

# Microinverter Using Li-Ion Battery

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**Abstract.** The micro-inverter is small, compact source of energy and can provide a single-phase output voltage of 230v and support a load power of 150W. This microinverter can be used to power up devices such as Wi-Fi routers, mobile chargers, Closed-Circuit Television (CCTV) cameras, emergency medical equipment, emergency lights, etc. The DC power required for the inverter is obtained from the stack of Li-ion batteries connected in a series-parallel combination. The charge controller ensures the charging of the individual battery of the stack has a balance of charging and provides the protection required for the battery. Existing microinverters use lead acid battery. The proposed converter uses Lithium-ion batteries as they are more efficient compared to lead acid batteries and require less space, have low self-discharge, and have higher energy density. The charge controller has been designed and simulated. The final circuit is fabricated on a Printed Circuit Board (PCB) which ensures uniform charge distribution optimizing the size and heat dissipation. The inverter uses a modified sinusoidal pulse width modulation signal generated by a PIC microcontroller. The H-bridge configuration uses MOSFET as a switch and is driven by opto-isolators. The 12V AC output of the H-bridge is converted into 230V ac using the step-up transformer. Testing of the project is carried out at individual stages, and the results are verified with theoretical values.

## 1 Introduction

The low-voltage DC sources, such as batteries, solar panels, or fuel cells, need to be converted using inverters to power-up critical appliances such as modems, CCTV cameras during power failures. The conventional Uninterruptible Power Supply (UPS) uses lead acid battery technology which is bulky with limited transient capabilities. The Li-ions batteries provide high power with longer back-up for the weight of the batteries considered. These batteries also provide better transients while switching over from the main supply to inverter. A two stages conversion is required to complete the process of inverting low-voltage DC into AC. The first phase involves turning a low-voltage DC source into a high-voltage DC source, and the second involves applying pulse width modulation to turn the high-voltage DC source into an AC waveform. Another approach which is most common in low-cost back-up UPC is to first obtain low-voltage AC from available DC source and then use a step-up transformer for obtaining the standard 230 volts. In this project the second method is employed.

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A modified Sinusoidal Pulse Width Modulation (SPWM) of the available DC voltage generates a true sine wave instead of the square wave while maintaining the same average power and RMS voltage. These inverters are appealing choices since they are significantly less expensive than pure sine wave inverters [1]. Moreover, the critical equipment which are power by these inverters does not require a pure sine waveform as they have internal ac-dc rectifiers. The low harmonic produced by these devices ensures quieter operation of motor loads and lower flickering in (Light Emitting Diode (LED) lights. It also produces better efficiency in electrical equipment due to better waveshape.

## 2 Li-ion Battery Charging

### 2.1 Li-ion battery

Lithium-ion (Li-ion) batteries are preferred rechargeable batteries mostly used in handy electronic gadgets, electric vehicles, and solar based systems. They are preferred over other types of rechargeable batteries as they have better energy density, lower rate of self-discharge, and larger life cycle. Here are some key facts about lithium-ion batteries [2][3]:

- Li-ion batteries use lithium ions as the charge carrier, which during charging and discharging shuttle between the anode (positive electrode) and cathode (negative electrode). The anode is typically made of graphite, while the metal oxide, such as lithium cobalt oxide (LiCoO<sub>2</sub>), lithium manganese oxide (LiMn<sub>2</sub>O<sub>4</sub>), or lithium iron phosphate (LiFePO<sub>4</sub>) is used for cathode [6].
- Li-ion batteries have a greater energy density than rechargeable batteries, such as nickel-metal hydride (NiMH) or nickel-cadmium (NiCd) batteries. This implies that the energy per unit volume is much higher.
- Li-ion batteries have a low self-discharge rate, which means they can retain their charge for longer periods of time when not in use [4].
- Li-ion batteries have a higher cycle life, which means that without significant loss of capacity the number of times they can be charged and discharged is much higher. However, their capacity may cease over time due to overcharging, deep discharging or due increase in temperature.
- Li-ion batteries require a precise monitoring circuit for safeguarding against overcharging, over- discharging, and short-circuiting. This circuit is commonly added into the battery pack or to the gadgets that uses these batteries [4].
- Li-ion batteries are susceptible to temperature variations and can be damaged if exposed to extreme temperatures. The recommended operating temperature range for most Li-ion batteries is zero degree C to 45 degree C. Li-ion batteries should be recycled properly to prevent environmental pollution and to recover valuable materials, such as cobalt, nickel, and lithium. Many countries have established recycling programs for Li-ion batteries [4].

## 3 Charging methods

The Constant Current (CC)- Constant Voltage (CV) charging method ensures that the battery is charged efficiently and safely. During the CC stage, the charging current is kept constant, which ensures that the battery is charged quickly and efficiently[2]. During the CV stage, the voltage is kept constant, which prevents the battery from overcharging and damaging itself. Lithium-ion batteries are rechargeable energy storage devices mostly used in smaller gadgets such as mobiles, laptops, and bigger loads such as electric vehicles because of their larger energy density and longer cycle life [4].

### **3.1 CC-CV charging method**

The charging method for lithium-ion batteries typically involves three stages: constant current, constant voltage, and trickle charging.

- In the first stage, continual current charging, to get the standard 3.7V the battery is charged with a constant current. This stage is used to quickly charge the battery and can be controlled by adjusting the charging current. The constant current stage can take up to 80% of the total charging time.
- The second stage, constant voltage charging, is used to reach the maximum battery capacity. The voltage is held constant while the charging current slowly decreases. The voltage level is typically set at 4.2 volts per cell. Once the battery reaches this voltage, the charging current is reduced to maintain a constant voltage. This stage can take up to 20% of the total charging time.
- Finally, the third stage, trickle charging, is used to maintain the battery at its maximum capacity. During this stage, the voltage is reduced to a lower level, and the charging current is very small. This stage helps to protect overcharging of the battery and can be used for long-term storage of the battery. It is important to keep in mind that lithium-ion cells should only be charged using a charger explicitly designed for lithium-ion batteries, as charging with an incorrect charger can lead to damage or even an explosion. Additionally, overcharging or overheating of the battery can also cause damage or failure, so it's important to monitor the cell during the charging process and avoid charging the battery in extremely hot or cold environments.

Overall, the CC-CV charging method is a reliable and efficient way to charge lithium-ion batteries.

## **4 Protections**

### **4.1 Over voltage protections**

Lithium-ion battery chargers typically have over-voltage protection circuits to avoid damage to the battery or associated components in the charging circuit. The over-voltage protection circuit works by monitoring the voltage of the battery during charging. If the voltage rises above a certain threshold, typically around 4.2 volts per cell, the protection circuit will take action to prevent further charging.

### **4.2 Balance charging**

To guarantee that each cell in a battery pack is charged to the same level, balance charging is a crucial technique employed in battery charging circuits. By using this method, it is possible to avoid undercharging some cells while overcharging others, which can lower battery capacity, shorten battery life, and present safety risks including overheating or explosion. Cell balancing circuits, charge control algorithms, active cell balancing, and passive cell balancing are some of the methods utilized to accomplish balance charging. In order to ensure the secure and effective charge of battery packs, balance charging is a crucial approach in battery charging circuits. It helps to prolong the battery life, improves safety, and optimize battery performance.

### 4.3 Over current protections

The LM317 is utilised in this circuit for over current protection. By connecting an external resistor between the adjust (ADJ) pin and the output pin, the LM317, a flexible three terminal adjustable voltage regulator, can also be utilised as a current regulator. The value of this external resistor then determines the current flowing through the load. Here, a 220 ohm resistor is connected to generate up to 600 mA of current. A 5k ohm pot is linked in series with a resistor to control the current.

## 5 Hardware Schematics

The hardware schematic is shown in Fig 1. Hardware for the battery charger uses LM317, a flexible three terminal adjustable voltage regulator, which can also be utilised as a current regulator by connecting series resistance between adjust and output pin. The LM339N voltage comparator is used to compares the battery voltage to reference voltage and produces 4.2 volt at the output side. Battery charging and over-voltage protection are both accomplished by transistor BD140. When 12V DC voltage is supplied to the battery charger circuit, it flows via the transistor emitter to the collector and charges the battery up to the voltage level corresponding to the ref voltage of the comparator. When the voltage is reached, the battery will no longer be charged because the power will flow through the transistor's base to the ground. This will be indicated by the LED.

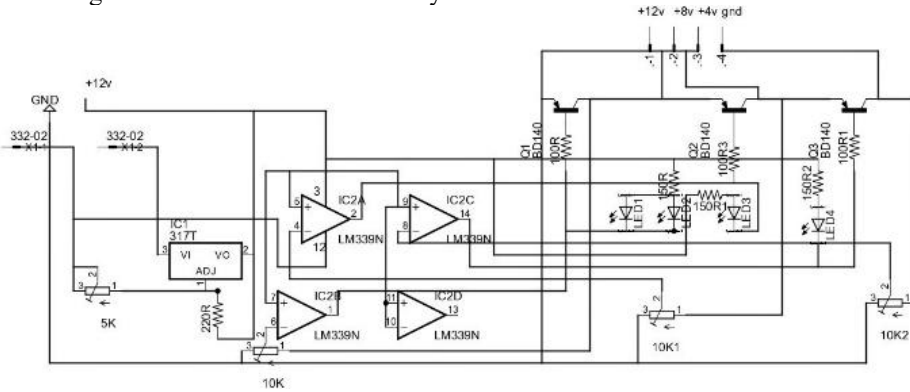
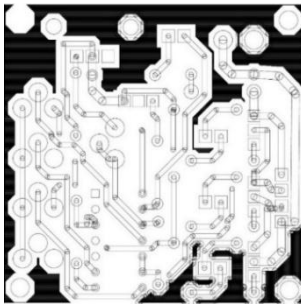
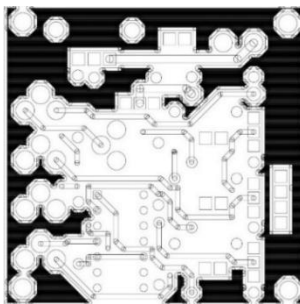


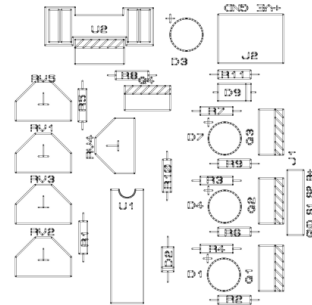
Fig. 1. Hardware Schematic



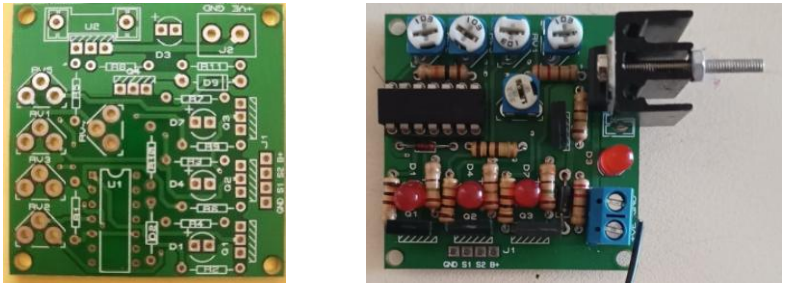
(a) Top layout



(b) Bottom Layout



(c) Assembly



(d) Battery Charge Controller PCB (e) Final assembled Battery Charge Controller

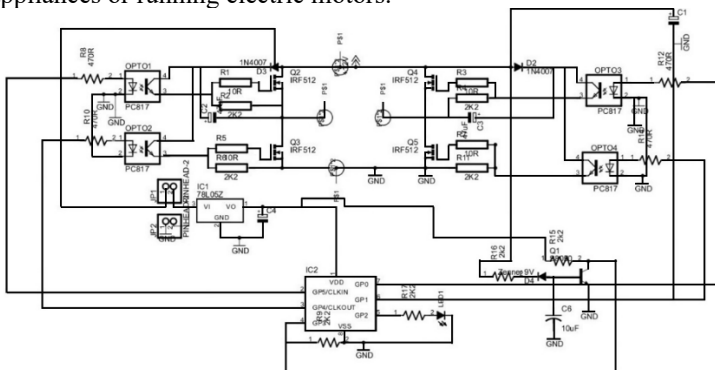
**Fig. 2.** Hardware implementation of Battery Charger

## 6 Inverter

A 12V to 230V H-bridge inverter is an electronic circuit that can convert a low DC voltage of 12V into a high AC voltage of 230V using an H-bridge configuration. The H- bridge is a circuit that allows the voltage to be switched between positive and negative, which is necessary for creating an AC voltage. An 4 MOSFET H-bridge with individual control to provide alternating voltage in each half cycle is used here. This creates the square shape with  $\pm$ DC voltage which then can be wave shaped to match the required AC waveform.

The input voltage of  $V_{DD}= 12V$  is first converted into a square wave using a pulse width modulation (PWM) technique. The PWM signal is then fed into the H- bridge, which consists of four switches (transistors or MOSFETs) arranged in a square configuration. Sinusoidal Pulse Width Modulation (SPWM) is a technique that can generate a more accurate sine wave output compared to a square wave PWM. The main advantage of using SPWM is that it reduces harmonic distortion, resulting in a cleaner output waveform. The H-bridge allows the output voltage to be switched between positive and negative, which creates an AC voltage. When one pair of switches are switched on, the output voltage is positive, and when the other pair is switched on, the voltage at the output is negative. By switching the pairs rapidly, the H-bridge creates a square wave with a frequency of 50Hz (or 60Hz in few countries) and an amplitude of 230V. The H- bridge output is filtered to remove the high-frequency components and to smooth out the waveform.

The output voltage can also be regulated by adjusting the duty cycle of the PWM signal. Overall, a 12V to 230V H-bridge inverter is a simple but effective way to generate a high AC voltage from a low DC voltage. It's commonly used in applications such as powering household appliances or running electric motors.



**Fig. 3.** Schematic of inverter

## 6.1 Sinusoidal PWM

The SPWM technique is an effective way to create a high-quality AC output voltage in micro inverter circuits from a DC input voltage. It is frequently employed in systems like solar power systems and uninterruptible power sources.

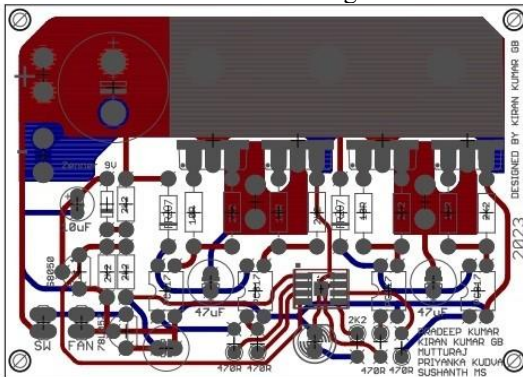
An input voltage of 12V is regulated to 5V using the 78L05 to PIC12f683. The modified PWM is created using the PIC 12f683. Pure sine wave via PWM, the carrier frequency used in this code is 50Hz. The output voltage can also be regulated by adjusting the duty cycle of the PWM signal.

Both under voltage and short circuit protection is provided in the microinverter circuit. PIC12F683 an 8-pin, 8-bit PIC microcontroller is used to generate the modified PWM. Algorithm used for SPWM generation using PIC12F683 can be listed as below.

- Configure input pins as outputs (GP0, GP1, GP4, GP5)
- Configure modules for PWM operation (GP4, GP1)
- Timer 2 for PWM frequency (50 Hz)
- Set initial duty cycle
- Initialize SPWM variables
- Calculate SPWM step size based on frequency and look-up table size
- If condition for short circuit detection and delay of 10ms to current to stabilize
- If no short circuit generates SPWM signals on GP5 and GP0.

## 6.2 PCB design of Inverter

The inverter PCB is designed using EAGLE electronic design automation (EDA) software tool. The designed micro-inverter has 230V, 150W output, and can run an ac load. The testing of the microinverter is done at stages and at different battery voltage and loading scenarios.



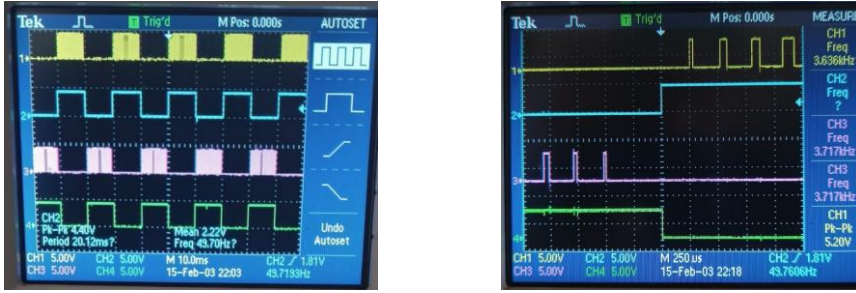
**Fig. 4.** Inverter PCB



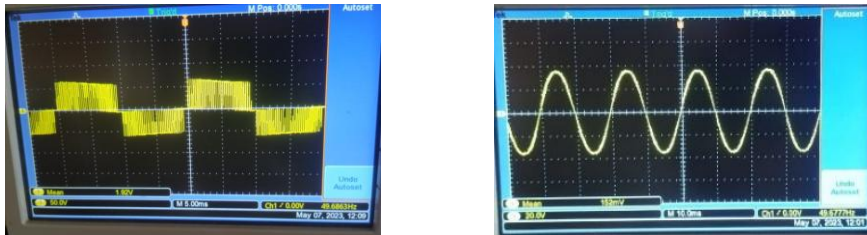
**Fig. 5.** Final Inverter PCB Assembly

## 7 Results and Discussion

Fig. 6 shows the SPWM signal generated. Here 50 Hz frequency is used as the reference. SPWM is generated only for half cycle as H bridge serve the purpose to generate negative or positive cycle. Modified SPWM improves the overall shape of the output waveform reducing the harmonic content.

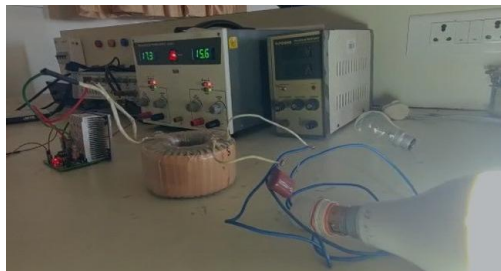


**Fig. 6.** Modified SPWM generated by DSPIC

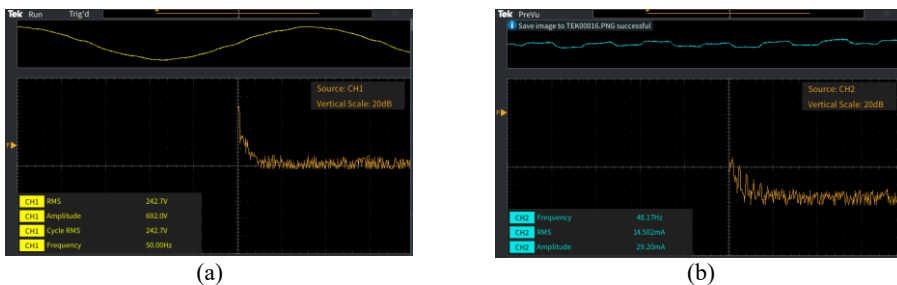


**Fig. 7.** Inverter PWM output and Sinusoidal waveform

Above Fig. 7 indicates the output waveforms at the output of the inverter and at the output of step-up transformer. The complete assembly of the hardware set-up is shown in Fig 8. The circuit can drive a load of 150W when the charger is connected to 12V, 6Ah Li-Ion. This set-up provides a continuous power supply for a duration of 30min when inverter is connected to a laptop. When powering smaller devices like LED bulb of 12W it provides 6-7 hrs of back-up without any issues. The cost of the overall se-up is comparatively higher as compared to lead acid battery-based inverters. But due to advantages of the Li-ion battery, its charging cycles, and its life, these Li-ion battery-based inverters can replace the existing inverters.



**Fig. 8.** Complete micro-inverter powered by laboratory RPS supplying LED bulb (22W)



**Fig. 9.** FFT of the output (a) voltage and (b) current

The FFT analysis of the output voltage and currents are carried out using high end Digital Storage Oscilloscope and are shown in Fig. 9. The above FFT analysis indicate that the Total Harmonic Distortion (THD) of the output voltage when measured at 20% of full load is around 10% and at full load around 5%. The THD of the output current is also well withing the above limit. The drawback of the proposed technology is that it uses bulky step-up transformer.

## 8 Conclusion

The paper discusses the implementation of microinverter for smaller electronic gadgets. This inverter uses Li-ion batteries in place of traditional lead acid batteries and shows promising results. The battery management system is designed to charge the battery at constant current and constant voltage based on the SoC of the battery and also prevents overcharging of the battery. The PCB for the BMS circuit is designed using Ki-CAD software. The efficiency of the battery charging is above 90% and can be improved if battery balancing is also implemented. The charged battery is then connected to microinverter using MOSFET H-bridge. The SPWM technique is implemented using PIC microcontroller. The overall THD of the output waveform can be improved with modified SPWM technique. The inverter PCB is designed to power up the load of 150W which can be used to provide faithful back-up to smaller gadgets like modems and emergency medical equipment.

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## References

1. S. B. Kjaer, and F. Blaabjerg 2003, "Design Optimization of a Single-Phase Inverter for Photovoltaic Applications," IEEE 34th Annual Power Electronics Specialist Conference. 2003. PESC '03., 15 June 2003 - 19 June 2003, Acapulco, Mexico, Volume **3**, ID.36 DOI: 10.1109/PESC.2003.1216616
2. Chen G-J, Chung W-H. Evaluation of Charging Methods for Lithium-Ion Batteries. *Electronics*. 2023; **12**(19):4095. <https://doi.org/10.3390/electronics12194095>
3. Guo S, Han Z, Wei J, Guo S, Ma L. A Novel DC-AC Fast Charging Technology for Lithium-Ion Power Battery at Low-Temperatures. *Sustainability*. 2022; **14**(11):6544. <https://doi.org/10.3390/su14116544>
4. Young, Chung-Ming & Chu, Neng-Yi & Chen, Liang-Rui & Hsiao, Yu-Chih & Li, Chia-Zer. (2013). A Single-Phase Multilevel Inverter With Battery Balancing, *IEEE Transactions on Industrial Electronics*. **60**. 1972-1978. 10.1109/TIE.2012.2207656.
5. DNK Power, "Battery Knowledge", <https://www.dnkpower.com/gel-cell-battery-vs-lithium-ion-battery/>(accessed December 11, 2024)
6. A Mamun A, M Elahi, M Quamruzzaman, M Tomal, 2013 "Design and Implementation of Single-Phase Inverter" *International Journal of Science and Research (IJSR)*, Vol.2, P 163-167.

7. René Behmann, Jack Phan, Artur Root, Michael Schmidt, Wolfgang G. Bessler, Integration of a lithium-ion battery in a micro-photovoltaic system: Passive versus active coupling architectures, *Solar Energy*, Volume **262**, 2023, 111748, ISSN 0038-092X, <https://doi.org/10.1016/j.solener.2023.05.025>..
8. Maswood. Ali. I & Al-Ammar. Essam "Analysis of a PWM Voltage Source Inverter with PI Controller under Non-ideal conditions" International Power Engineering Conference-193-198. <https://doi.org/10.1109/IPECON.2010.5697104>.
9. Anand. D & Jeevananthan. S, Modeling and Analysis of Conducted EMI Emissions of a Single-Phase PWM Inverters, *Asian Power Electronics Journal*, Vol. **4**, No.3 December 2010.
10. René Behmann, Jack Phan, Artur Root, Michael Schmidt, Wolfgang G. Bessler, Integration of a lithium-ion battery in a micro-photovoltaic system: Passive versus active coupling architectures, *Solar Energy*, Volume **262**, 2023, 111748, ISSN 0038-092X, <https://doi.org/10.1016/j.solener.2023.05.025>.