



Pure Sine Wave SPWM Micro-Controller Based Active Front End

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Abstract

Power Quality (PQ) issues like undesirable Total Harmonic Distortion (THD) has rendered ineffective many power supply system by the very fact that the devices to benefit from them suffer poor performance occasioned by the debilitating effects of their THD that is beyond the acceptable threshold. This has caused premature destruction of coils in electromagnetic devices serviced by such unsavory power deliveries. Some sensitive equipment can suffer severe performance set back or become completely inoperable when subjected to supply from such poor power quality units. Improved power supply quality can be achieved by employing the use of sinusoidal pulse width modulation (SPWM) template, infused through a microcontroller to feed an ingeniously crafted Active Front End (AFE) Topology. This paper elicits the benefits of having a surer paradigm for effecting better power quality; by comparing, it provides power delivery of lower THD. Power supplies of this genre are capable of providing more efficient delivery to electromagnetic devices, thus enhancing the performance of those traditional power electronic devices. Newer and more sensitive high-end equipment will be better serviced by this Novel power supply initiative.

Keywords: Harmonics, Total Harmonic Distortion, Power Quality, sinusoidal pulse width modulation, Microcontroller, Active Front End, Electromagnetic Devices.

1. INTRODUCTION

The main concern of electricity consumers until recently has been the reliability of the supply. Customers nowadays desire not only reliability but also quality for newer generation of sensitive equipment. Power quality (PQ) is a term that refers to “maintaining the near sinusoidal waveform of the voltages and currents of the power distribution bus at a rated magnitude and frequency” [1] Poor power quality could be from loads, equipment and components as well as subsystems of transmission and distribution systems and they depend on amplitude or frequency or both frequency and amplitude [2]. Power quality disturbances would be any event or deviation in one of voltage, current or frequency of supply that would result in customer equipment failure or mal- function. Power quality disturbances are categorized into voltage sag, voltage swell, transient, harmonic, voltage notch, and flicker. The study of various phenomena that cause power quality disturbance to occur as well as the monitoring and characterization of each phenomenon helps in the development of mitigation strategy [3]. Active front end technologies are recognized by many as the best technology for mitigating harmonics with different levels of performance. Active front-end power electronic converters are connected to an AC mains/source either with a transformer or without a transformer. These converters use semiconductor switches as rectifiers instead of the diode bridges which are otherwise generally used and if they are controlled in an appropriate way, the amplitude of the generated harmonics is reduced [4]. In sinusoidal pulse width modulation

(SPWM) technique a digital waveform is generated, for which the duty cycle can be modulated such that the average voltage waveform corresponds to a pure sine wave. This is achieved by comparing a low power sine wave reference with a high frequency triangular carrier wave. This SPWM signal are then used to control switches acting as the gating signal. A microcontroller is used to generate these control signals by encoding a sine wave with a triangular carrier signal. Pulses are generated whenever sine wave value is higher than the triangular wave value [5].

2. TOTAL HARMONIC DISTORTION (THD)

Non-linear loads draw currents that are not perfectly sinusoidal, which results in voltage waveform distortion containing harmonics. Harmonics are a form of voltage or current waveform distortion. Harmonics have frequencies that are integer multiples of the waveform fundamental frequency. Thus, harmonic distortion is the degree to which a waveform deviates from its pure sinusoidal values as a result of the summation of all these harmonic elements. A common measurement of the cumulative amount of harmonic distortion is Total Harmonic Distortion (THD), which is the summation of all harmonic components of the voltage or current waveform compared against the fundamental component of the voltage or current wave expressed as a percentage [6] as shown in Equation 1.

$$THD = \frac{\sqrt{\sum V(h)^2}}{V(1)} \times 100\% \quad (1)$$

Where $\sum V^{(h)^2}$ - Summation of the harmonic voltages and $V^{(1)}$ - Voltage of the fundamental frequency. Where $V^{(h)}$ is the amplitude of the harmonic components. In line with IEEE standards [1], the recommended limits on voltage harmonics are thus set at 5% for THD and 3% for any single harmonic. Keeping low THD values on a system ensures proper operation of equipment and a longer equipment life span [1].

3. PQ MONITORING AND ANALYSIS

Power quality monitoring involves gathering, analyzing, and interpreting raw measurement data into useful information. The process of gathering data is usually carried out by continuous measurement of voltage and current over an extended period. The process of analysis and interpretation has been traditionally performed manually, but recent advances in signal processing and artificial intelligence fields have made it possible to design and implement intelligent systems to automatically analyze and interpret raw data into useful information with minimum human intervention [7]. The RMS magnitude of voltage supply is used in the power quality standards for detection and characterization of voltage events. Newer and more accurate techniques of analysis used for the detection of power quality disturbances have evolved over the years. Wavelet transformation has the ability to analyze different power quality problems simultaneously in both time and frequency domains. Discrete Fourier transform (DFT) is used to determine the frequency content of a periodic discrete time signal with period N samples amongst others [8].

4. PROPOSED METHODOLOGY

4.1. Three phase design

The study seeks to simulate and implement a laboratory scale three phase power supply fed with 300V DC supply from a boost converter to give a 415V AC output voltage comparable to that from the utility grid (Figure 1).

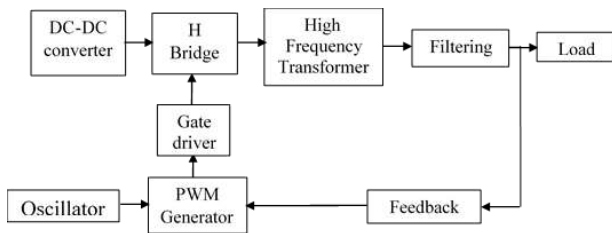


Figure 1: Block Diagram of Proposed System.

Furthermore, monitoring, measurements and analyses of the power quality for THD of the AC output of the three-phase inverting system will be carried out. SPWM is implemented with PIC 18F4311 programmed in MPLAB. MOSFET semiconductor switches were used in the full bridge with the output taken at the output of a high frequency transformer. The inverter circuit comprises three sections mainly, namely; the oscillator, the driver, the output (MOSFET) sections, low battery / overload protection circuit, and the transformer. The charging mode implements the transformer, the FET's internal diodes and

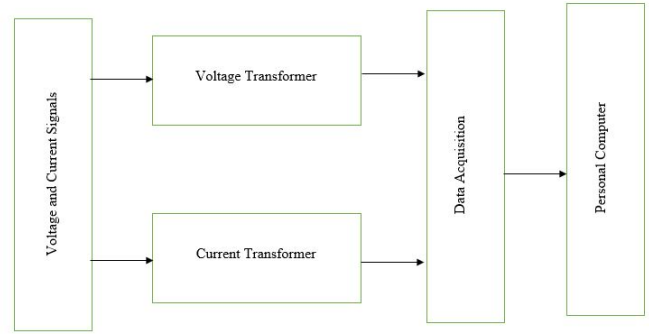


Figure 2: Block of proposed virtual PQ instrument.

the charging control circuit. A third operation mode implements a seamless transfer between the aforementioned modes. This mode implements a delay circuit, electromagnetic relays and power supply circuit.

4.2. Three phase supply simulation

SPWM in a three-phase inverter uses three sinusoidal reference signals of equal magnitude at the frequency of the desired output but displaced from each other by 120° compared with a triangular carrier signal waveform of suitably high frequency

$$V_a = V_m \sin \omega_t \quad (2)$$

$$V_b = V_m \sin \left(\omega_t - \frac{2\pi}{3} \right) \quad (3)$$

$$V_c = V_m \sin \left(\omega_t - \frac{4\pi}{3} \right) \quad (4)$$

Where V_m is the amplitude of the reference signals and ω_t represent the angle of displacement as shown in Equations 2, 3 and 4. The triangular carrier wave signal has 'five-time value points' $(0, \frac{1}{4fc}, \frac{1}{2fc}, \frac{3}{4fc}, \frac{1}{fc})$ with corresponding output values $(0, V_c, 0, -V_c, 0)$ in one cycle. This is simulated in MATLAB Simulinks for FFT analysis.

4.3. PQ monitoring

A virtual PQ data logger developed in LabVIEW® is proposed. The data logger logs RMS values of the three-phase voltage and current signals. The overall block diagram of the virtual PQ monitoring is shown in Figure 2.

The system consists of the voltage and current transformers, the data acquisition component and a personal computer. Voltage and current signals in the three-phase supply are transformed into -10V to 10V signals as system input and are fed into the data acquisition card (NI myDAQ) for A/D conversion. The acquired signals are logged in an excel sheet. The converted digital signals are afterwards analyzed, computed, and output by the computer.

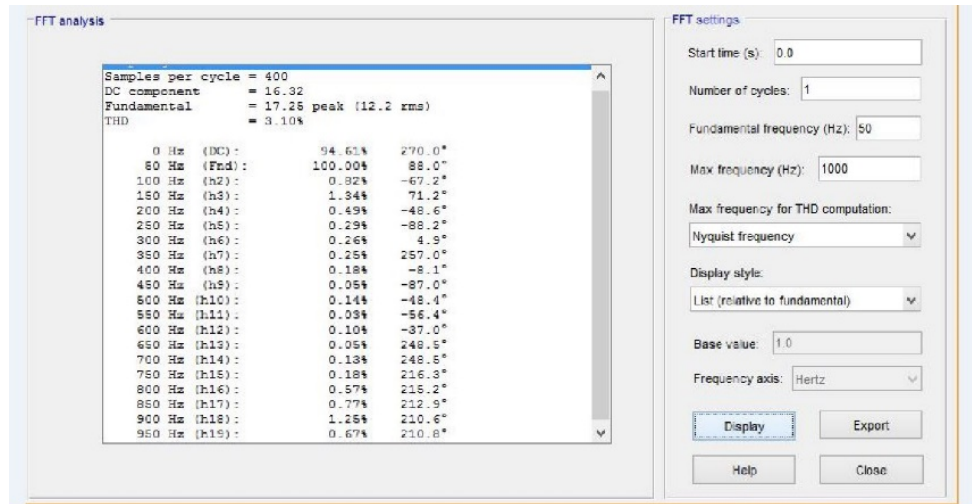


Figure 3: FFT analysis of simulated model in MATLAB Simulink

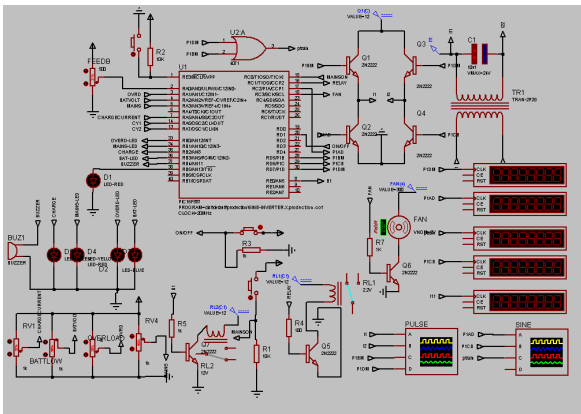


Figure 4: Circuit Diagram of the sine wave inverter

Table 1: Voltages at each harmonic frequency.

FREQUENCY [HZ]	VOLTAGE [$V^{(h)}$]
0	0
50 (fundamental)	240
100	1.45
150	2

5. RESULT AND DISCUSSION

The Figure 4 represent the generalized circuit from which the oscillograph in Figure 5 was obtained. Simulation result of the active front end DC-AC converter gave a result of 3.10% THD with the highest been the 3rd harmonics (1.34%) which are still within the limits of 5% [1] for THD and 3% for individual harmonic component for a LV-MV distribution system.

Figure 6 shows the design phase of the inverter circuit depicted in Figure 7.

From calculation, the obtained result is very similar to the simulation result as shown in Equation 5.

$$THD = \frac{\sqrt{(240^2 \times 1.45^2 \times 2^2)}V}{240v} \times 100 = 2.9\% \quad (5)$$

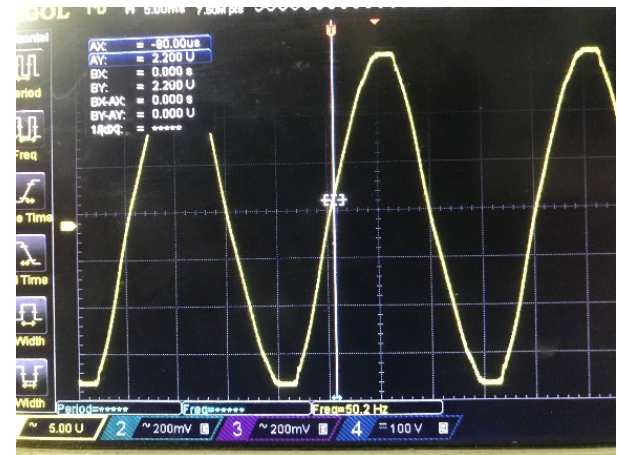


Figure 5: Output waveform of the sine wave inverter

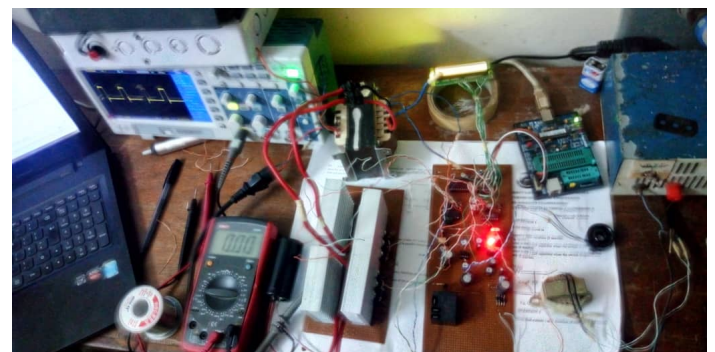


Figure 6: Design phase of the sine wave inverter



Figure 7: Finished and packaged sinewave inverter prototype

The obtained result is better than the simulated result because of the use of LC filters. With the use of this 2nd order filter, the third harmonics and its integral multiples were attenuated to the barest minimum thereby giving a lower THD value as compared to the simulation result thus giving a more improved sinusoidal waveform.

6. CONCLUSION

It is very clear that the proposed methodology meets the requirement of a lower harmonic distortion, engendering improved power quality in the active front end design.

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