Design and Implementation of a Novel Vector-controlled Drive by Direct Injection of Random Signal

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Abstract

The distribution of harmonics of an inverter output voltage in a PWM inverter can be improved by using a Random Pulse Width Modulation (RPWM) scheme. RPWM dose not affect the fundamental frequency component of voltage, however it can significantly reduce the acoustic noise and mechanical vibrations of an inverter-fed ac motor drive. Up to now, RPWM has been studied in many researches and various RPWM techniques have been introduced, but none of them have actually shown the effects of the behavior of the random signal on the frequency spectrum of the inverter output voltage and performance of the motor drive. In this paper, three different methods of random signals are employed. These different methods and the Probability Density Function (PDF) of the random signal generator will be studied and the performance of the drive is examined. Also a new method in utilizing random signal is proposed. In this method, the random signal is injected to reference value of the quadrature-axis current. It should be noted that the RPWM technique can not be utilized in hysterisis drives. Here, the random signal with different PDF is injected directly to quadrature axis current. The injection of random signal will directly affect the output responses. In this research, comparison between RSPWM technique and direct injection of random signal has been carried out. Different criteria such as total harmonic distortion (THD), torque ripple and frequency spectrum, efficiency and mechanical vibration have been analyzed. The indirect field oriented vector control drive is simulated by using Matlab-Simulink first, and the effects of various methods of employing random signal are compared and the best alternative is introduced. For the validation of the simulation results an experimental set-up is built. The experimental results confirm the simulation outputs. The simulation and experimental result show superiority of Direct Injection of Random Signal (DIRS) method in comparison with randomized Sinusoidal pulse width modulation (RSPWM) technique. Also it is realized that the DIRS method is very simple for implementation and does not need any extra hardware.

Keywords

FFT, field oriented control, harmonic components, RSPWM, spectrum

1. INTRODUCTION

Sinusoidal pulse width modulation (SPWM) drives could improve the harmonic content of output voltage of inverters, but it can't remove the high frequency harmonic effects (e.g. EMI) and output torque [Bose, 1986]. Output torque ripple in steady state condition generate acoustic noise and mechanical vibration in motor structure [Habetler and Divan, 2000; Murphy and Turnbull, 1988]. High frequency harmonics generate iron core losses, hot spots and some part of iron may be damage.

In the past years, PWM technique is advanced for generating suitable outputs in inverters [Bose, 1986, Holtzs, 1992]. SPWM and its modified types are perhaps the most commonly used ones. RPWM is a new and effective method for ac drive which can effectively be used in practical applications by engineers [Kirlin et al., 1994; Pedersen and Blaabjerg, 1992].

In this method, the harmonic content is distributed and spread in length of spectrum continuously. This characteristic improves the mechanical vibration, EMI, and harmonic losses at low frequency [Trzynadlowski et al., 1994; Blaabjerg et al., 1995].

RPWM is presented by three methods:

(1) Randomized switching frequency
(2) Randomized pulse position
(3) Random switching technique

In this paper, a new method which is injecting the random signal to reference value of the quadrature-axis current is proposed.

A novel approach is proposed which can be used in all vector controlled drives is proposed. Direct Injection of Random Signal (DIRS) to quadrature axis current is a simple and effective method to improve the harmonic contents and mechanical vibrations. In DIRS method, characteristics of random signal such as average, variance and frequency spectrum directly affect the output parameters. In the DIRS method, random signal is directly injected to Iq. Frequency spectrum of random signal affects the output current and voltage of inverter [Legowski et al., 1992]. Unlike the RSPWM method, with changes in the parameter of random signal, output waveform and its frequency spectrum is varied in the wide range. In the other hand, implementation of DIRS method is very simple and practical and doesn't need to any extra hardware.

Three different methods of employing the random signal and Probability Density Function (PDF) of the random signal generator will affect the performance of the drive. Also they affect the frequency spectrum of output voltage of inverter [Boys and Handley, 1992, Holtzs, 1992].

In this paper, the effects of various random signal producing methods in an DIRS and RSPWM indirect field-oriented control scheme of an induction motor drive are simulated and a comparison between two methods has been done. The results obtained from experimental set-up confirm the simulation results.

2. CALCULATION OF RANDOM SIGNAL LIMITATION (N_{smax}, N_{smin})

One can find that too large extreme values of $N_s\ (t)$ will lead to the following phenomena: (i) too low-frequency harmonic components that may result in undesired mechanical vibration; (ii) too high frequency switching that will increase the switching loss. It follows that the determination of suitable random signal magnitude is very important [Stemmler and Eilinger, 1994]. Therefore, N_{smax}, N_{smin}, minimum and maximum of random signal should be selected correctly.

If N_s (t) = N_{smin}, then frequency output voltage will be equal to:

$$f_{s0} = KV_{s0}, f_1 = f_{1max}, \Delta f \tag{1}$$

Where V_{s0} is the modulator reference voltage to make main switching frequency.

Coefficient modulation frequency is:

$$m_f = m_{f\,\min} = \frac{f_{s\,\min}}{f_{1\max}} \tag{2}$$

In this state, the harmonic frequency parts are near to the main part. If the main frequency is placed in $f_{1min} < f_1 < f_{1max}$, then harmonic spectrum can be a reference for Nsmin determination. For canceling the Δf frequency part, we use the lowest harmonic frequency.

$$f_{hmin} = f_{1min} + \Delta f \tag{3}$$

For different applications, we can change f_h at different zones. In this paper, f_h is defined by

$$f_h = (m_{fmin} - 4)\, f_{1max} \tag{4}$$

This choice is a reasonable choice for single and three phase inverters. Therefore

$$f_{\min} = 4 + (\frac{f_{h\,\min}}{f_{1\min}}) = 4 + \frac{(f_{1\max} + \Delta f)}{f_{1\max}} \tag{5}$$

$$N_{s\,\min} = (\frac{m_{f\,\min}\, f_{1\max}}{K}) - V_{s0} \tag{6}$$

For N_{smin} determination, these stages are as below

(1) Determination of $KV_{S0} = f_{s0}, f_1 = f_{1max}, \Delta f$

(2) Determination of $f_{h\min}, m_f = m_{f\,\min} = \frac{f_{s\,\min}}{f_{1\max}}$

(3) N_{smin} is calculated from relation (6)

By this method, also we can determine limit of N_{smax}.

3. SIMULATION RESULTS OF THE PROPOSED SCHEME

The proposed scheme is applied on two different drives; the first one is an open control loop scheme with random signal while the second one is a vector control drive with RSPWM switching. The diagram of the former case is shown in Figure 1 and the latter case is shown in Figure 2. A random signal with various PDF has been applied to the current control loop and the results have been taken. In the other hand, a random signal is injected to quadrature-axis reference current (Iq in Figure 2) and change the quantities of random signal and simulate various variance of random signal. The results are summarized in Figure 3 for convenience.

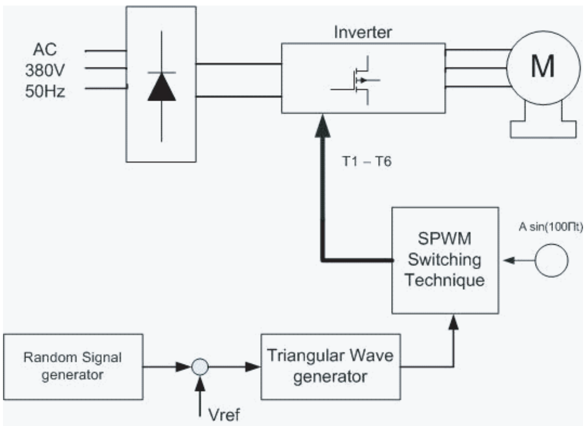


Fig. 1 Diagram of open control loop with random signal

Figure 3 shows total harmonic distortion (THD) of the current and voltage waveforms with applying random signals in the control scheme. As can be seen in Figure 3(a), THD of current and voltage vary with variance of random signal. The minimum THD is occurred in about 30 % of variance of random signal. It is demonstrated from Figure 3 that random signal with variance

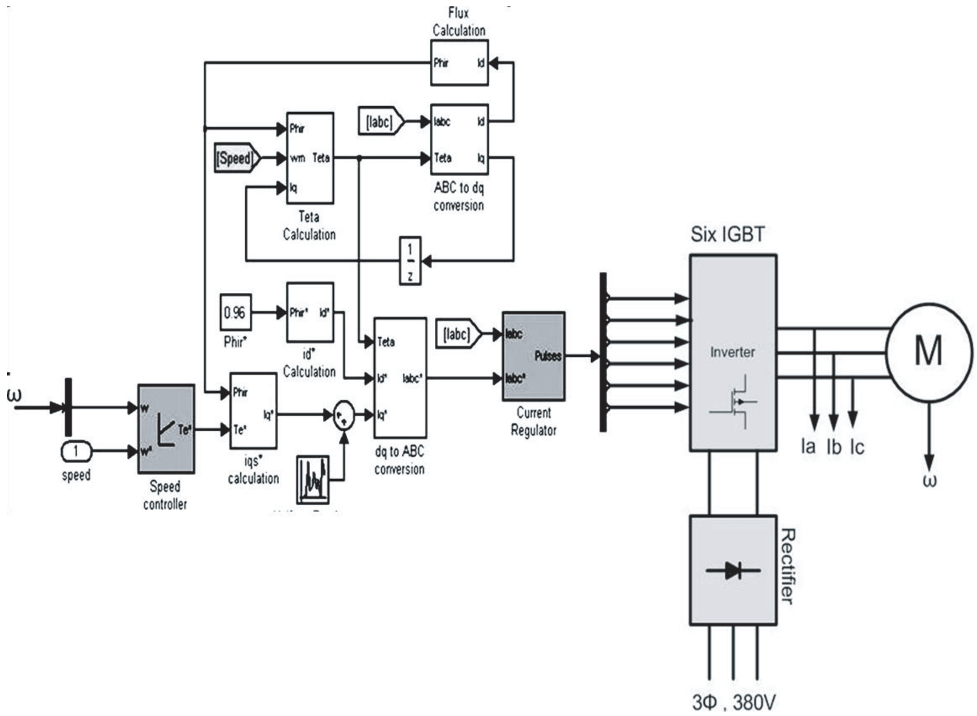
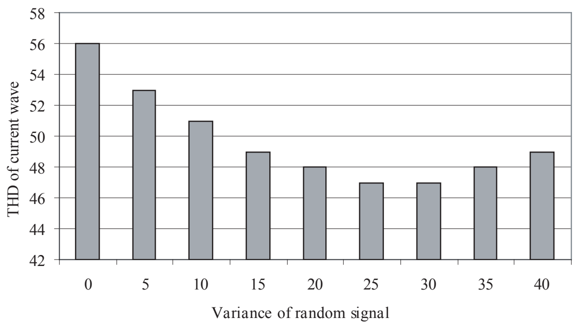
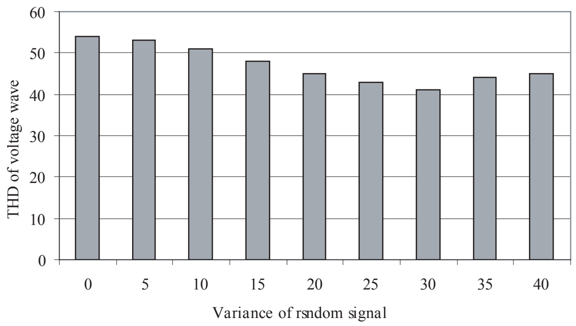


Fig. 2 Vector control drive with RSPWM switching



(a) THD of current wave



(b) THD of current wave

Fig. 3 Comparison of employing various random signals, in a closed-loop vector control scheme

of 30 % has the best result in improving the spectrum characteristics of the output voltage and in reducing the acoustic noise and mechanical vibration.

Concentration of the harmonic components on a specific frequency causes resonance, mechanical vibrations and EMI effects. Without utilizing random

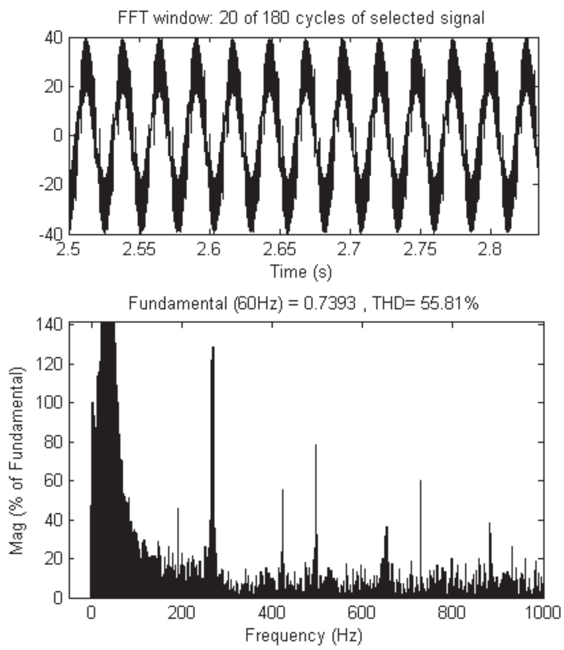


Fig. 4 Simulated current wave forms of the motor and the spectrum without Random signal injection

signals, the spectra of voltage and current have some peak values in some significant frequencies. One can see these peak values on current and voltage spectra in Figures 4 and 5.

For example, The FFT of current has a peak on about 250 Hz, which can cause torque ripple and the harmonic components near 1,000 Hz and higher can causes EMI effect.

Figure 6 shows the effect of utilizing random signal

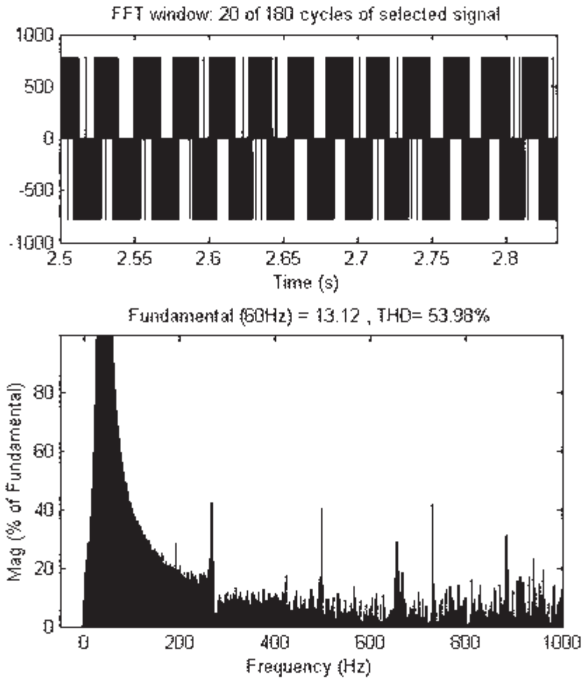


Fig. 5 Simulated voltage wave forms of the motor and the spectrum without random signal injection

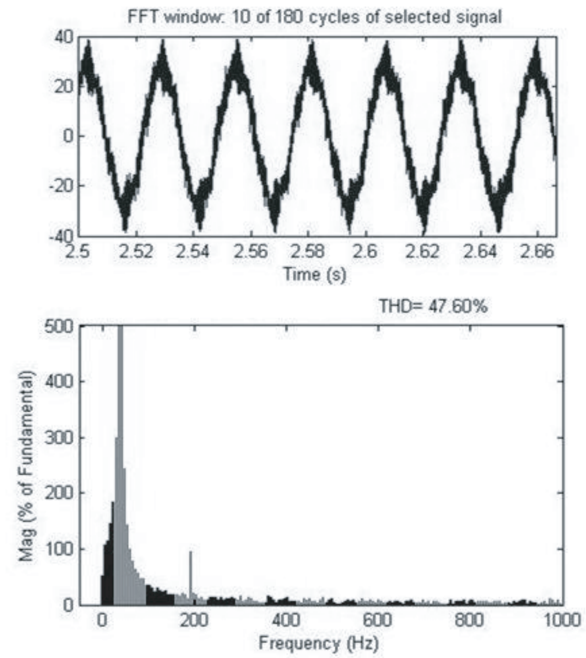


Fig. 6 Simulated current wave forms of the motor and the spectrum with normal Random signal (30 %)

with 30 % variance. It can be seen that the proposed method removes the peaks in FFT of current and reduce the THD.

Also the harmonic components are distributed. The proposed method has a similar effect on voltage and the simulation results are shown in Figure 7.

Because the random signal distributes the harmonic component of current, the torque ripple is reduced significantly.

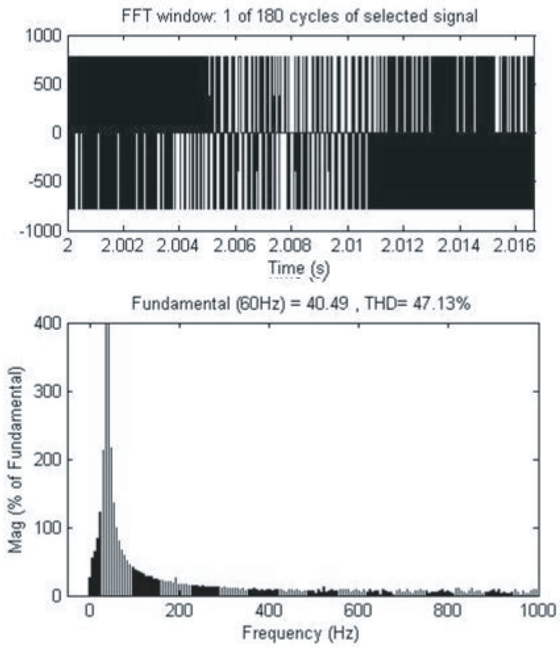


Fig. 7 Simulated voltage wave forms of the motor and the spectrum with normal Random signal injection (30 %)

The torque ripple is shown in Figure 8 for the case of without random signal. It can be seen that the torque ripple is considerable in this case. But using the proposed method can reduce the torque ripple.

As the Figures 8, 9 show the torque ripple is reduced by utilizing random signal and the random signal with 30 % variance has most significant effect on torque ripple reduction.

It should be noted that the PDF of above random signal is normal (Gaussian). In the random signal generation, two parameters are very important. Average and variance. Average of random signal (μ), cause to increase DC amplitude and variance (σ), increases the range of frequency spectrum of random signal.

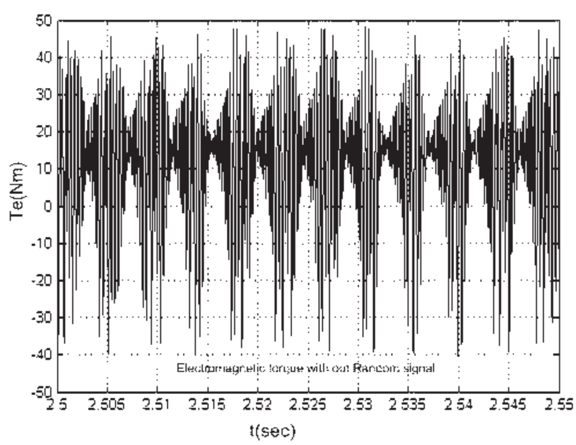


Fig. 8 Simulated ripple of electromagnetic torque of the motor in steady state without Random signal

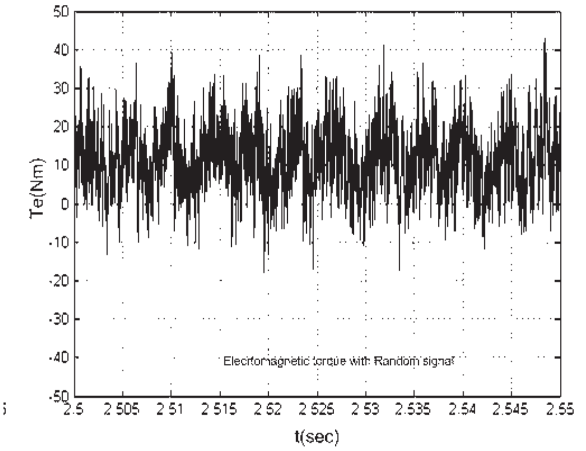


Fig. 9 Simulated ripple of electromagnetic torque of the motor in steady state with normal Random signal (30 %)

4. EXPERIMENTAL RESULTS

To validate the simulation results an experimental set-up has been designed and constructed. An indirect field-oriented induction motor drive with the proposed RSPWM current-controlled voltage source inverter is tested. It consists of a voltage source inverter, an induction motor with its rotor mechanically coupled to a mechanical load, a current-controlled PWM switching scheme, an indirect field-orientation mechanism, a speed feedback control loop and a random frequency triangular wave generator. The induction motor used here is 2 P, 2 A, 550 W, 380 V, 2890 rpm. The normal random signal has these properties: $\mu = 0$ and $\sigma = 0.6$.

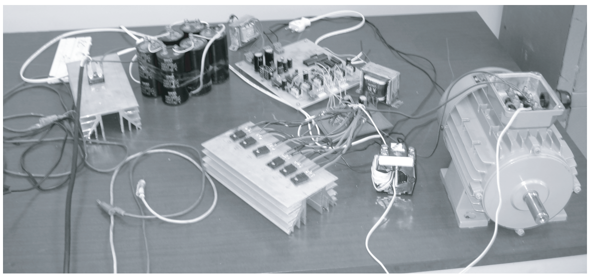


Fig. 10 The experimental set-up

To generate the random signal practically, random signal generator with variable variance has been designed with electronic devices and its block diagram is shown in Figure 11. Firstly, the random data is generated by using standard distribution function such as normal and Poisson.

Then this data is registered in a memory. By using D/A converter, digital data is converted to analogue signal and added to I_q current.

The measurement of voltage and current of an indirect field-oriented control of an induction motor drive is shown in Figures 12 and 13.

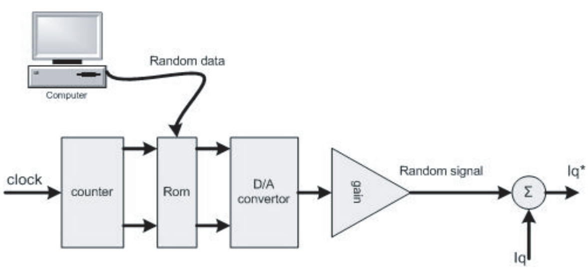


Fig. 11 Direct injection of random signal to Iq

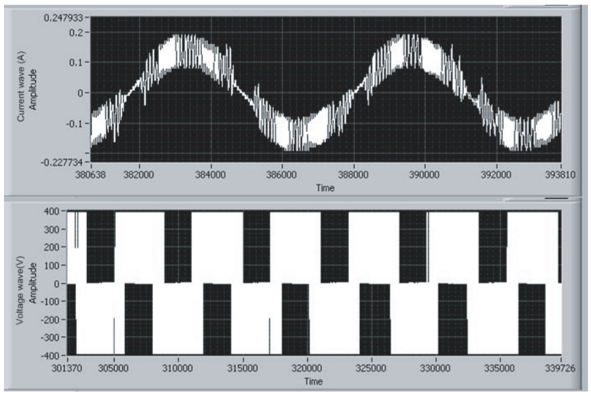


Fig. 12 Current and voltage wave without random signal injection

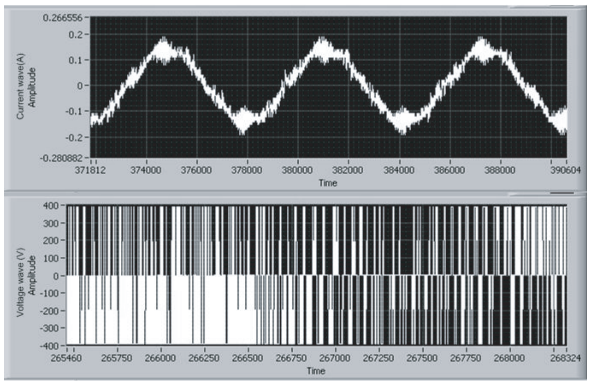


Fig. 13 Current and voltage wave with normal random signal

In Figure 14, the frequency spectrum of current wave in two cases is shown. In the first, frequency spectrum of current wave without using random signal is shown. It can be seen that energy of signal is concentrated at some frequencies. But in other case, random signal with 30 % variance is used. In this case, power of main harmonics are distributed in length of frequency spectrum

It can deduce that when the random signal is a normal (Gaussian) random with $\mu = 0$ and $\sigma = 0.6$ the best results are obtained and the simulation results correspond to experimental results within 5 %.

In the practical vector controlled drives, DIRS method has many advantages in compare with RSPWM technique. the DIRS technique can be utilized in all types of vector controlled drives such as hysterisis drives.

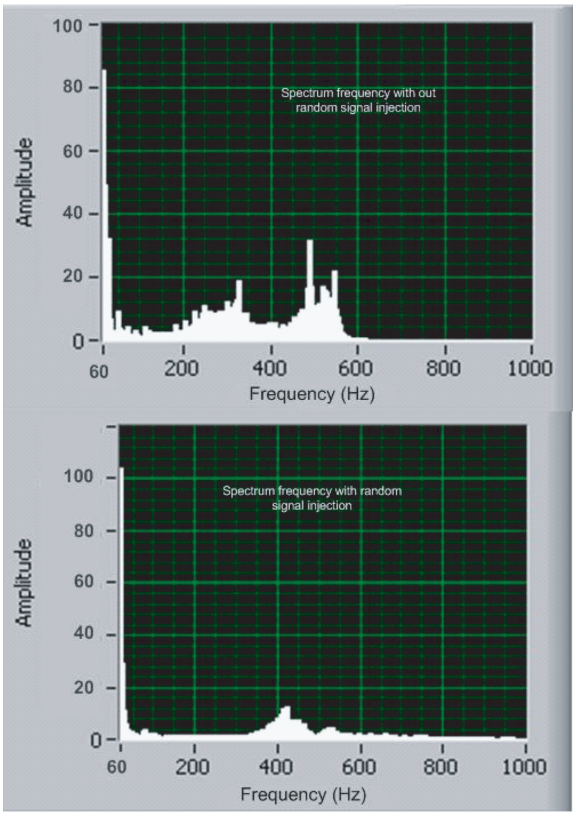


Fig. 14 Frequency spectrum of output current

By this new method, the random signal with different generation function can be injected to quadrature axes current and signal characteristics are directly injected to output responses. Also DIRS method is very simple for implementation and does not need to any extra hardware and complicated software.

5. CONCLUSION

In this paper, a new aspect in design and implementation of vector-controlled drive by direct injection of random signal (DIRS) in an indirect field oriented vector controlled drive is explained. Its effects on the voltage and current THD, torque ripple, core and switching losses and drive performance are obtained. Two important quantities of random signals which have significant effects on drive performance namely PDF and Variance are studied. The proposed system in various cases is simulated and the results are analyzed. It is concluded that if the random signal with normal PDF and 30 % variance is injected to the reference signal of quadrature axis current, the best results are achieved from simulation. The experimental results confirm the conclusion, too.

It should be noted that the RSPWM technique can not be utilized in hysterisis drives. By this new method, the random signal with different PDF can be injected to quadrature axis current. The injection of random signal will directly affect the output responses. Also DIRS method is very simple for implementation and does not need any extra hardware and complicated software.

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