Inverters –Dynamic load responses as a result of the impressed Inverter output waveform

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Abstract – **Inverters have been on the market since a need arouse to produce AC from a DC source, probably long before the beginning of PV systems. With the growth in the PV industry, the need for better, more cost effective inverters is ever present. At the same time, the need for a range of inverters covering a wide range of power and applications are becoming a salient issue. Currently there are various types of inverters on the market, ranging from square wave, modified sinewave, pure sinewave, lightweight high frequency inverters (sine or modified sine), heavy 50Hz transformer topology inverter etc. Often the cost of the inverters and not the quality of the waveform prescribe the choice of inverter. The purpose of this study is to investigate the dynamic response of various loads on various types of inverter waveforms.**

I. INTRODUCTION

A wide range of inverters is in existence. Sophistication ranges from, reliable square wave - lightweight [both Sinewave and modified sinewave] inverters, as well as inverters that can be connected in parallel -, to form redundancy arrangements[1][2][3][4] [5][6][7][8]. Loads, such as single phase induction motors used in bore hole pumps, refrigeration equipment etc. work on most of these inverters, but the life time of the motor is often reduced, due to excessive heating. Loads such as magnetic and electronic ballast's of fluorescent lights have a different response to modified sinewave and sinewave inverters. Tests done by various researchers indicated a possible reduction in lifetime of various components due to the usage of modified sinewave inverters[9][10][11].

A. Objective

The objective is to investigate and explain the differences in the result due to the impressed waveform under the following conditions:

a) Difference in start up and running response of single phase motors with both sinewave and modified sinewave QS inverters.
b) The effects that a varying DC link voltage of a modified sinewave QS have on the starting capability of a single phase motor.
c) The effect that sinewave and modified sinewave have on capacitive loads. Typical l oads are, fluorescent lights, Electronic ballast, TVs, Microwave ovens, Computers, etc.
d) The effect sinewave and modified sinewave have on inductive/capacitive loads such as fluorescent lights with a magnetic ballast.

II. EXPERIMENTAL SETUP

Various driving wave forms were used. The sinewave source consisted of the Escom supply. The square wave and modified sine wave waveforms were generated by a H-bridge of which the DC link voltage could vary. The following wave forms were tested:

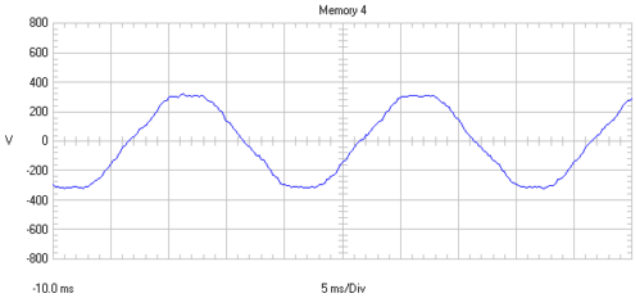

Figure 1 – Escom sine wave supply

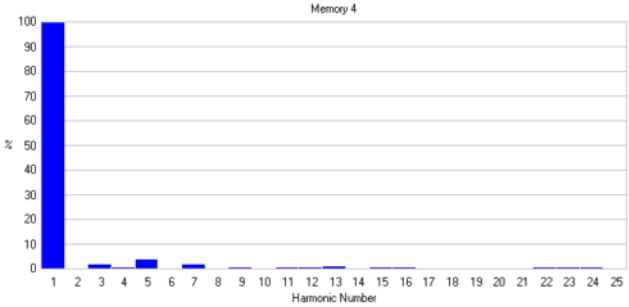

Figure 2 – Frequency Spectrum of sine wave

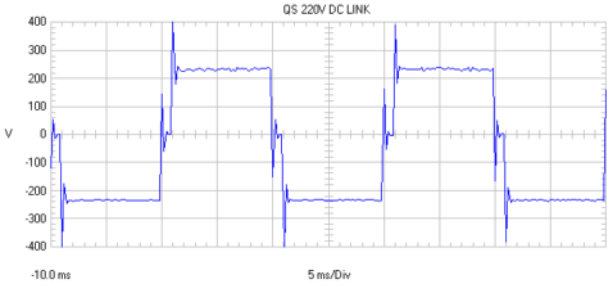

Figure 3 - Square wave with a 230V voltage peak

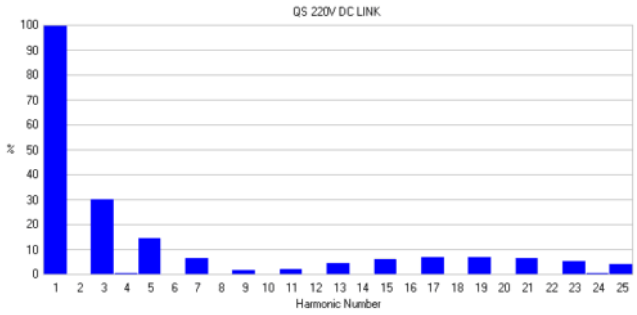

Figure 4 – Frequency Spectrum of 220V QS

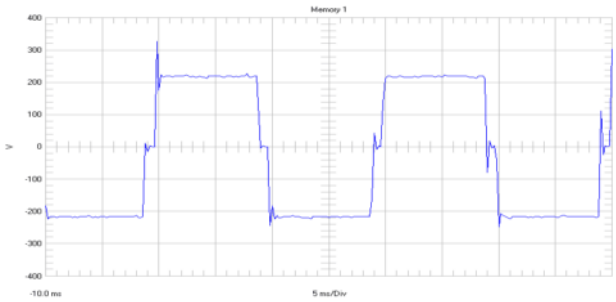

Figure 5 - Voltage Waveform – 250V QS

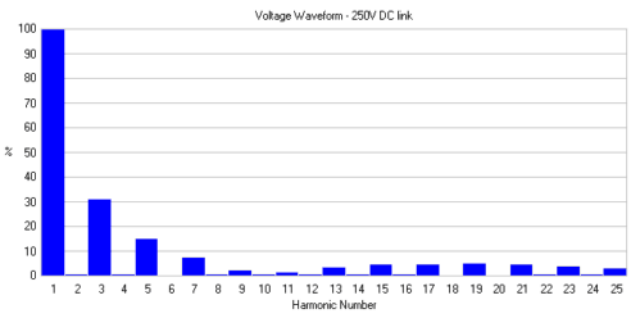

Figure 6 – Frequency Spectrum of 250V QS

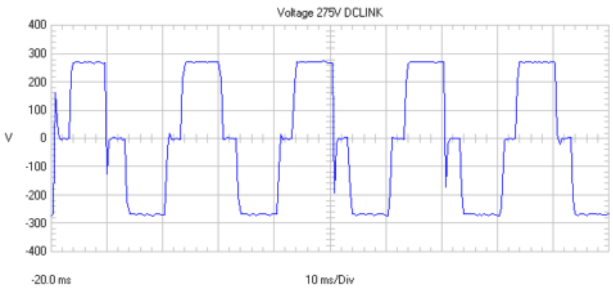

Figure 7 – Voltage wave form 275V QS

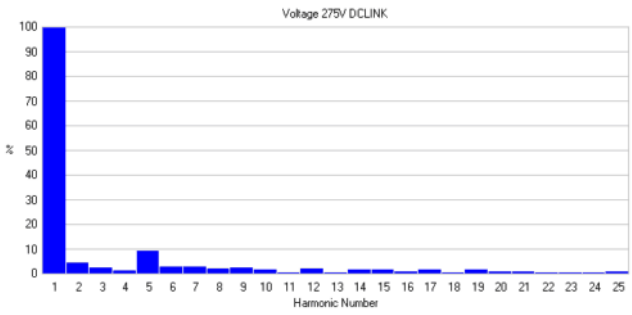

Figure 8 – Frequency Spectrum of 275V QS

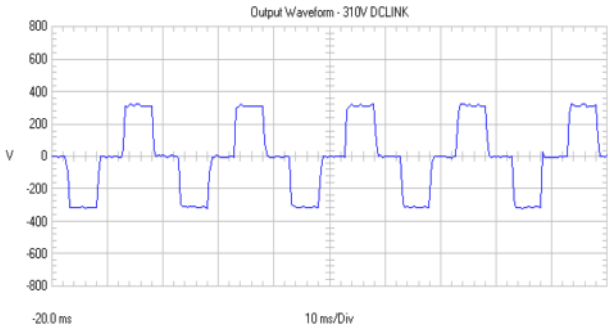

Figure 9 - Voltage Waveform - 310V QS

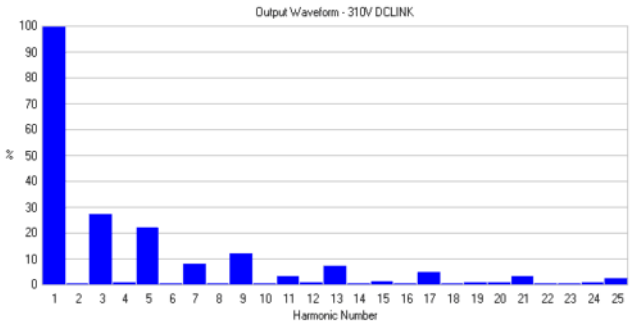

Figure 10 – Frequency Spectrum of 310V QS

From the above figures, it is clear that the tested waveforms do have a diverse frequency content. Measurements and recordings were done using a Fluke 99 oscilloscope and related software.

III. EXPERIMENTAL RESULTS

A. Loads with a Diode Bridge and capacitor bank as input stage i.e. Electronic Ballast

A high percentage of commercially available loads, fall in this cat egory. The input stage is typically a full bridge rectifier which charges up a capacitor. Computers, Electronic ballast fluorescent lights, VCRs, TVs, some microwave ovens, radios, etc can be categorised under this.

These loads draw a high current peak , during start up. A load consisting of 6 x 40W fluorescent lights with electronic ballast was tested. **Figure 11** shows a current peak of 40A during start up.

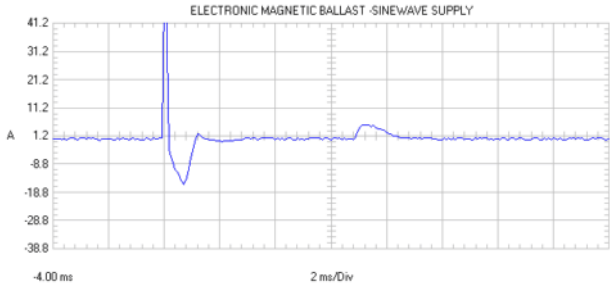

Figure 11 - Electronic Ballast – During Start up - Sinewave supply

The start up current pulse caused by the application were more or less the same for all the applied voltages.

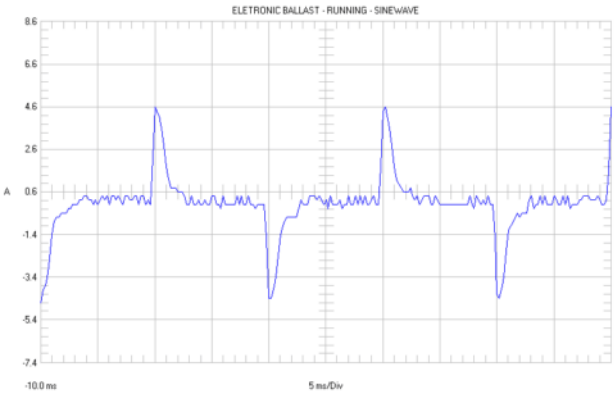

Figure 12 - Electronic Ballast -Running- Sinewave

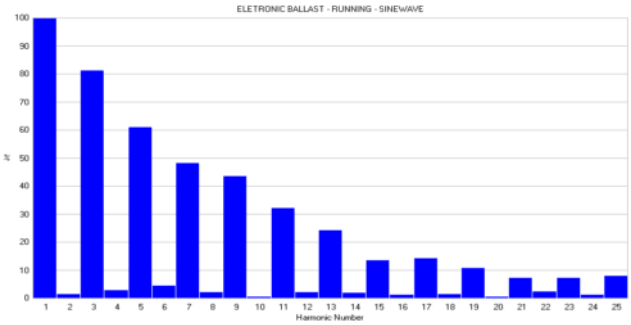

Figure 13 - Frequency Spectrum - Electronic Ballast Running Sinewave

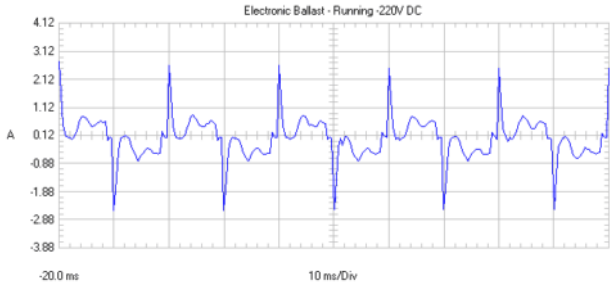

Figure 14 - Electronic Ballast - Running at 220V QS

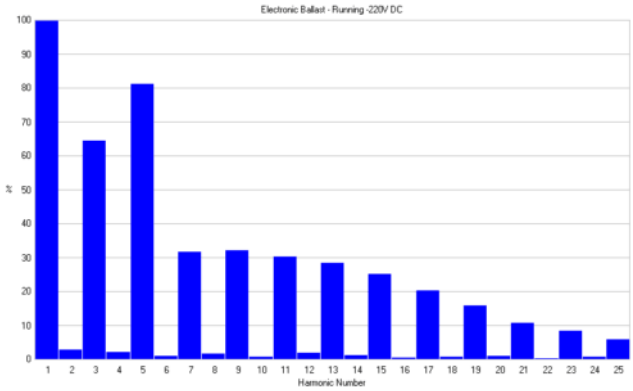

Figure 15 – Frequency Spectrum – Electronic Ballast Running at 220 V QS

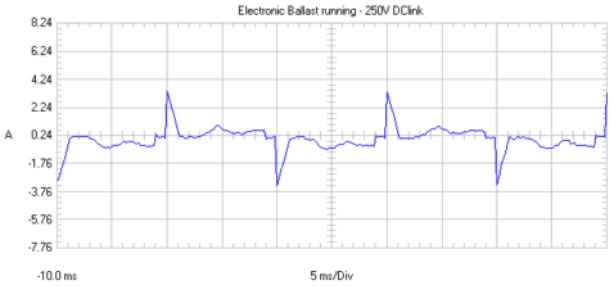

Figure 16 –Electronic Ballast – Running– 250V QS

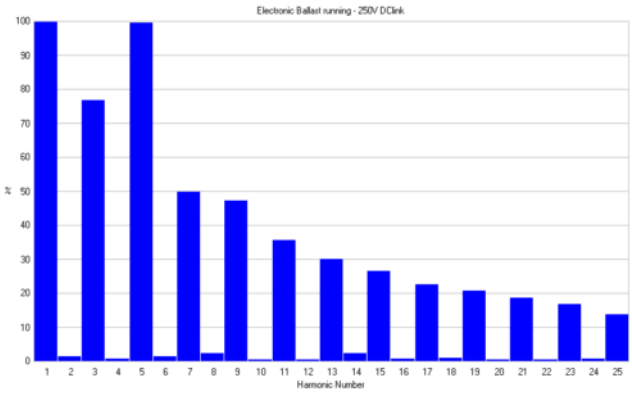

Figure 17 - Frequency Spectrum Electronic Ballast Running 250V QS

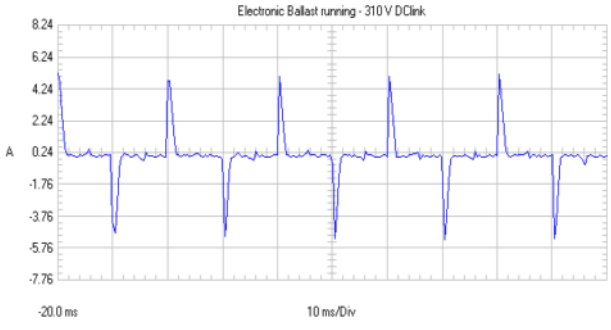

Figure 18 - Electronic Ballast - Running at 310V QS

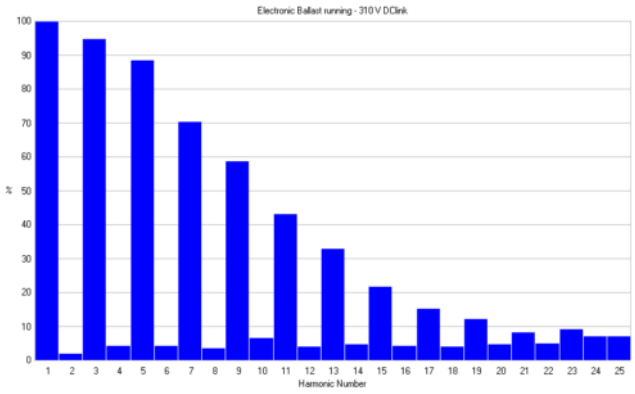

Figure 19 - Frequency Spectrum - Electronic Ballast - Running at 310V QS

Discussion

Although the "High current pulse" during start up is similar to all the applied wave forms. The current peak, as well as the frequency content varied. Experience in this f ield, as well as work done by various other authors [11] showed that, the lifetime of equipment is reduced. This could only be explained on hand of the much higher frequency content within the current wave form. It is very no table how the 5 th and then the 3rd harmonic content increase with the voltage peak. Various (11 -18W) electronic fluorescent lights were disassembled and the main cause for failure was found to be. The input capacitor bank– as per photo.

Figure 20 - Failed capacitor of 11W Fluorecscent light

B. *Si*

Single phase motors is often used in static as well as mobile applications. Examples of this is compressor fridge's, bore hole pump, mobile pumps, emergency water replacement & pumps as used by emergency services etc. A general "complaint" exis t that square wave or modified sine wave heats up motors. A 200W fridge compressor was used as load. The start up times were recorded as follows:

	Start up time	Current
Sinewave	240 ms	9A
220V DC link	580 ms	peak 3,9A
250V DC link	630 ms	peak 6,5A
275V DC link	440 ms	peak 9A
310V DC link	2sec	peak 10,5A

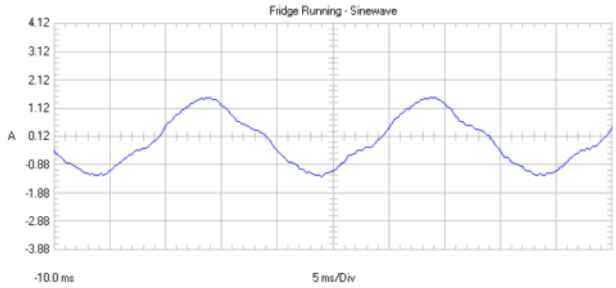

Figure 21 – Motor Running with sinewave Escom supply

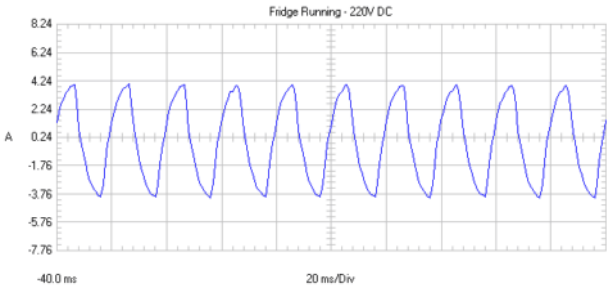

Figure 22 - Motor Running with a 220V QS

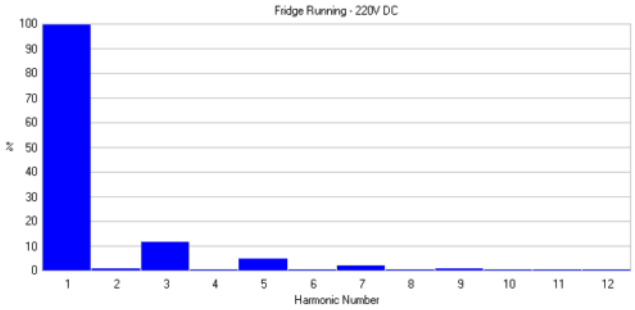

Figure 23 – Frequency Spectrum of current drawn with a 220 QS

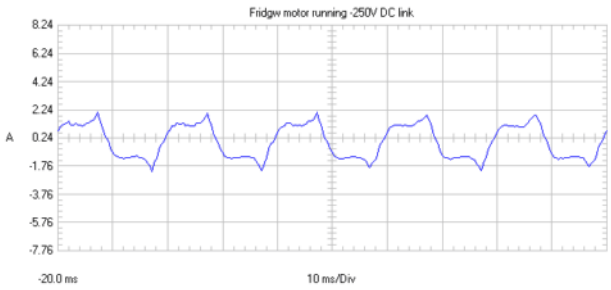

Figure 24 - Motor Running with 250V QS

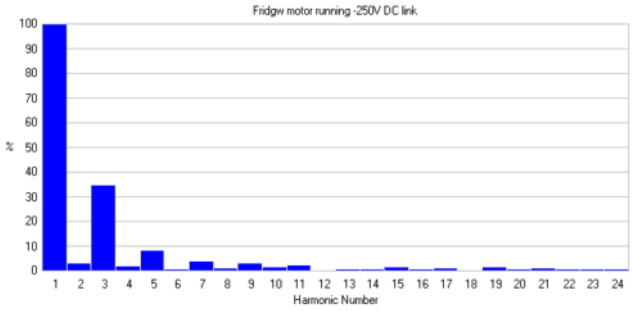

Figure 25 – Frequency Spectrum of current drawn 250V QS

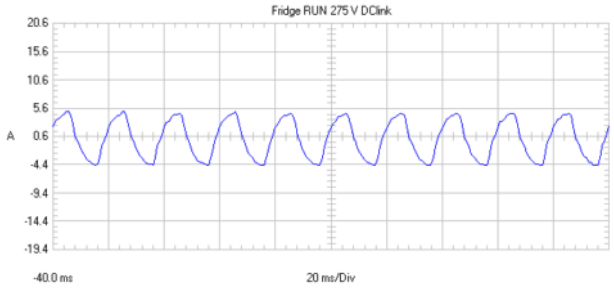

Figure 26 - Motor Running with 275V QS

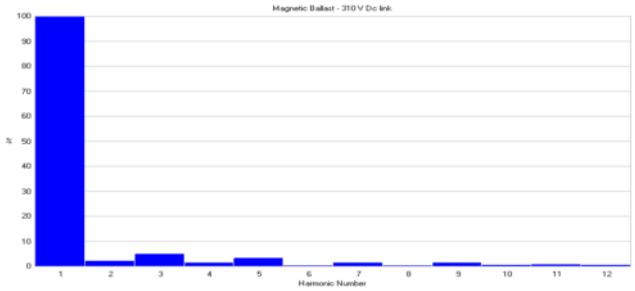

Figure 27 – Frequency Spectrum of Motor Running with 275V QS

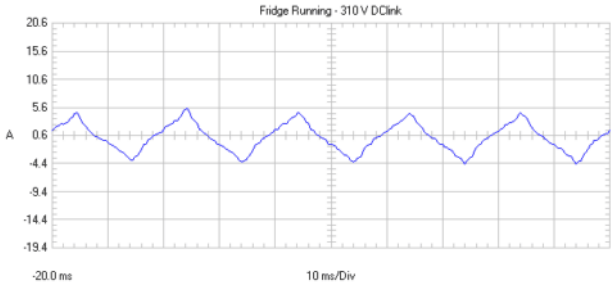

Figure 28 – Motor running with 310V QS

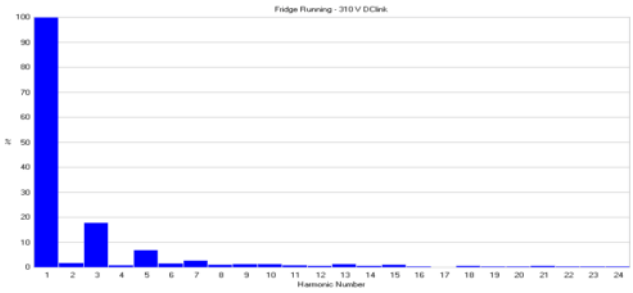

Figure 29 – Frequency Spectrum Motor Running- 310V QS

The harmonic contents of the different supply voltages are diverse (**Figure 21**..**Figure 28**) shows the frequency content of the supplied wave form. The 3 rd and 7th harmonic would "warm" the motors up. The sinewave supply is the best as it has no high frequency components. It is followed by modified sinewave with a DC link value of approximately 270V peak.

C. Behaviour of loads with universal brush motors.

Universal motors (brush motors) can work from both AC and DC supp lies. A wide variety of products on the market have these motors e.g. drills, grinders, weed eaters, some food processors, and some sewing machines. A 750W Black & Decker drill was used as load. Start up responses and the result was as follows:

	Time	Current Peak	Running Current
Sinewave	100ms	20A	1.75A
220V DC	80 ms	11,2A	1.3A
250V DC	60 ms	18A	1.65A
275V DC	60 ms	19A	1.7A
310V DC	140 ms	20A	1.7A

A slower start up of the drill at a high voltage peak of 310V is noticeable. The start up periods i s faster than even the sine wave, but rotation speed of the drill was also noticeable, indicating an under voltage.

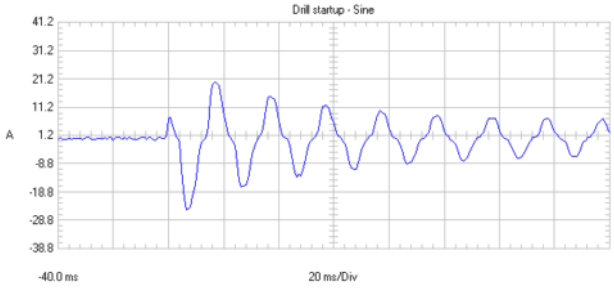

Figure 30 - Drill start up- Sinewave supply

Other than that no real difference in dynamic responses were visible. Slower start up of the drill under condition of 310V DC link is caused by the high harmonic content. This however reduced during running. It is clear that a universal type motor thus "Prefer" a fuller waveform to start. I.e. The 250V peak wave form has a 90% duty cycle, the 275V peak wave form has a 80% duty cycle and the 220V peak has a 96% duty cycle. Whereas the 310V peak only has a 60% duty cycle.

CONCLUSION

A wide variety of tests were done on various loads and supply voltage combinations. **The results are widespread. As a general result, it is clear that it is not possible for any version of a modified sinewave to replace a pure sinewave source.**

All "movable" equipment such as single phase motors, universal motors etc. tend to prefer a lowe r voltage peak with a fuller duty cycle (When not full sinewave). It is

visible from the start up times of both the above mentioned tested motors.

The electronic ballast, which represents a wide variety of commercial loads, prefer a lower voltage peak. The reason for this is the reduction is harmonic content, as well as a lower current peak. Most of these loads would work very well with just DC supply, due to the fact that they have been designed for 230V sine wave applications. It was found that some loads i.e. VCR, some computers etc, would not work if the peak is below 255V DC. Thus a "optimum" Quasie or modified sinewave supply for these loads are a voltage peak of approximately 265V which is current peak limited.

The only loads found to be depen dant on the voltage peak, was the magnetic ballast fluorescent lights and microwave oven. Both the products require the voltage peak. This is very applicable with the sinewave supply.

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