A study and Implementation of a controller used in a full-bridge inverter of distributed generation systems

Dr. Kareem K. Jasim
Eng.Mahdi Sarhan
Energy and Renewable energy center
University of technology

SUMMARY:

In this work we study one of single phase control way to be used in low and medium power systems. These power systems used in designing solar and wind energy sources. As examples the hybrid vehicles , solar houses and hospitals that need clean , efficient and steady state energy sources. Moreover, the size and mass of these inverters reduce available vehicle storage space. An ideal solution is to provide a small inverter for each battery, so that its charge can be maintained individually and a low-distortionsine wave can be applied to the motor. A battery charger is then intrinsic in this layout. This work presents the development and implementation of a such a multilevel inverter. Two separate designs are constructed, each including a master module and six slave modules. A battery charger is then intrinsic in this layout.

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١.INTRODUCTION:

١,١ *Electric Vehicle Power Electronics:*

Factory-built electric vehicles used a high-voltage battery pack consisting of many series cells, nominally ٣٠٠V or above.

An inverter employing full-amplitude pulse-width modulation (PWM) drove the main motor in both cases. PWM was used to generate a set of time-averaged, near sinusoidal voltages for the motor.

١,٢ *The Multilevel Inverter as a Solution:*

A multilevel power inverter is a system that can produce a varying output voltage from a given number of interconnected sources without the need for full-amplitude PWM [٦]. The multilevel topology being considered here, intended exclusively for a drive motor application in an electric vehicle, consists of many batteries in series through full-bridge inverters that can act as three-state sources: positive twelve volts, zero volts, or negative twelve volts (roughly). In this design, the number of voltage output levels for each line-to-neutral voltage is twice the number of batteries per phase plus one. [١] Typical drive motors are three-phase induction machines; this type will be the focus in this project.

A basic schematic can be seen in Figure (١). The aim of this thesis is to develop a control algorithm along with a complete implementation this thesis is to develop for this setup. The major goal is to achieve the highest possible output frequency while managing the batteries to have the highest range capacity and the most equal charge, while keeping hardware costs to a minimum.

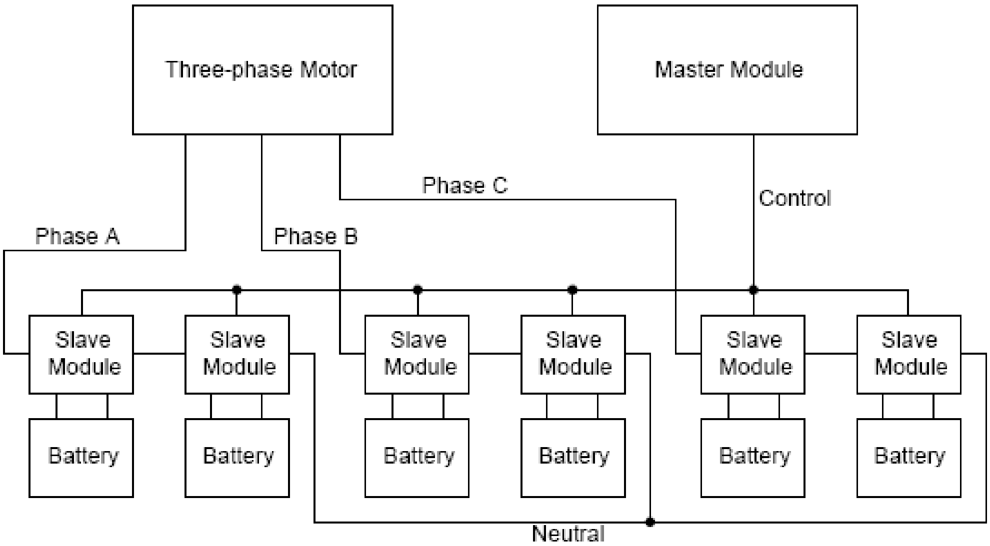


Fig.(١) Basic overview of the multilevel inverter. [١]

The multilevel topology suggested here solves many of the problems associated with traditional PWM drives. [٢] on negative, turn off, or watch the bus for more extended data (arguments). [٢][٤]

٢ Battery Selection Algorithm Design:

٢. ١ *Theory:*

Some type of algorithm to decide when each battery module should turn on or off is necessary to support variable-frequency and variable-amplitude waves. Three duplicate algorithms are needed, one for each motor phase. The inputs to the algorithms must be line-to-neutral phasors — either sin(t), sin(t) + sin(٣t)/٦, or sin(t)−sin(٣t)/٢, each shifted by ١٢٠ and ٢٤٠ degrees of fundamental for algorithms two and three respectively. [٩]

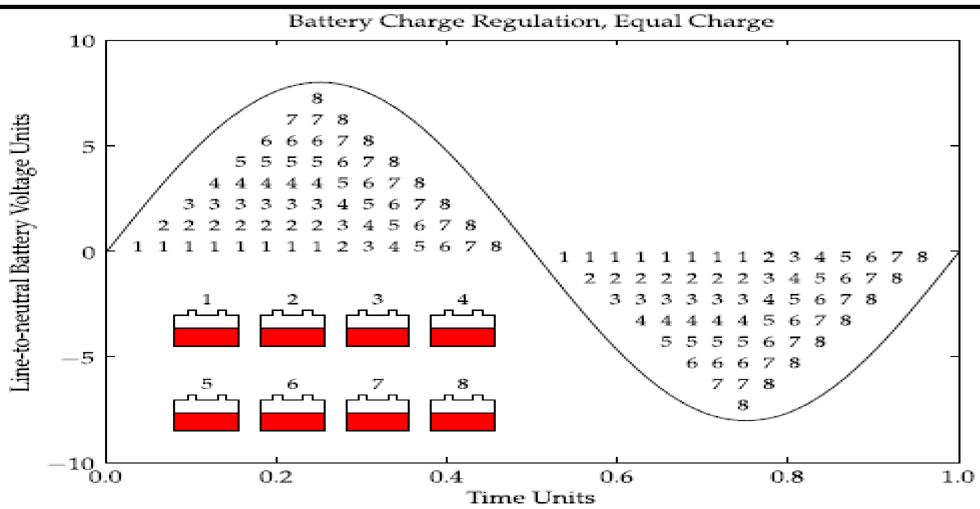


Fig.(٢) Battery charge regulation, equal charge.

In an ideal environment, each battery contains an equal amount of charge and therefore should be discharged the same amount as the rest. A visualization of one algorithm's output is shown in Figure(٢). It resembles a pyramid, where each battery is on for an equal amount of time. An equal charge will be taken out of the batteries in this case only for a constant-current load, which is quite different from the actual load — but the general technique can still be demonstrated. [٢,١٠]

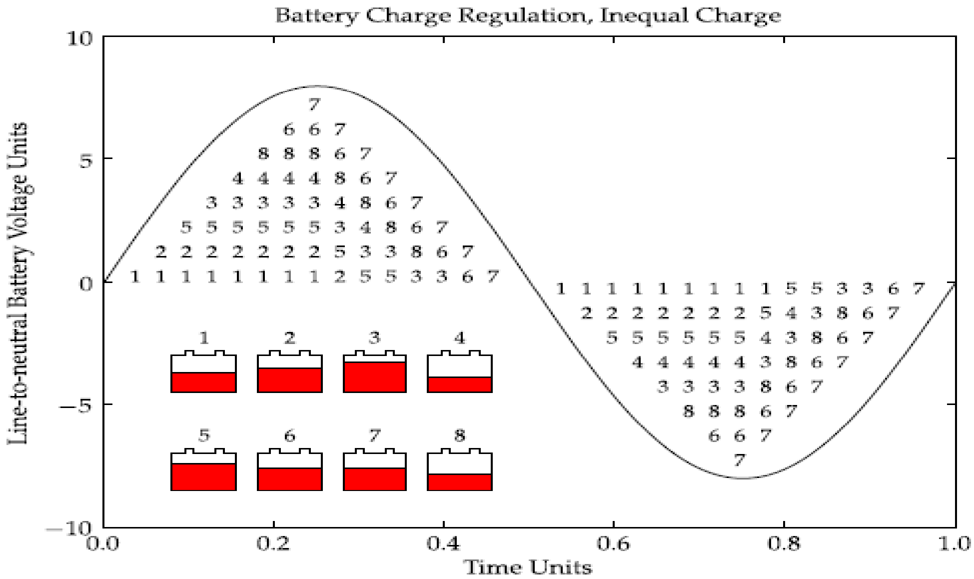


Fig.(٣) Battery charge regulation, Inequal charge.

For a pack of in equally charged batteries, a scheme such as that shown in Figure(٣) could be used. Battery ٣ has the highest remaining charge and Battery ٤ has the lowest. Therefore, the amount of time Battery ٣ is switched on is longer than that of Battery ٤ (١٩ vs. ١٣ time units respectively). The disadvantage of such a scheme is the complication in attaining the goals set forth: ١) battery modules should only switch at most two times a half-cycle to reduce bus loading, and ٢) there should be sufficient time between module transitions to keep inductive ringing to a minimum.

In conclusion, analysis needs to be done to derive the true discharge distribution for any given output waveform. [١٢]

٢. ٢ Single-Cycle Discharge Distribution:

Figure (٨) depicts the synthesized output voltage for a single-phase ٤٠-battery module string, the largest to be accommodated. Figure(٤) shows the associated difference shifted only for clarity — between two subtracted line-to-neutral waveforms. Though the peak voltage in the former figure varies, the amplitudes of the differences do not. This is accomplished by third-harmonic injection. The switching scheme used here is similar to that in Figure(٣), where batteries are turned on and off in the same order, with the exception of the small negative excursion on the negative third harmonic. [١٣]

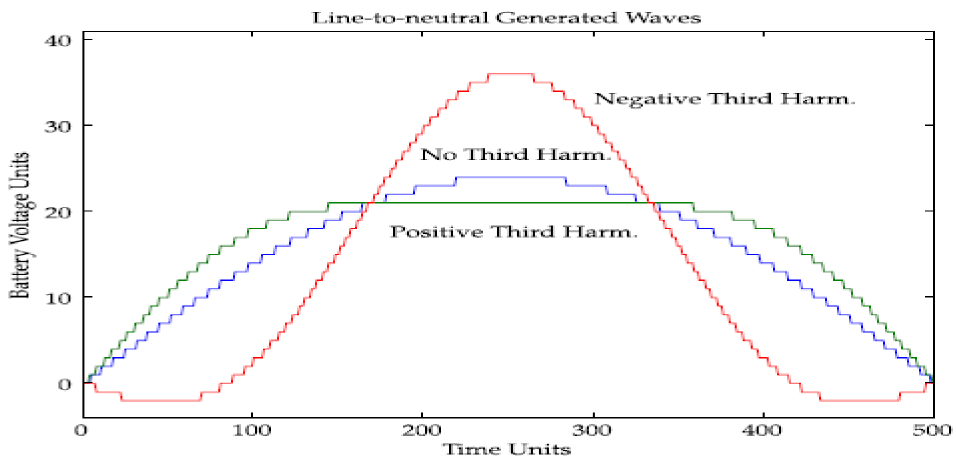


Fig.(٤) Line-to-neutral generated waves.

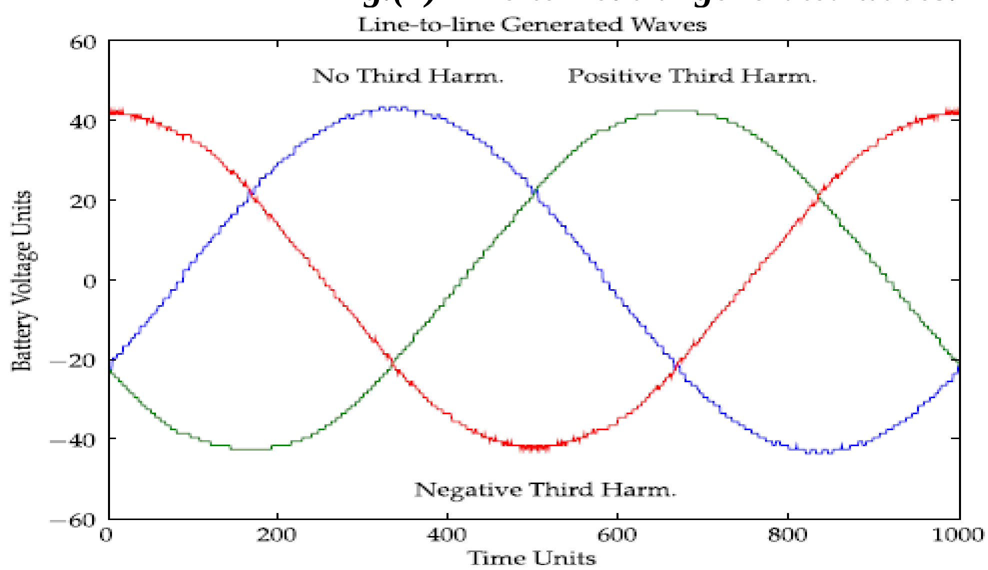


Fig.(٥) Line-to-line generated waves.

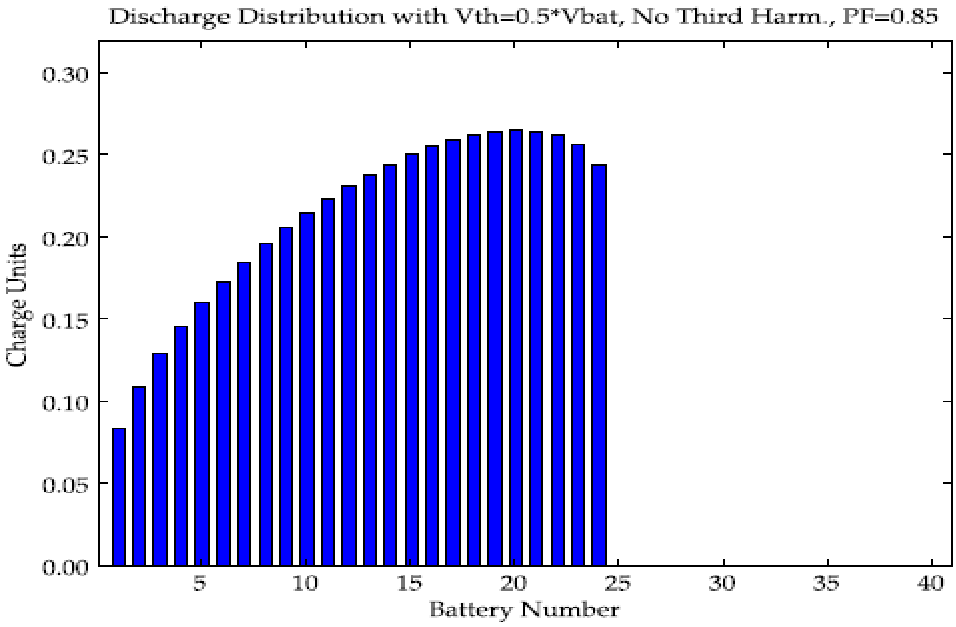


Fig.(٦) Discharge distribution, no third harmonic, σ=٠,١١٢.

Figures (٦) shows the distribution of charge taken out of the batteries for a half-cycle. Notice the much lower standard deviation (σ)for the negative third-harmonic injection. It would provide a way of spreading out the charge distribution for a simplistic algorithm. [١٥]

٢,٢ *Battery Charging:*

The source of most, if not all, power for vehicle recharging will come from ١٢٠/٢٤٠vac single-phase grid outlets. During charging, the three module strings are connected in series and are placed across the outlet terminals along with a small series inductor to smooth the battery voltage transitions. The goal is to create a seemingly resistive load so that the outlet's load current waveform will exactly resemble its voltage in shape and phase. The voltage across the inductor, placed across two identical ٦٠Hz AC voltage sources shifted in phase by ٢Θ can be represented as follows:

VL = ١٧٠V [cos(٣٧٧t+٢ Θ)-cos(٣٧٧t)]=-٣٤٠V.sin(٣٧٧t+ Θ).sin(Θ)……………..(١)

The inductor ٦٠Hz current is then:

I_L =-٣٤٠V.sin(Θ)/L ∫sin(٣٧٧t+ Θ)dt = ٣٤٠V.sin(Θ)/٣٧٧L. cos(٣٧٧t+Θ)…………..(٢)

I_L(rms) = ٣٤٠V.sin(Θ)/√٢,٣٧٧L at ٦٠Hz ………………………….(٣)

The ripple current that results is:

I_{Lr}= ١٠V/L ∫sin(١١٣١٠t)dt = - ١V/١١٣١L . cos(١١٣١٠t) …………………..……....(٤)

$I_{Lr(rms)}$ = ١V/√٢. ١١٣١L at ١,٨ kHz………………………………..(٥)

$I_{Lr(rms)}$/$I_{L(rms)}$ ≈ ٠,٠٠١/sin(Θ) ≈ ٠,٠٢٨ for ٢Θ=٤° ……………………(٦)

The power factor at the fundamental current angle Θ, disregarding ripple, is:

PF = cos(Θ) ≈ ٠,٩٩٧٥٦ for ٢Θ = ٤°٥ ………………………(٧) [١٦]

٢,٣ *Motor Control:*

AC motors are not as simple to control as DC motors because there are two variables to regulate instead of one: amplitude and frequency. This work does not take the approach of field-oriented control (FOC), which requires many motor parameters and a shaft speed sensor. There is no standard for shaft speed sensing; the EV١ used a custom ١٢٨-line sensor built-in to the transmission assembly. Speed sensors are often costly and difficult to add, and most AC motors have no published parameters. Speed estimation is a difficult task, and V/Hz control is not sufficient by itself because it requires a speed command which is unsuitable for automobiles. [٤,١٨]

٣. SLAVE MODULE DEVELOPMENT:

٣,١ *Hardware Design One:*

٣,١,١ Power Section:

The conduction loss for the module operating at the maximum RMS phase current of ١٥٠A is continuously ٤٥W assuming a ١m on-resistance from temperature rise.

This can be spread fairly evenly across the four MOSFETs with certain techniques.

Though ٤٥W is high for the module's size, it is encapsulated in thermal epoxy and such a current will be rare. Note that a ٧٥A current will produce one-quarter this loss. Neither the motor nor the batteries will be able to stand ١٥٠A for long because of resistive heating. The total module switching loss for one transition cycle can be approximated as:

$E_{loss} = V_{bat} I_{phase} (t_r + t_f)/٢$ joules……………………..(٨)

The energy stored in a stray inductor can be calculated with the following standard equation:

$E = LI^{٢}/٢$ joules. ……………………………………(٩)

٣,١,٢ *Microcontroller*:

Cost is the most important factor in selecting microcontrollers for the slaves because of the sheer number (typically ٤٥–٦٠) that will be in a vehicle.

The ATTiny٢٤ offers an adjustable internal clock, a ١٠-bit A/D converter, nearly one instruction per cycle, data EEPROM, and self-programmable Flash memory [١٦]. A serial port peripheral is not important to have, since it easily can be implemented in software. The ATTiny٢٤ can clock itself up to about ١٦ MHz without an external crystal; ١١,٢٥MHz will be used to coincide with the ٩٣٧,٥kBd serial transmissions, giving twelve cycles. Up to ١٠٠٠ instructions can be Stored in the processor's non-volatile memory and it has enough pins for all the necessary functions. [١٩]

These include two main gate drive outputs (both with LEDs), a gate driver enable line, two DC/DC converter gate drive outputs, voltage and temperature sense lines, transmit and receive lines, and an input button (actually on the reset pin).٣٤ The ATTiny٢٤ supports up to ٥V operation.

٣,١,٣ *DC/DC Converter:*

Due to the isolation of batteries, generating a ١٢V vehicle accessory supply (for headlights, etc.) is difficult. It requires each module to have an individual high frequency transformer and two small MOSFETs driving it, here in a push-pull configuration for ease of gate drive. Each module should be able to supply about ٢A of output current at ١٢V; ٤٥ of these paralleled outputs would equal ٩٠A total, comparable to an alternator in an internal combustion engine vehicle. The GM EV١ requires a high-voltage supply, nominally the same as the twenty-six ١٢V batteries in series, ٣١٢V. Twenty-four ١٢V outputs in series (instead of parallel for conversion electric vehicles) would make ٢٨٨V, perfectly acceptable for this purpose. [٢٠]

٣,١,٤ *Printed Circuit Board:*

The first hardware design does not call for a four-layer PCB; a two-layer with added copper thickness is acceptable. The extra copper aids in current conduction and heat spreading/dissipation. The board was designed in Cadence OrCAD Layout and produced by Silver Circuits in Malaysia. The design one slave's schematic can be seen in Figure (٧).

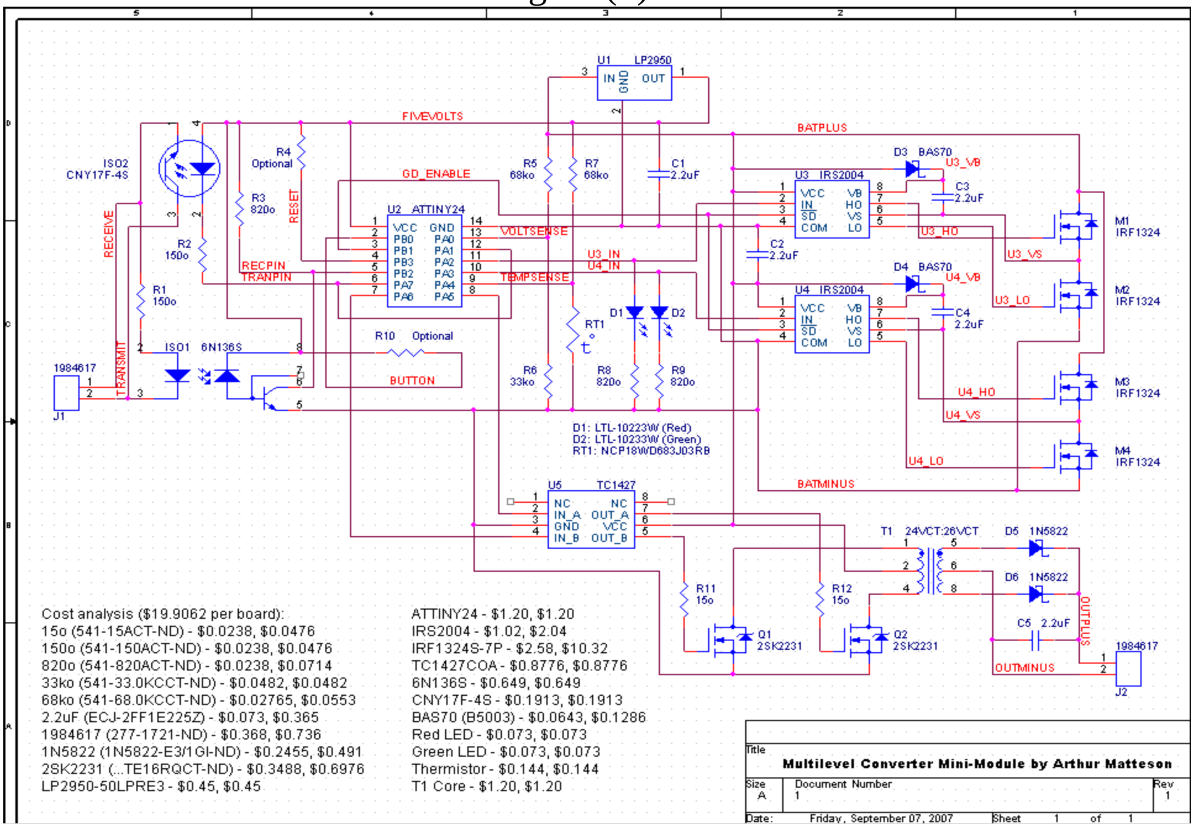


Fig.(٧) Slave module design one schematic.

٤. MASTER MODELE DEVELOPMENT:

٤,١ Hardware Design:

The dsPIC٣٠F٤٠١١ DSC is the heart of the master module [٧]. It provides slave communication signals, throttle and current A/D inputs, contactor signal outputs, USB signals, as well as others. It is available as a ٥V-capable, ٤٠-pin DIP or ٤٤-pin TQFP (thin quad flat pack). In this work, the DIP is chosen because it can fit into an inexpensive ZIF (zero insertion force) socket for replacement, instead of needing to be disordered like the TQFP. Five volts is the only voltage node that supports full-speed operation, or ٣٠MIPS, so the supply bus voltage is an easy decision.

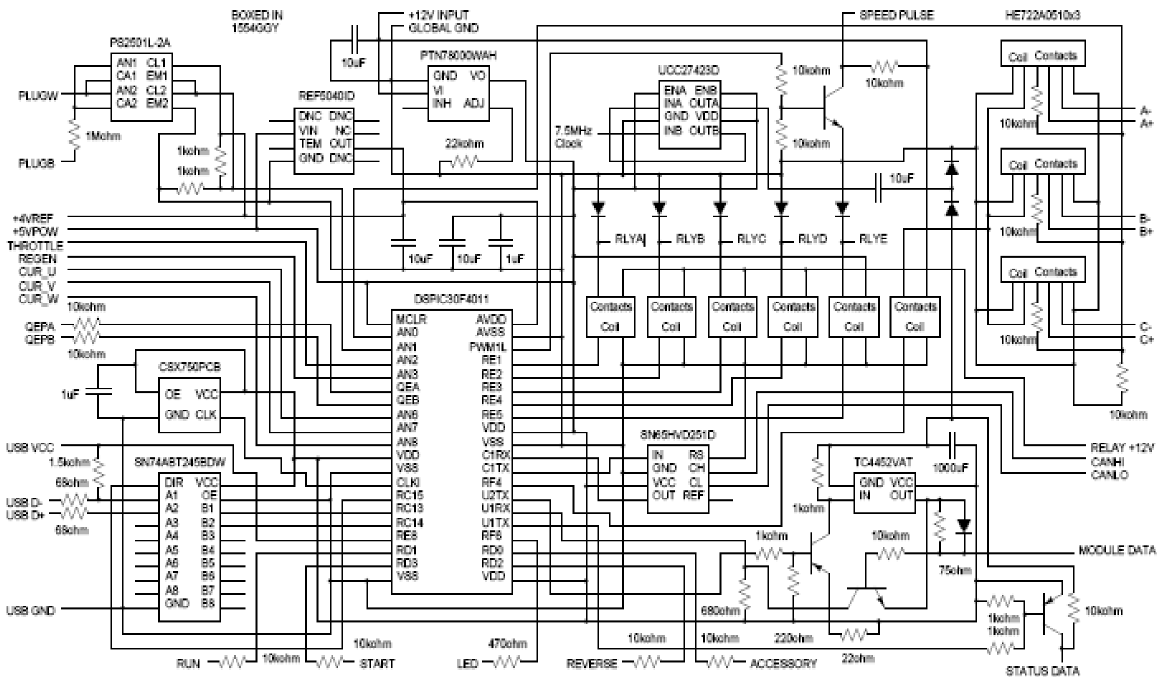


Fig.(٨) Master Module Design One Schematic. [٢٠]

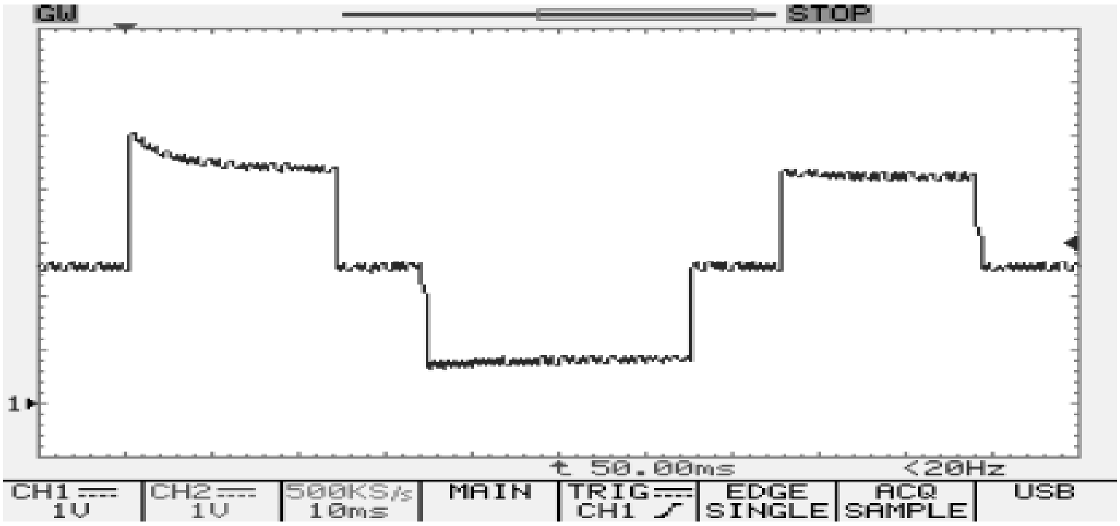
٥.RESULRTS:

Various results have been recorded in this work. Most are either oscilloscope graphs or matplotlib graphs of USB-acquired data from the master module.

Figures (٩),(١٠), and (١١) are oscilloscope plots of a slave module's operation.

The first shows a current waveform with ±١٣٠A peaks, demonstrated with an approximately resistive load (halogen light bulbs). The second depicts a slave MOSFET going into avalanche conduction. Since the MOSFETs are rated for ٢٤V, the ٢٣V peak is fairly accurate. The duration of the avalanche pulse is ١,١٦µs. The module in question had only four IRF١٣٢٤Ss populated. The third shows two ٨٠٠ns dead-times of a module performing PWM. These dead-times are necessary to prevent cross-conduction and energy waste.

voltage



Time

Fig.(٩) Slave module output. Current waveform, ١٣٠A peak.

Voltage

Fig.(١٠) Slave module MOSFET Avalanche waveform, ٢٣V peak.

Voltage

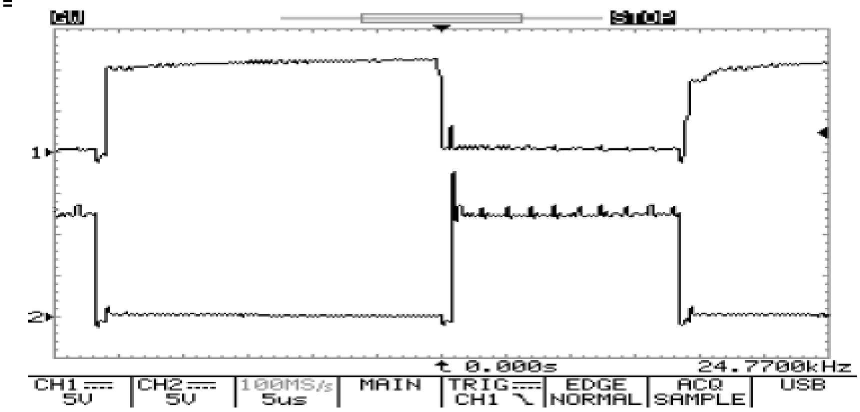


Fig.(١١) Slave module PWM illustrating an ٨٠٠ns Dead Time Voltage.

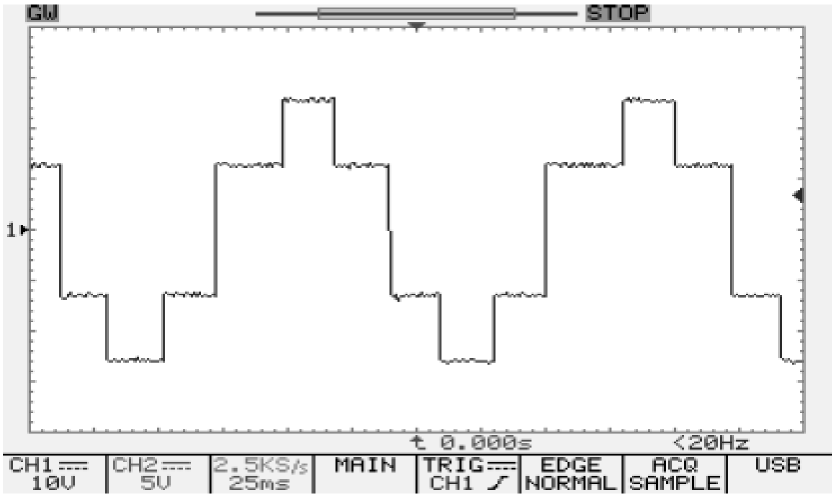


Fig.(١٢) Line-to-line Inverter output voltage, six total slave modules.

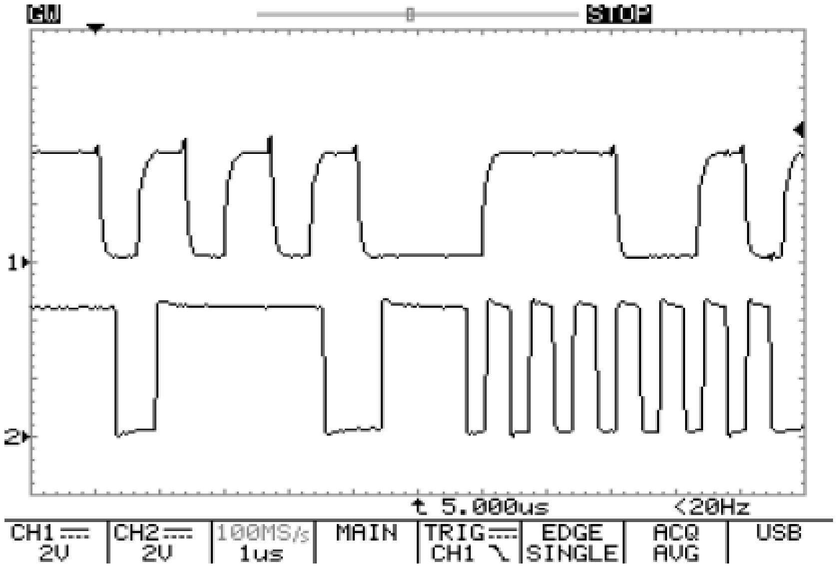


Fig.(١٣) Design Master multitasking during a USB transfer.

Figure (١٢) is a plot of a line-to-line voltage with six total batteries and slave modules. No PWM is being conducted here.

Figure (١٣) shows the design-one master's availability during a USB transfer. The lower curve's high time represents time during which the master can send out module tokens. The upper curve shows the USB D- line.

٦. CONCLUSIONS:

The first system design was functional enough to demonstrate the multilevel inverter topology. It moved the EV١ about five feet, limited only by the garage length, with six batteries and battery modules. Torque control was demonstrated on a rewound ٣/٤HP induction motor. The slave modules unfortunately had reliability issues, mainly under no load. The IRS٢٠٠٤ gate drivers never functioned properly and would explode without warning. The master's token buffering was difficult to implement and only moderately reliable—some of the problems were never fully debugged. Not being able to turn on the slaves' outputs continuously was a major disadvantage for debugging.

Finally, the master's USB interface was second-rate.

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دراسة وتنفيذ مسيطر للاستخدام فى مبدلات انظمة التوليد

أ. م. د. كريم كاظم جاسم

المهندس مهدى سرحان

مركز بحوث الطاقة والطاقات المتجددة

الجامعة التكنولوجية

الخلاصة:

يتضمن العمل فى هذا البحث احدى طرق السيطرة فى مبدلات الطور الواحد المستخدمة فى منظومات القدرة الواطئة والمتوسطة والتى تستخدم فى تصميم مصادر الطاقة الشمسية وطاقة الرياح ومن الامثلة على ذلك السيارات الهجينية والبيوت الشمسية والمستشفيات التى تتطلب مصادر طاقة نظيفة وكفوءة وبلا انقطاع.

وفى حالة استخدام هذه المبدلات لتشغيل المركبات فان حجم وكتلة هذه المبدلات تقلل من مكان الخزن للطاقة فى هذه

المركبات. ويكون الحل المثالى لتجهيز مبدل صغير لشحن بطارية واحدة لكى تكون شحنتها محفوظة وتزود موجة جيبية ذات تشويش واطىء الى محرك المركبة المستخدمة.

ويظهر هذا العمل ايضا تطوير هذا المبدل المتعدد المستوى . كما تم بناء وتنفيذ نوعين مختلفين من هذه المبدلات.