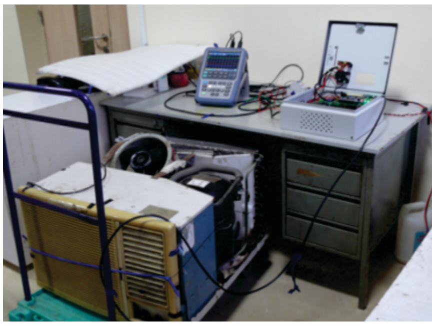
HVAC System

10

Solar Powered Two Phase Variable Frequency Inverter Drive

Ashish Kumar Pandey*, Mahesh B. Patil, Vivek Sanadhya and S. Mukhopadhyay
Control & Instrumentation Division, Bhabha Atomic Research Centre, (BARC), Trombay-400085, INDIA



Hardware Full Load Test set up

ABSTRACT

This paper demonstrates the design and development of a two phase variable frequency drive (VFD) utilizing Insulated Gate Bipolar Transistor (IGBT) module in a three-leg inverter topology to control speed of single phase Induction Motor(IM) driving fixed speed reciprocating or rotary compressors, which are commonly used in air conditioning applications. The drive is capable of performing capacitor-less operation of single-phase induction motors up to power rating of 3 kW. It can be powered with both Solar PV panel and single phase AC power source. The key industrial features such as inrush current control, soft starting and various protection schemes have been incorporated into the VFD system design. The hardware design of a low-cost, compact inverter stack along with firmware implementation is presented. The Maximum Power Point Tracking-based (MPPT) algorithm have been implemented in the VFD and can be brought in if this solar inverter is the only load on the installed solar panel to maximize power utilization. Testing of the drive housed in a wall-mounted industrial enclosure, was conducted using a 2-TR air conditioning unit and the results are presented.

KEYWORDS: *MPPT, Solar Insolation, Three leg topology, Capacitorless operation, Single phase induction motor*

Introduction

The Heating ventilation air conditioning (HVAC) system powered by single phase 230V, 50Hz power supply make significant part of household/office load and conventionally operates in ON-OFF mode, because of fixed speed operation of compressor motor.

The commonly used single-phase IM in HVAC system are capacitor start (CS), capacitor start-capacitor run (CSCR) and permanent split capacitor (PSC) type which draws high current (8-10 times) at every turn on-turn-off cycle. Also due to fixed speed operation it is lossy and less energy efficient system [1]. Recently, HVAC system integrated with BLDC motor driven compressors in part load applications instead of IM was developed to increase system efficiency, ease of operation etc. However, this approach suffers from high capital costs. Moreover, this HVAC inverter systems powered by solar power have additional requirement of battery & associated controller [2].

This paper describes the design of a low cost VFD system which can be powered with solar PV panels without battery. This leaves an opportunity to run the same HVAC system on single phase 230V, 50Hz supply during night time when solar power is not available. The block diagram (Fig.1) shows that the main and auxiliary windings of single phase IM are connected to two legs, whereas the common point is connected to third leg of inverter. The dc link formed by capacitor C, C1 & C2 can be powered from solar PV panel or Voltage Doubler rectifier.

The signal conditioning board receives the signal from voltage sensors, current sensors and gate drivers. It generates appropriate control PWM pulses to drive IGBTs. The arm base MCU receives and transmits signal to User Interface along and signal conditioning board.

*Author for Correspondence: Ashish Kumar Pandey
E-mail: akpandey@barc.gov.in

Hardware Design and Development

The main challenge was to make the inverter compact, rugged, reliable, efficient, low cost and at par with commercial HVAC inverters. The low cost, compact (60mm x 55mm) SEMITOP series, Trench-4 IGBT module is used as inverter bridge. Each IGBT is driven by PWM switching pulses of magnitude +15V and -7V generated by optocoupler isolation based gate driver IC. Short circuit protection and under voltage protection are integrated in the gate driver IC. It conforms to UL 1577 and IEC60747-5-5 regulatory requirements.

The PV input voltage(V_{pv}) and DC link voltage measurement are carried out by high impedance isolated amplifier[5]. The amplifier has high input voltage range of 2V, ±20uV/^{o}C drift error and high CMTI with fail safe mode operation. It provides galvanic isolation between high voltage DC link and signal electronics and enables accurate measurement of DC link voltages. The sensitivity of voltage sensors are 4.5mV/V .The DC link current (I_{dc}), PV input current (I_{pv}) and motor phase currents are measured by industrial grade, high precision isolated hall effect current sensor with accuracy of <=1% and sensitivity of 100mV/A. The hall effect sensors[6] provides CMTI of <=50kV/us and CMRR of 5uA/V with bipolar provision of current measurement.

The high temperature grade, high Comparative tracking index (CTI) Power PCB (Fig.2) with dimension 210mm x 160mm, 2mm thickness, was developed with integrated module type IGBTs mounted over aluminum heat sink. The power board houses the isolated voltage sensor, hall effect current sensor, gate driver for individual IGBTs, NTC temperature measurement, and short circuit protection circuitry. The layout design is carried out with IPC2221A directives and meeting standard EMI, EMC guidelines to minimize effect of high voltage noise on low voltage signal electronics. The board is designed with the voltage rating of

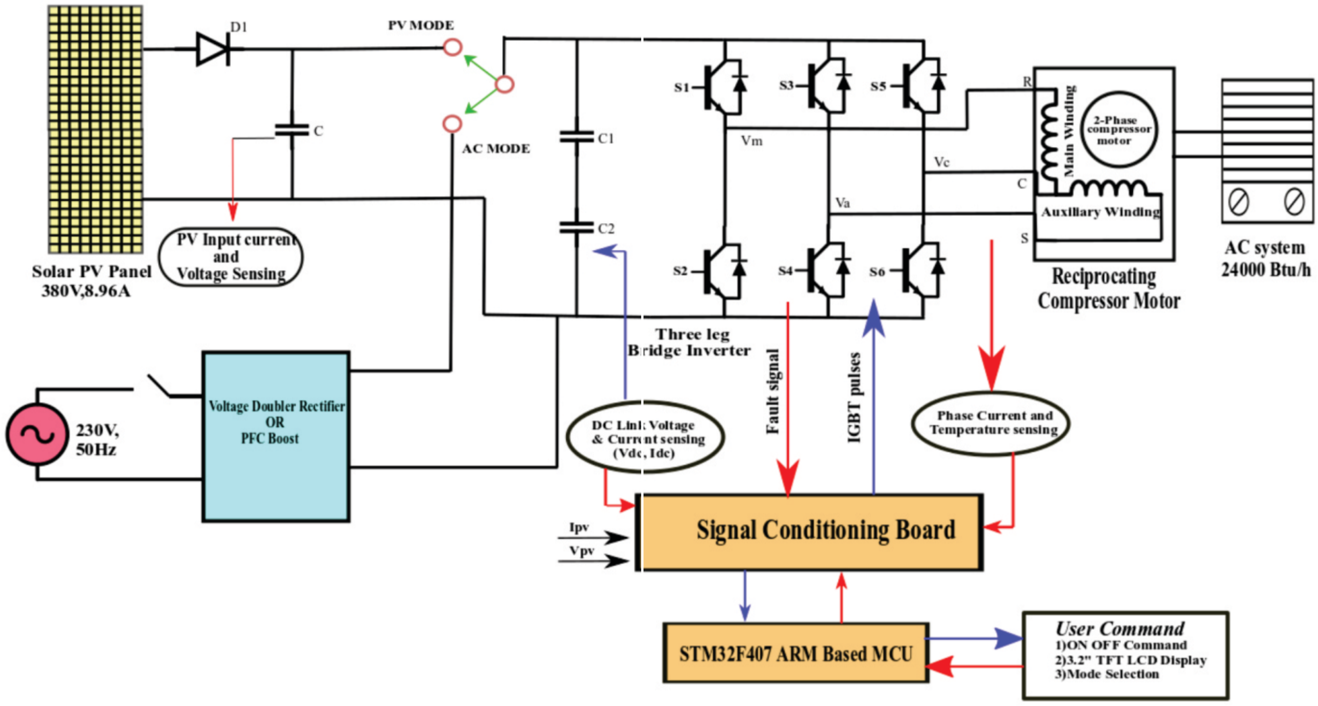


Fig.1: Block diagram of Air conditioning compressor drive powered by both solar power and 1-phase 230V, 50Hz AC supply.

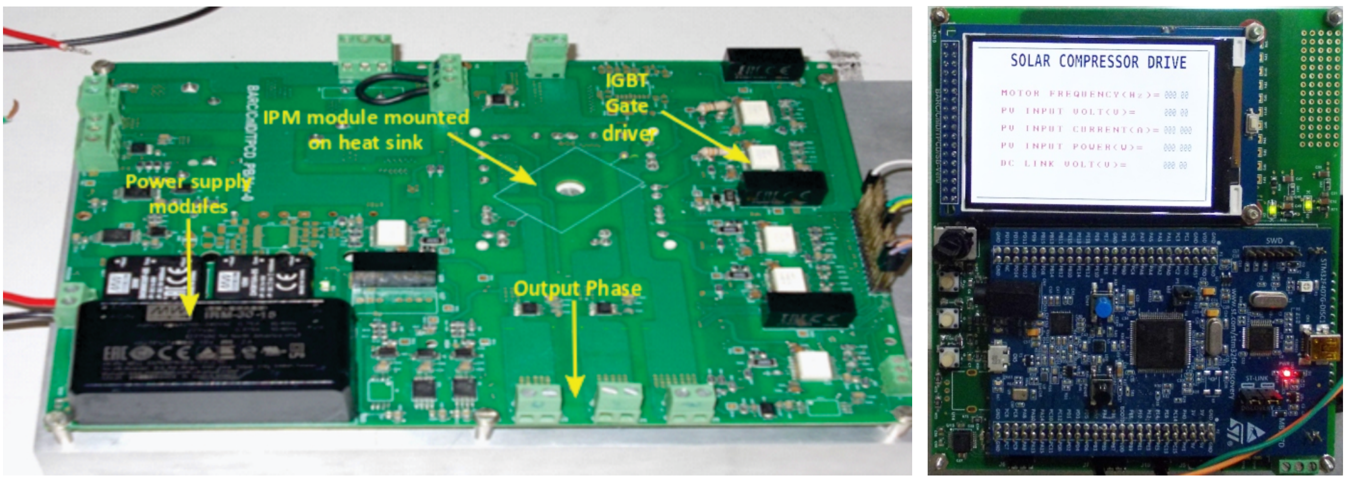


Fig.2: Power board with three leg IGBT Inverter module mounted on heat sink and Signal board with ARM based MCU unit, 3.2" LCD module and user interface.

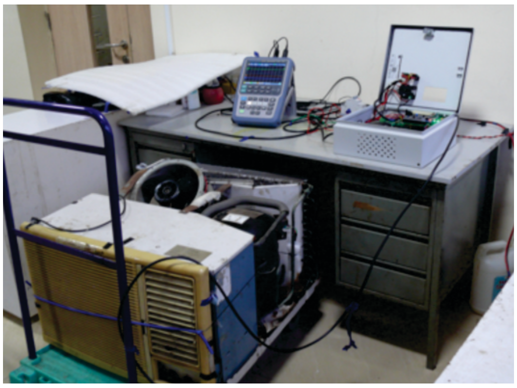
1kV and track width to support 25Arms current. Phoenix make terminal connectors are provided on the board for connecting input power source from PV panel or 1-ø 230V, 50Hz and motor terminals directly. The Signal board (Fig.2) was developed which have microcontroller unit(MCU),operational mode selector rotary switch (Fig.3) and 3.2" TFT graphics LCD which displays essential parameters. The differential and single ended signals received from power board are conditioned by operational amplifier circuitry [7]. The signal board is mounted over the power board and housed in a wall mounted metal enclosure panel (Fig.3) with external MCBs and panel mounted switches.

Software Development

The control algorithm is implemented on a ARM based, 168MHz, 32bit MCU unit which have advanced PWM generation timers for motor control application. The two windings of single phase IM are powered with two orthogonal generated phases which ensures capacitorless operation and run as a two phase motor with a net starting torque. A carrier based Sinusoidal pulse width modulation (SPWM) technique is implemented to generate 90^0 phase shifted IGBT control pulses [3]. The scalar control (constant V/F) algorithm for single phase IM [3] is used to control speed of compressor motor based on the available solar isolation. The Incremental conductance hill climbing MPPT [8] algorithm is implemented to maximize power output from the solar PV panels at any given solar insolation [4]. The drive can be operated in Solar mode and AC mode based on available solar insolation.

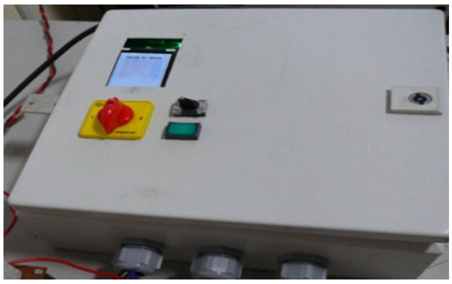
Results & Discussion

The performance characteristics are measured at various solar insolation by testing in different seasons to estimate the minimum and maximum power requirement of motor with the achieved cooling temperature. The Fig.4 shows voltage and current waveforms of motor windings at a minimum frequency of 14Hz and 31Hz at DC dink of 325V (230Vrms). The voltage developed (Fig.4, c) at motor terminals are switching in nature due to IGBT switching. The current waveforms are smooth and sinusoidal in nature with lower



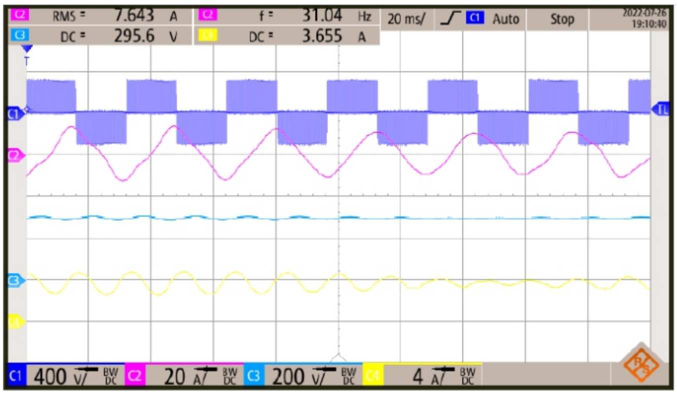
(a) Hardware Full Load Test set up.

(b) Power and Signal Board.



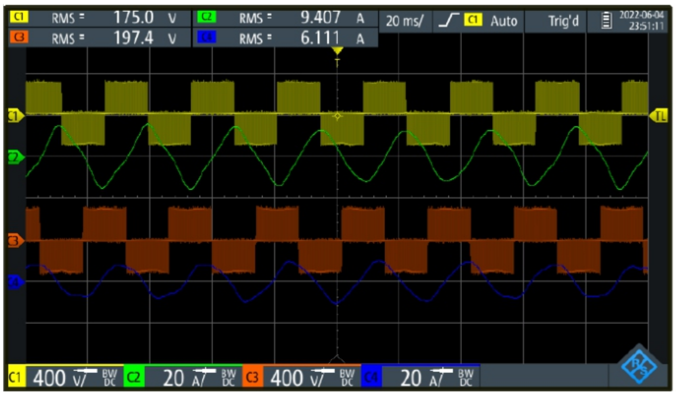
(c) Compressor drive Enclosure.

Fig.3: Air conditioning compressor drive powered test setup. (a) Inverter stack powering 2.3kW Compressor motor in 2-Ton AC unit. (b) Powered board and signal board assembled in a 300mm x 300mm x 210mm IP55 housing. (c) Compressor drive system in a wall mounted IP55 metal enclosure.

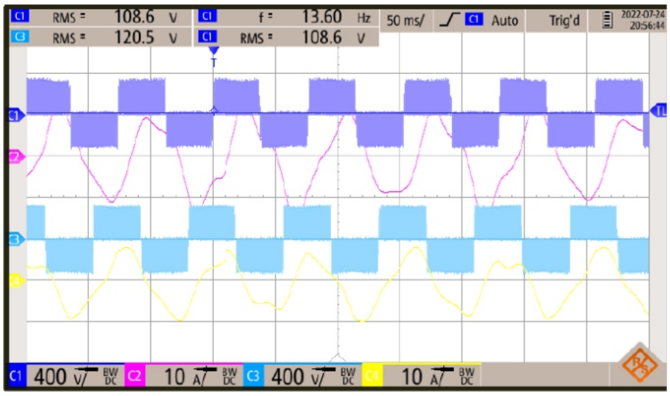


(a) PV voltage & current waveform at 31Hz.

(b) PV voltage & current waveform at 14Hz.



(c) Motor winding voltage & current waveform at 31Hz.



(d) Motor winding voltage & current at 14Hz.

Fig.4: Test waveform at various solar insolation. (a) PV voltage, current main winding voltage & current at 31Hz. (b) PV voltage, current main winding current at 14Hz. (c) Voltage & current waveform at motor windings at 31Hz. (d) Voltage & current waveform at motor windings at 14 Hz.

distortion due to inductive nature of motor windings. The DC link voltage and current waveform are presented in Fig.4 (a,c). The minimum power requirement is around 450W at which the compressor motor runs at 840rpm (14Hz) and attains rated speed 50Hz with 450V(50Hz), 2.2kW input power.

The compressor is able to successfully regulate the temperature from 17°C to 25°C.

Conclusion

A low cost compact 3kW two phase variable frequency drive system is developed for single phase compressor motors. It is interfaced with Solar PV panel and AC source. The low power mode is tested at lower solar insolation levels. The drive system is able to successfully drive a 2.3kW compressor motor at a power input of 450W at speed of 840rpm.The soft starting feature limits input current rise during transient condition to rated values. The low speed operation leads to power saving and speed regulation helps in achieving better temperature control and increased comfort level.

References

[1] A.S. Ba-thunya, R. Khopkar, Kexin Wei and H.A. Toliyat, "Single phase induction motor drives-a literature survey" IEMDC 2001. IEEE International Electric Machines and Drives Conference (Cat. No.01EX485), Cambridge, MA, USA, 2001, pp. 911-916, doi: 10.1109/IEMDC.2001.939428.

[2] Singh, S., & Singh, B. (2015). Solar PV water pumping system with DC-link voltage regulation. International Journal of Power Electronics.

[3] Kumsuwan, Yuttana et al. “A carrier-based unbalanced PWM method for four-leg voltage source inverter fed asymmetrical two-phase induction motor.” The 2010 International Power Electronics Conference - ECCE ASIA - (2010): 2469-2476.

[4] Songbai Zhang, Zheng Xu, Youchun Li and Yixin Ni, "Optimization of MPPT step size in stand-alone solar pumping systems," 2006 IEEE Power Engineering Society General Meeting, Montreal, Que., 2006, pp. 6, doi: 10.1109/PES.2006.1708887.

[5] AMC1311x High-Impedance, 2-V Input, Reinforced Isolated Amplifiers datasheet (Rev. C).

[6] TMCS1101 1.5% Precision, Basic Isolation Hall-Effect Current Sensor With ±600-V Working Voltage datasheet.

[7] OPAx192 36-V, Precision, Rail-to-Rail Input/Output, Low Offset Voltage, Low Input Bias Current Op Amp with e-trim datasheet (Rev. E).

[8] T. Esram and P.L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," in IEEE Transactions on Energy Conversion, vol. 22, no. 2, pp. 439-449, June 2007, doi: 10.1109/TEC.2006.874230.