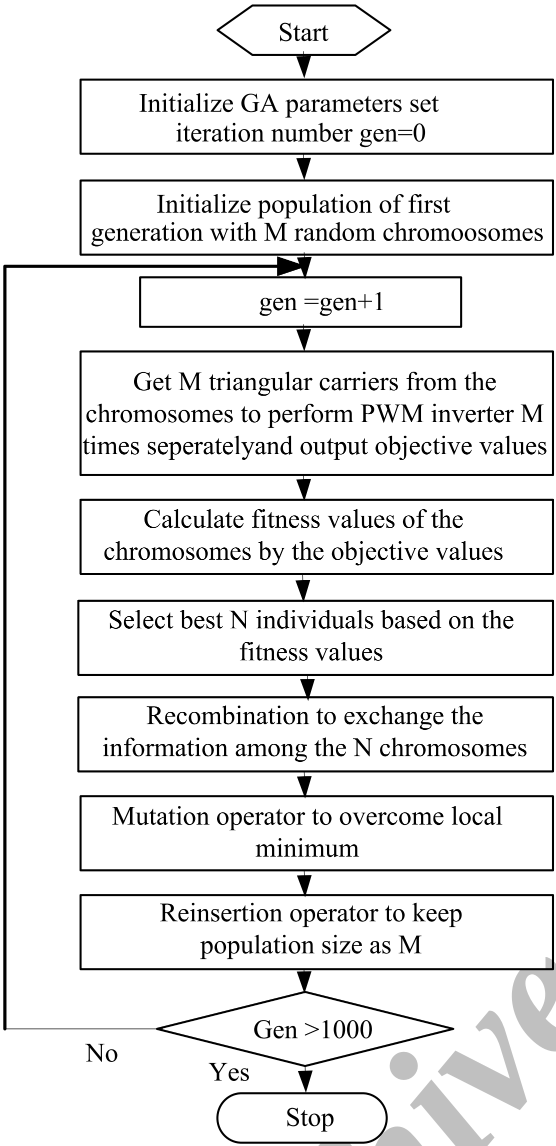


Fig. 1. GA Operation flowchart.

fitness value implies that strings that fit the objective function well have a higher probability of contributing one or more offspring in the next generation. This process of reproduction is, of course, an artificial version of natural selection. Crossover is a two-step process that involves mating and swapping of partial strings. Each time the crossover operator takes action; two randomly selected strings from the mating pool are mated. Then, in the case of a simple crossover, a position along one string is selected at random, and all binary digits following the position are swapped with the second string. The result is two entirely new strings that move on to the next generation.Mutation follows crossover and protects against the loss of useful genetic information (1's and 0's). The operator works by randomly selecting one string and one bit location and changing that string's bit from a 1 to a 0 or vice versa. The probability for mutation to occur is usually very small, roughly one mutation per 1000 bit transfers.

The three genetic operators, reproduction, crossover, and mutation, provide an effective search technique using natural selection and random number generation [9].

Advanced operators, such as dominance, inversion, and segregation exist, but are generally not essential for good results to many problems [10]. In some cases, the advanced operators can degrade the performance of the genetic algorithm [11]. This paper explains the real-valued GA performed on an offline PC with the Matlab software. In simulation studies, the following GA program parameters may yield satisfactory results:

- Initial population size—1000;
- Maximum number of generations—500;
- Probability of crossover—0.7;
- Mutation probability—0.05;
- Mean of the carrier frequencies—about 10 kHz;
- Initial range of real-valued
- Strings—(0.000 067; 0.0002);
- Performance measure—one of THD, WTHD, and DF of PWM inverter output voltage;

With gradient convergence processing, the THD of the PWM inverter output voltage is reduced by 5% (from 0.9141 to 0.8715) at the 500th generation and the optimized carrier sequence is yielded. For the standard PWM and random PWM, the x-axis refers to the number of sinusoidal cycles. For the GA-optimized, the x axis represents the number of genetic generations. The harmonic distortions of random PWM vary in different sinusoidal cycles. In order to compare it with other PWM strategies, the averaged value of harmonic distortions of the random PWM are calculated by

$$ATHD = \frac{\sum_{i=1}^{M} THD(i)}{M} \quad (1)$$

$$AWTHD = \frac{\sum_{i=1}^{M} WTHD(i)}{M} \quad (2)$$

$$ADF = \frac{\sum_{i=1}^{M} DF(i)}{M} \quad (3)$$

where ATHD is the average value of THD, AWTHD is the average value of WTHD, and ADF is the average value of DF in M sinusoidal cycles. In this paper, M = 500.

Applying the GA to different carrier frequencies, the corresponding optimized PWM carrier sequences are obtained. The GA-optimized PWM strategy not only spreads harmonic energy, but also achieves the best THD (reduced about 5%) compared with other PWM strategies at different carrier frequencies. If WTHD is selected as the optimized target, the GA-optimized PWM strategy has better WTHD than other PWM strategies but the improvement is not significant when the switching frequency is higher than 5 kHz. If DF is used as the optimized target, the GA-optimized PWM strategy has the best DF compared to other PWM strategies.

III. Experimental Setup

The block diagram of the experimental facility consists of a TMS320F2812 DSP board, an inverter module, a digital oscilloscope, a PC host computer, and a set of power supplies and the set up is as shown in Fig. 2.

The photograph of the experimental bench as shown in Fig. 3.

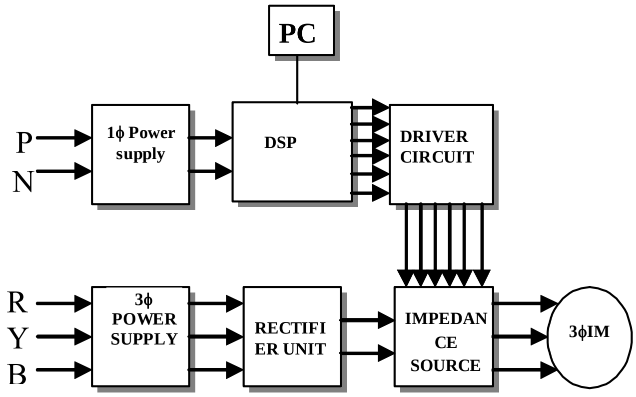


Fig. 2. Block diagram of experimental setup.

Digital Signal Processor (DSP) TMS320 F2812 board is available from Texas instruments as a development tool. It is one of the processors that executes most of the programs of the control algorithm. The DSP kit provides a complete development environment, and includes the DSP board, power supply, on-board JTAG compliant emulator and specific version of the Code Composer Studio Integrated development Environment. The DSP board itself has nearly all peripheral signals available on the board headers, making it easy to interface the board with other system hardware.

IV. Power Circuit Design

Orbitron type – IRFP450 MOSFET is selected for this research which has the ratings as 10 Amps, 500 V. The losses in the MOSFET is calculated as

$$\text{Conduction Loss} = I^2 \times R = 10^2 \times 0.1 = 10\ \text{W}$$

$$\text{Switching Loss} = VI \times (t_r + t_f) \times f\ /2$$
$$= 500 \times 10 \times 150 \times 10^{-9} \times 12 \times 10^3 / 2$$
$$= 2.2\ \text{W}$$

$$\text{Total Loss/MOSFET} = \text{Conduction Loss} + \text{Switching Loss}$$
$$= 10\ \text{W} + 2.2\ \text{W}$$
$$P = 12.2\ \text{W}.$$

Heat Sink - If the junction and ambient temperature are assumed a 125°C and 50°C, respectively.

$$T_J = P \times (\theta_{JC} + \theta_{CS} + \theta_{SA}) + T_A$$
$$125 = 12.2(0.65 + 0.24 + \theta_{SA}) + 50.$$
$$\theta_{SA} = 3.55$$

Therefore, P124 Heat Sink is used in this research, where P is total MOSFET loss, θ_{jc} is thermal resistance, junction to case, θ_{cs} is thermal resistance, case to sink, θ_{SA} is thermal resistance, sink to ambient, T_A is ambient temperature, and T_J is Junction temperature.

The values of snubber circuit elements obtained from the relationship are as follows. The value of capacitance is given by

$$C = 10(VA / V_S^{\,2})(60 / f)\ \mu\text{F}$$

where C is capacitance value in micro farad, VA is full load volt ampere rating of bridge rectifier, V_s is voltage applied to the circuit, and f is operating frequency Therefore, $C = 0.1\mu\text{F}$. The value of resistance is given by $R = 2D\ L/C$. Assuming $D = 0.65$, L =transformer leakage inductance = 0.4 mH. The calculated R=1 kΩ.

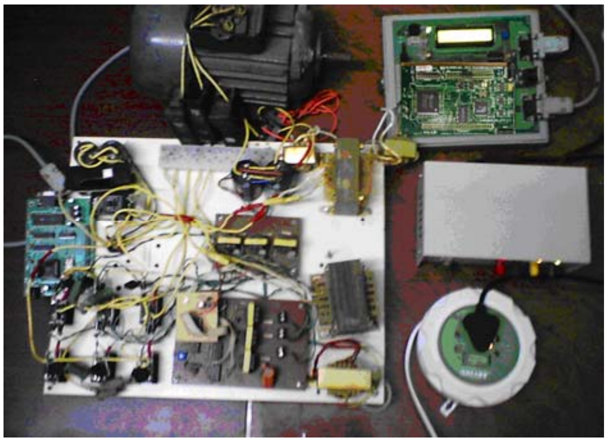


Fig. 3. Photo of GA based ASD system.

The schematic diagram of the circuit used in the experimental set up is shown in Fig. 4. The driver circuit shown in Fig. 5 consists of a rectifier unit, opto-coupler and an amplifier arrangement. The rectifier is used to convert AC voltage to DC voltage. This DC voltage is regulated and is given to the amplifier section. The opto-couplers are used to isolate the low and high voltage operations. The firing pulses from the controller are given to the opto-coupler which supplies the firing pulses to the amplifier arrangement consisting of transistors. The switches are turned on according to the sequences provided by the controller, which inverts the DC voltage to a three phase AC voltage. The DC voltage for the inverter is supplied in a single module.

V. Design of Firing Circuit

In the circuit diagram of the driver circuit shown in Fig. 5 the pulses corresponding to the zero crossing of the input voltage wave are detected. A ramp is generated with the zero crossing of the voltage wave as the reference. This is fed to a comparator, which compares the reference signal to the ramp. The output of the comparator is a square pulse which is differentiated to get exact coincidence of the ramp voltage and the input voltage wave. This is fed to a monostable multivibrator, which gives pulses of minimum width for successful triggering of MOSFETS. This pulse is then isolated by an isolator. By varying the reference voltage, the point of coincidence of ramp and reference voltage are varied and hence the firing angle is varied. The MOSFET requires a fast transfer of charge to and from the gate electrode for fast switching. The signal from the control circuit is not capable of driving the MOSFET. In order to strengthen the pulse and to provide the isolation between the control circuit and power circuit, an opto-coupler based driver circuit is developed. The pulse from the control circuit is connected to the input of the high frequency opto-coupler, 6N136 through an octal buffer 74244. The pulse output from the opto-coupler is not a perfect square wave. So the wave shaping circuit is needed which is built using the inverter buffer, IC7406. The output of the IC7406 is pulled up to 15 V. The 15 V pulse is fed to the Totem pole transistor 2N2222 and 2N2907. The two transistors are NPN and PNP type respectively which forms the Totem pole configuration, which are used as the pulse

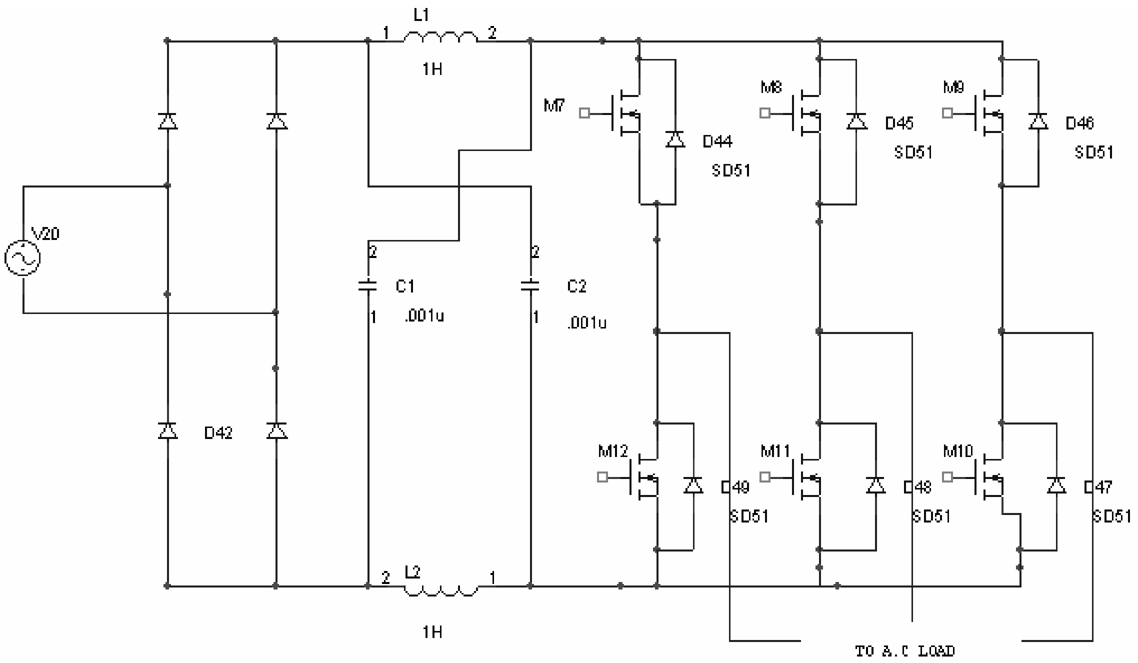


Fig. 4. Simulated circuits.

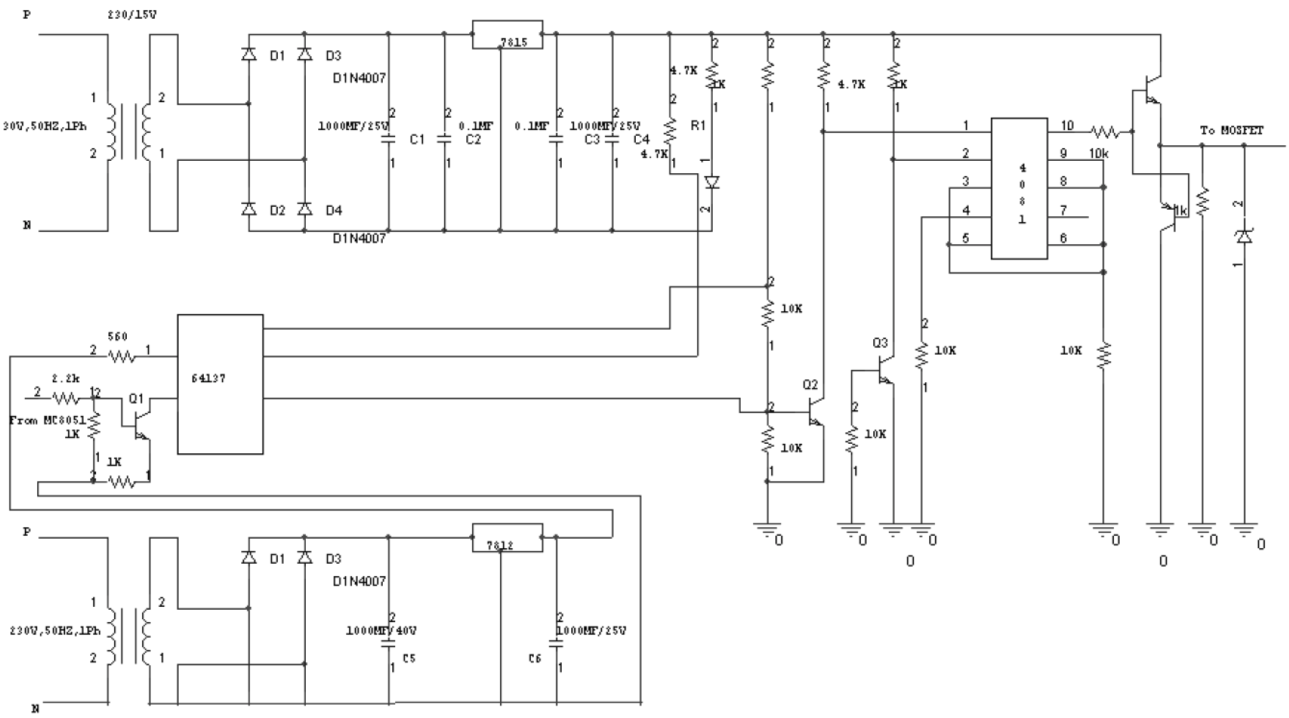


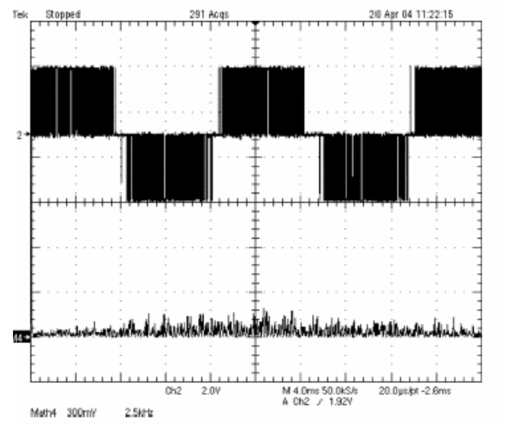
Fig. 5. Driver circuit.

amplifiers. Moreover these transistors are operated in the saturation region or cutoff region, as source and sink current is very fast. The switching speed also depends on the gate impedance. For high speed switching, a 10-ohm, half watt resistor is connected at the output circuit. A 12-volt zener diode is used so that the gate pulse does not exceed 12 V. This is a type of protection given to the MOSFET circuit.

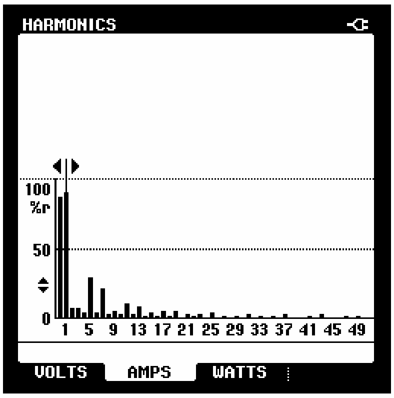
The inverter output of standard PWM and its spectrum are shown in Figs. 6(a) and 6(b) respectively. The inverter output of random PWM and its spectrum are shown in Figs. 7(a) and 7(b), respectively.

The inverter output of GA optimized PWM and its spectrum are shown in Figs. 8(a) and 8(b), respectively.

In order to compare the performances of standard PWM, Random-carrier-frequency PWM, and GA-optimized PWM, the Normalized output voltage of the PWM inverter and the corresponding harmonic spectrum are derived experimentally and displayed on a digital oscilloscope. On all oscilloscope screens, the upper trace is the normalized line-to-line voltage, time base of 4 ms/div, and magnitude of 2 V/div, while the lower trace is the spectrum with a frequency base of 2.5 kHz/div and magnitude of 300 mV/div. From the harmonic analyzer output shown in Fig. 6(b), of the standard PWM inverter, the 3rd, 5th, 7th harmonic contents are 14%, 30% and 23% respectively. From the harmonic analyzer output shown in Fig. 7(a), of the random PWM inverter, the 3rd, 5th, 7th harmonic



(a)



(b)

Fig. 6. (a) Inverter output of standard PWM, and (b) Harmonic analyzer output of standard PWM.

contents are 11%, 25% and 21% respectively. From the harmonic analyzer output shown in 8(b), of the Genetic Algorithm Optimized PWM inverter, the 3rd, 5th, 7th harmonic contents are 10%, 15% and 9% respectively. From the above observations, it is noted that the Total Harmonic Distortion (THD) GA optimized PWN inverter is less. Also, the distortion factor in GA optimized PWM inverter is less compared to the standard PWM and random PWM.

VI. CONCLUSION

To improve conventional PWM inverter performance by reducing harmonic distortions of output voltage and by spreading harmonic energy, a real-valued GA has been employed to optimize the carrier frequency of the modulation process. Experimental studies have demonstrated that the GA-optimized PWM technique is a promising method and an economical approach to improve the power quality of PWM inverters. The proposed optimizing strategy may be applied in variable-frequency dc–ac inverter, UPSs, and scalar- controlled low performance ac drives.

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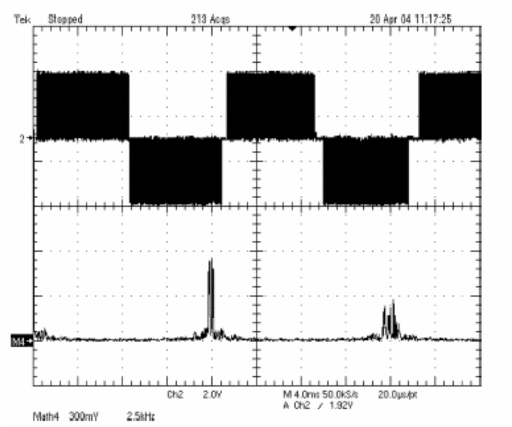
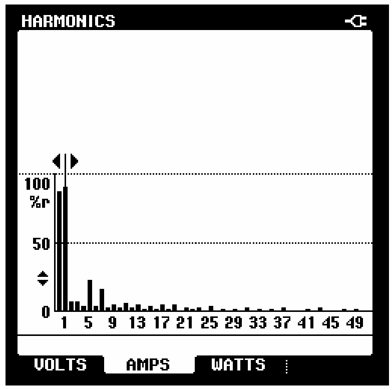
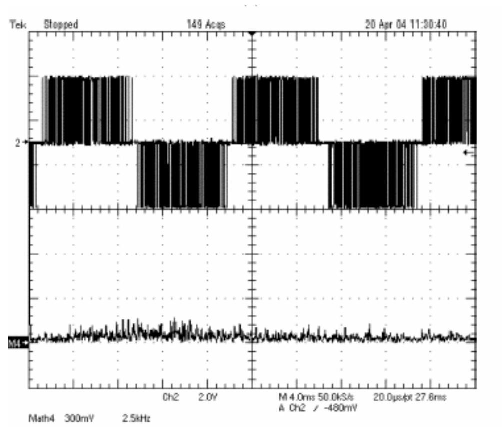


(a)

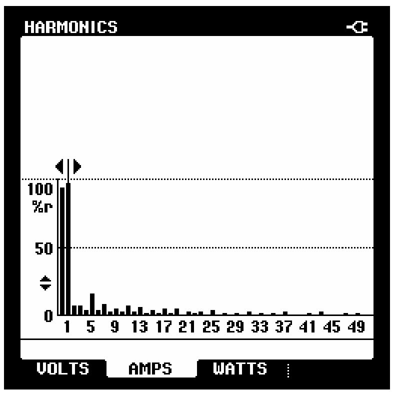


(b)

Fig. 7. (a) Inverter Output Of Random PWM, and (b) Harmonic analyzer Output Of Random PWM.



(a)



(b)

Fig. 8. (a) Inverter Output of GA-optimized PWM, and (b) Harmonic analyzer Output of GA-optimized PWM.

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