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Experimental Study of Cooling Performance and Electrical Parameters in a Microcontroller-Driven Inverter AC System

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Abstract

Recent advancements in air conditioning (AC) technologies, such as inverters, enable the compressor to remain activated despite reaching the setpoint temperature. This study investigates the cooling performance and electrical parameters of a split inverter AC system controlled by a microcontroller in order to determine the operational performance characteristics of the air conditioning system. An ATmega 2560 microcontroller integrated with PZEM, DS18B20, and LCD I2C sensors monitors was 8,525 Btu/h capacity split inverter AC. During a 1-hour experimental run, the temperature differential between supply air (T_{supply}) and return air (T_{return}) stabilized at approximately 17 °C, with T_{supply} reaching a minimum of 8.5 °C. T_{return} remained relatively constant after 500 s with no fluctuations. Moreover, power draw maintained an average of 750 W (1 PK) with no variations, exhibiting an inverse relationship with T_{supply}. The maximum energy consumption recorded during the experiment was 1,373 kWh. As expected based on fundamental thermodynamic principles, the energy usage showed a direct proportional relationship with the total runtime of the system. That is, the longer the AC system was engaged, the higher the total energy required to maintain the cooling effect. Overall, microcontroller-based split inverter AC enables real-time performance monitoring and efficient operation, representing a promising technology.

Keywords: Inverter AC System, Microcontroller Monitoring, Performance, Efficiency.

1. Introduction

Air conditioning systems are frequently utilized to optimize indoor environmental conditions for human comfort [1]–[3]. Thermal comfort is defined as the state of mind expressing satisfaction with the thermal environment, which is determined by various physiological and environmental factors. The provision of comfortable environmental conditions in occupied spaces has been correlated with improved workplace productivity and satisfaction. Air conditioning systems are capable of providing thermally comfortable environmental conditions, typically defined as an indoor air temperature range of 20−26°C and relative humidity of 50−80% [4]. Various air conditioning technologies currently exist in the commercial market, including split or ductless systems, centralized units, and window or through-wall air conditioners. Recent advances have focused on improving efficiency, utilizing more environmentally-sustainable refrigerants, and reducing electrical energy consumption through innovations such as inverter-driven compressors. Variable-speed inverter systems modulate cooling capacity to match building load, optimizing energy use compared to traditional fixed-speed equipment [5], [6]. Inverter is a device to change the frequency [7]. Air conditioning units with inverter technology utilize an advanced compressor design that allows the compressor to remain in an activated state even after the target temperature has been achieved. The inverter enables variable speed control of the compressor, differing from traditional fixed-speed AC compressors which can only run at a constant speed. This variable compressor speed capability improves temperature regulation, efficiency, and performance of air conditioning systems with inverter technology compared to conventional fixed-speed units [8]. The advantage offered by this technology is that it is capable of saving electricity consumption.

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In contrast to non-inverter AC where the compressor operates when the temperature changes [9]. There are many advantages to inverter air conditionings compared to non-inverters.

AC performance is affected by various factors such as usage factor, cooling load and refrigerant characteristic factor [10]. Hence, experimental studies regarding air conditionings are suggested to obtain performance in real conditions. In recent years various technologies have been developed for measuring AC parameters such as temperature, relative humidity (RH), power, amperage and electrical energy consumption. Conventional devices such as thermometers, hygrometers and ammeters are slowly being abandoned. The proper technological breakthrough is the microcontroller. Microcontroller technology is a microdevice with a single IC (integrated circuit) chip [3], [11]. Microcontroller can be integrated with various sensors such as temperature and humidity sensors. This technology is popularly applied in various sectors such as industry, transportation, energy [12]. The advantage of this technology is that it is capable of providing real-time measurement results and can reduce conventional methods in order to be more modern and efficient [13]. In addition, the role of the microcontroller refers to the 4.0 revolution era with implementing intelligent and automated systems in order to make research can be more developed and efficient. However, there are still many previous researchers applying conventional methods in their studies.

The study from Presetyo et al. [14] is a performance investigation on a split inverter AC power system. The current study utilizes conventional method. The capacity of the split wall AC investigated is 0.5 PK. Three digital thermometers, and two single manifold gauges were used in this study. The dimensions of the props are 180 cm and 90 cm for the height and width respectively. Study shows the average temperature of the evaporator is 17 °C. The main drawback of this method is that measurement results cannot be provided in real-time. Hidayati's study [15] investigated air humidity in split ACs with a capacity of 18.000 Btu/h. AC with 8 years lifetime is used in this study. The study shows that the maximum temperature is reached at 22.3 °C with an initial temperature setpoint of 20 °C. This research applies conventional methods of measurement. Manual thermometer and RH meter were used in this research for measurements. Study fro Erham et al. [16] shows the design of a new online monitoring system for the coefficient of performance (COP) of air conditioners. The system uses an Arduino Uno microcontroller and various sensors to measure temperatures, pressures, humidity, voltage, and current. The data is then displayed on a laptop screen using MS Excel and PLX-DAQ software. The results show that the proposed method is able to determine the COP quickly and accurately, with a predicted time savings of 2 hours or 80%.

This paper presents research examining a split inverter air conditioning unit with a cooling capacity of 8,525 Btu/h that utilizes microcontroller technology. The investigation analyzes several parameters of the split inverter AC unit, including temperature, electrical measurements such as power, current, voltage, and overall energy consumption. The microcontroller implemented in this study is the ATmega 2560 model. The temperature analysis provides insights into the cooling performance of the split inverter AC system. Examining the electrical parameters allows for an understanding of the power consumption characteristics and operating efficiency of the unit. In particular, current and voltage measurements enable calculations of the electrical power usage. Monitoring the overall energy consumption reveals the total electrical energy required for operation over time. The use of the ATmega 2560 microcontroller enables precise control and monitoring of the split inverter AC system [17]. This research provides technical details and performance analysis of a modern split inverter AC unit with microcontroller-based control and monitoring. The data and findings presented serve as a reference for further research and development of energy-efficient air conditioning systems.

2. Method

2.1 Experimental Setup of Investigation

Figure 1 shows an experimental setup for testing the performance of a split AC inverter based on microcontroller technology. The investigation was carried out in the Bali State Polytechnic laboratory. This split wall inverter AC is installed in the investigation area with a capacity of 8,525 Btu/h. The main experimental components are: Microcontroller ATmega 2560, PZEM 004-T, temperature sensor DS18B20, LCD I2C 20×4 and laptop. Microcontroller is applied to record measurement results in real-time.

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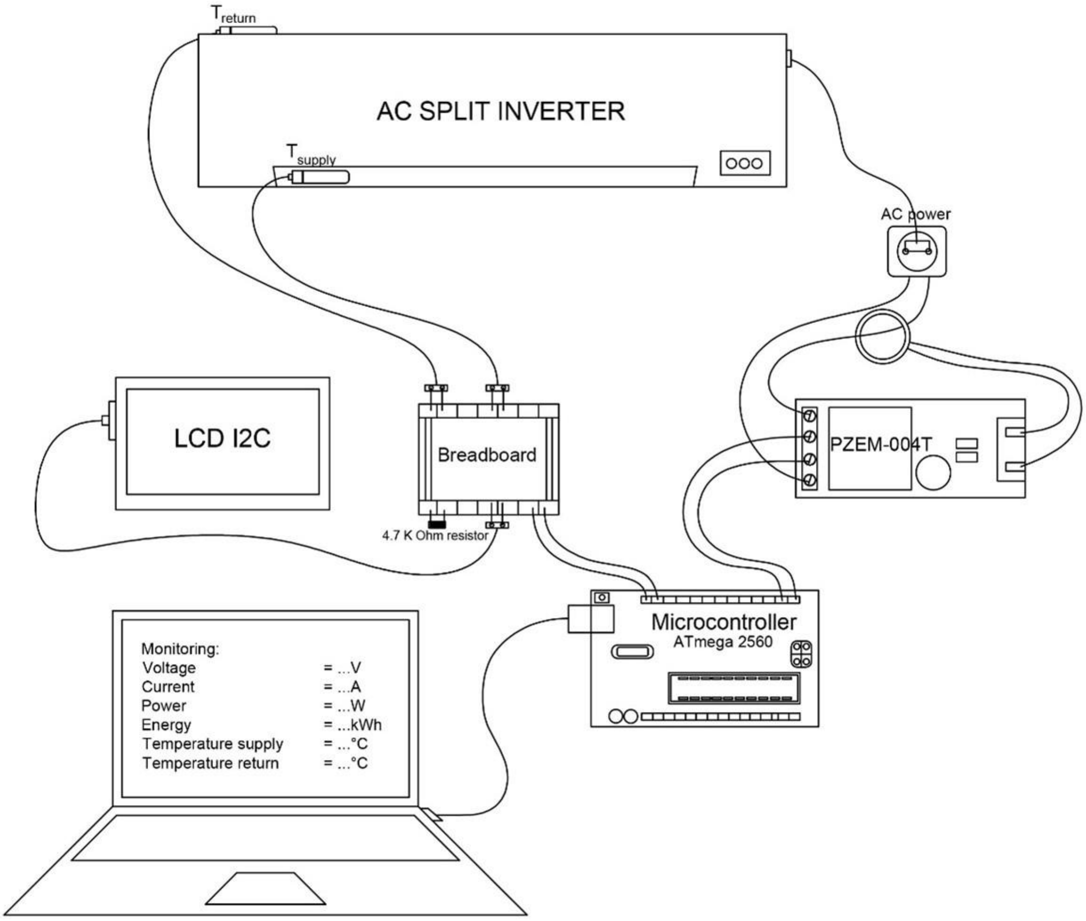

Figure 1. Experimental Setup of Investigation

This device integrates all sensor components including PZEM, LCD, and DS18B20 sensors. ATmega 2560 microcontroller specifications are shown in Table 1. Arduino IDE software is used to enter commands on each sensor with a laptop. Each sensor library is installed in the Arduino IDE application. Breadboard 400 tie point is applied in this research. Both DS18B20 temperature sensors were placed in the evaporator in (return) and out (supply) of the AC split inverter. This temperature sensor has the capability of measuring range from −55 °C–125 °C and an accuracy of ±0.5% [18]. The temperature sensor resolution can be set up to 9, 10, 11, and 12 bits depending on requirements. A 4.7 K Ohm resistor is used in this study.

Table 1. Microcontroller specifications [11]

Type	Description
Microcontroller	ATmega2560
Operating voltage	5V
Input voltage	6-20 V
Digital I/O pins	54 (of which provide PWM output)
Analog input pins	16
DC current per I/O pins	20 mA
Flash memory	256 kB of which 8 kB used by bootloader
SRAM	8 kB
EEPROM	4 kB
Clock speed	16 MHz

PZEM-004T V3.0 is the upgraded version to replace the old PZEM004T V1.0 [19]. This module serves all these basic requirements of measurement PZEM-004T as a separate board [20]. PZEM-004T has the advantage in its ease of use because it can be directly installed on a power network cable that is already installed without having to remove the power cable. I2C 20×4 LCD works for displaying experimental measurement results. An integrated microcontroller installation schematic with sensors is shown in Figure 2. The DS18B20 temperature sensor data line is interfaced to digital pin 7 of the ATmega 2560 microcontroller. The receive (RX) and transmit (TX) communication pins of the PZEM power monitoring module are linked to digital pins 11 and 12 respectively. A 4.7 kilohm pull-up resistor is connected between the data line and VCC pin of the DS18B20 to facilitate 1-Wire protocol communication. The SCL and SDA I2C pins of the liquid crystal display (LCD) are paired with the corresponding SCL and SDA pins on the ATmega 2560. The VCC and GND pins of the LCD are also connected to the power and ground rails of the microcontroller circuit.

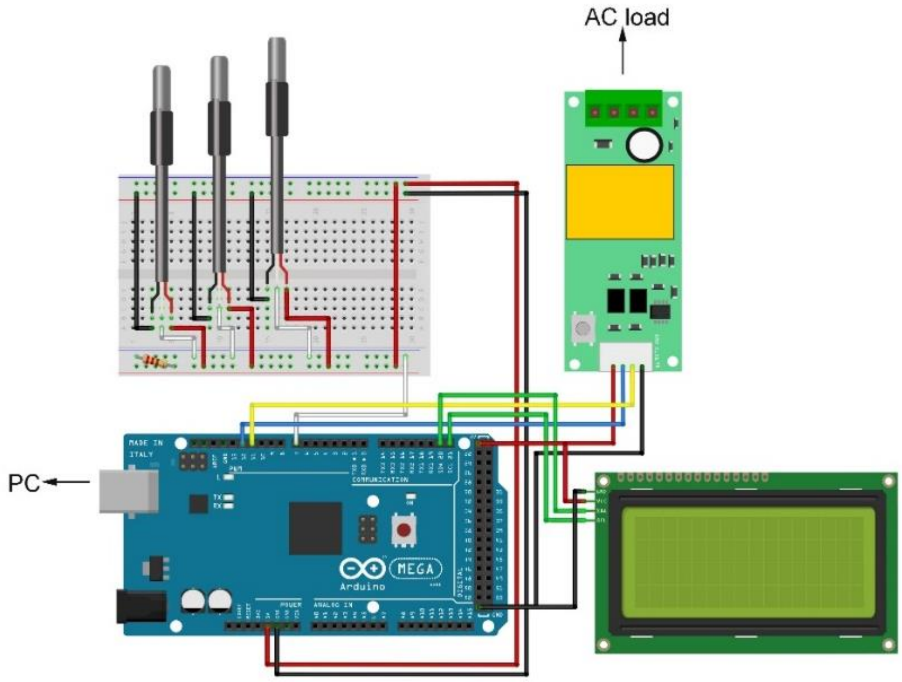

Figure 2. Schematic Microcontroller Installation

The experimental investigation was conducted over a duration of one hour. The air conditioning (AC) temperature setpoint was maintained at 18 °C throughout the testing process. Real-time monitoring were enabled through live visualization on a laptop display as well as a secondary liquid crystal display (LCD) module interfaced via I2C communication protocol. The parameters evaluated included voltage (V), electrical current (A), power (W), energy consumption (kWh), and output frequency (Hz). Additionally, the supply temperature (T_{supply}) and return temperature (T_{return}) of the split inverter AC unit were continuously measured. By holding the desired setpoint temperature constant and tracking the electrical and thermal performance metrics, this experimental methodology allowed for detailed characterization of the operational behavior of the split inverter AC system under controlled steady-state conditions. The live data displays offered real-time insights while the data logs enabled further post-processing and analysis of the full experimental results. The parameters selected for measurement provide comprehensive information on the efficiency, power quality, cooling capacity and temperature control capabilities of the evaluated split inverter AC unit.

3. Result and Discussion

3.1 Temperature Result

The split inverter air conditioning system under investigation in this study utilized the hydrofluorocarbon refrigerant R140A (1,1,1,2-Tetrafluoroethane). The experimental setup was installed in the mechanical engineering department laboratory facilities at Bali State Polytechnic. The research aimed to comprehensively characterize and evaluate the operational performance of this split inverter air conditioning unit under controlled conditions. Figure 3 shows the supply and return temperature

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profile of the split inverter air conditioning (AC) system under at an 18 °C temperature setpoint. Initial temperatures were observed at 26 °C for T_{supply} and 27.5 °C for T_{return}, indicating ambient room temperature conditions prior to activation of the air conditioning system. From the observation, it can be seen that the supply temperature drops significantly to 11.75 °C at around 500 s. This rapid temperature reduction is due to the heat absorption occurring in the evaporator coil from the surrounding air, which enables the phase change of the refrigerant from liquid to vapor state [21]. The supply temperature drops up to 9.5°C during the investigation. However, the lowest temperature is reached, down to 8.5°C in approximately 3300 s, this indicates that the evaporator coil had reached its fully cooled equilibrium state by this point [8].

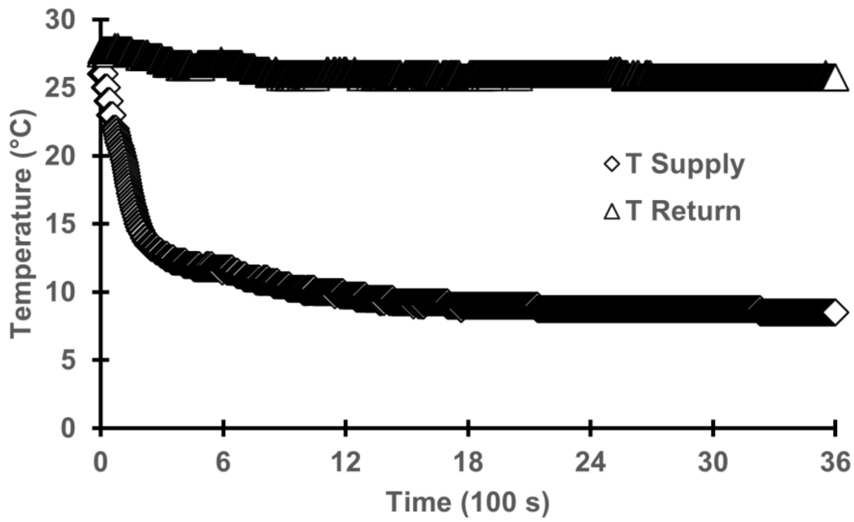

Figure 3. Supply and Return Temperature Profile of the Split Inverter Air Conditioning (AC) System under at an 18 °C Temperature Setpoint

From about 300 s, there was no visible fluctuation in the supply temperature. At 1,000 s it can be seen that T_{supply} tends to be constant until the end of the investigation. The controlled steady-state supply temperature in alignment with the setpoint demonstrates the effective cooling capacity and temperature regulation capabilities of the system under the tested operating conditions. The return temperature profile shows an initial reading of 27.5 °C which drops to 26 °C within the first 36 s, indicating the influence of the evaporator beginning to absorb heat from the ambient room air [22]. No visible fluctuations in T_{return} during the testing process. Room temperature conditions are almost similar to T_{return}. This is due to room temperature being absorbed into the evaporator. Comparing the two temperature profiles, the data reveals an average temperature difference of 17 °C between the T_{return} and T_{supply} across the full test period. This differential aligns with standard specifications for split inverter air conditioning systems, which require a minimum temperature difference of 8 °C between return and supply temperature [23]. The large 17°C differential obtained experimentally verifies the strong cooling effect achieved by the 8525 Btu/h capacity split inverter air conditioner unit under steady-state conditions. Overall, the temperature regulation performance and wide separation between the T_{return} and T_{supply} demonstrates substantial cooling capabilities for the tested split inverter air conditioning system in maintaining thermally comfortable supply air parameters.

3.2 Electrical Parameters Result

Figure 4 shows the voltage profile of the split inverter air conditioning (AC) system under at an 18 °C temperature setpoint. At the beginning of the test period, the initial recorded voltage was 231.2 V. Visible fluctuations in the voltage measurements can be observed from the start until approximately 2500 s into the experiment. The single-phase power supply used to operate the AC unit in this study typically maintains a voltage of 220 – 240 V. The minimum voltage observed was 224.5 V at 842 seconds, while the maximum was the initial 231.2 V reading. From 2900 to 3600 s, the voltage remained relatively stable with minor variations. The voltage fluctuations at the beginning of the test run may be attributed to the initial ramping up of the AC system and compressor. As the system reached steady-

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state operation, the voltage stabilized likely due to the constant speed maintained by the inverter controller [8]. The applied voltage stayed within the expected range for single-phase power, verifying proper operation of the AC unit. Monitoring the voltage profile provides insights into the electrical power supply characteristics and performance of the microcontroller-driven inverter AC system [9]. The steady voltage during continuous operation indicates efficient electrical control by the inverter module.

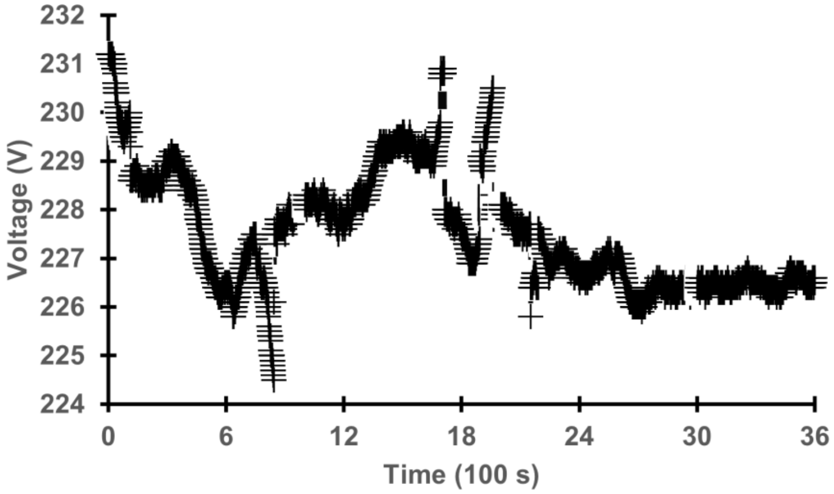

Figure 4. Voltage Profile of the Split Inverter Air Conditioning (AC) System under at an 18 °C Temperature Setpoint

Figure 5 shows the electric current profile of the split inverter air conditioning (AC) system under at an 18 °C temperature setpoint. From the observations, it can be seen that the electric current is around 0.11 A in 12 s. This initial low current is attributed to the startup transient of the air conditioning system, which represents the primary electrical load [22]. As the air conditioner reaches steady-state operation, the current increases to 2.4 A at 55 s and remains relatively constant around 2.94 A until 112 s. The maximum electric current observed during the experiment was 3.92 A. Within the measurement resolution, fluctuations in the electric current were not detected. Overall, these results demonstrate that the air conditioning system draws higher steady-state currents of 2-4 A, while the initial startup current is an order of magnitude lower around 0.1 A.

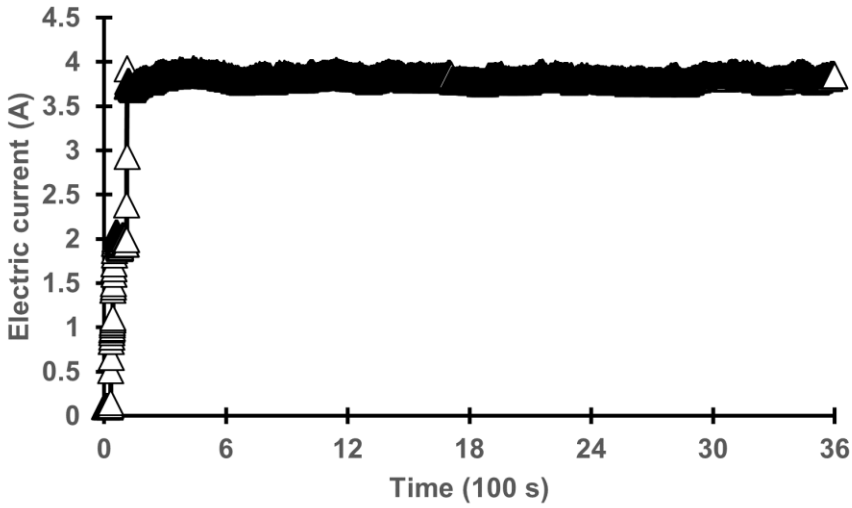

Figure 5. Electric Current Profile of the Split Inverter Air Conditioning (AC) System under at an 18°C Temperature Setpoint

More interesting results can be seen in Figure 6 which shows the power profile of the split inverter air conditioning (AC) system under at an 18 °C temperature setpoint. From the figure, it can be seen that the power consumption increases by 749.4 W in about 115 s. Power consumption was found to be

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relatively constant and no fluctuations were observed. The sustained power consumption aligns with the 1 PK capacity rating listed for the 8,525 Btu/h split inverter air conditioner unit under investigation. As shown in the current consumption plot, current draw directly correlates with power, as expected based on the relationship shown in Equation 1:

$$P = I \times V \quad (1)$$

where P is the power in watts (W), V is the voltage in volts (V), and I is the electrical current in amperes (A).

This fundamental relationship between power, voltage, and current is derived from Ohm's law and Kirchhoff's circuit laws [24]. The microcontroller system recorded both the V and I over time during the experiment, which enabled calculation of the instantaneous power consumption (P) at each measurement point based on Equation 1. Tracking P provides insights into the electrical energy utilization of the air conditioning system under the controlled test conditions.

Moreover, comparing the power curve with the supply temperature profile reveals an inverse dependence, wherein lower T_{supply} temperatures correspond to elevated power consumption, and vice versa. This inverse correlation is attributable to the increased power required by the refrigeration cycle components to reject larger amounts of heat from the supply air stream, thereby achieving lower temperatures. During periods of lower T_{supply}, the evaporator must absorb substantial heat from the surrounding environment to evaporate the refrigerant, necessitating greater compressor power and higher current draw from the inverter drive. Thus, the observed power consumption behavior closely aligns with the dynamics of the cooling system and reinforces the relationships between electrical power, current, and thermal performance [25].

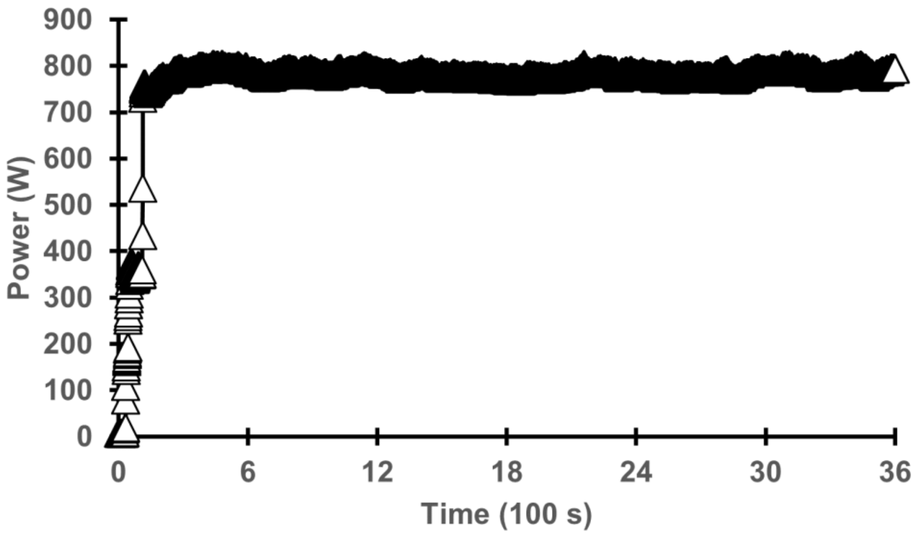

Figure 6. Power Profile of the Split Inverter Air Conditioning (AC) System under at an 18°C Temperature Setpoint

Figure 7 shows the energy consumption profile of the split inverter air conditioning (AC) system under at an 18°C temperature setpoint. At approximately 44 s into the experiment, the energy consumption begins to steadily increase in a linear trend, as observed from the data. Throughout the duration of the investigation, the energy consumption parameter remains stable with no fluctuations. The maximum energy consumption reached is 1,373 kWh, occurring towards the end of the observation period. This peak energy consumption value is influenced by the electrical load placed on the AC system [26], which in this case is the split inverter AC unit operating under tested conditions. The linear rise in energy usage indicates a constant power draw by the AC unit to maintain set temperature. The lack of fluctuations suggests steady state operation without power surges. The peak consumption represents the maximum energy required to provide sufficient cooling by the AC unit to match the thermal load conditions [22].

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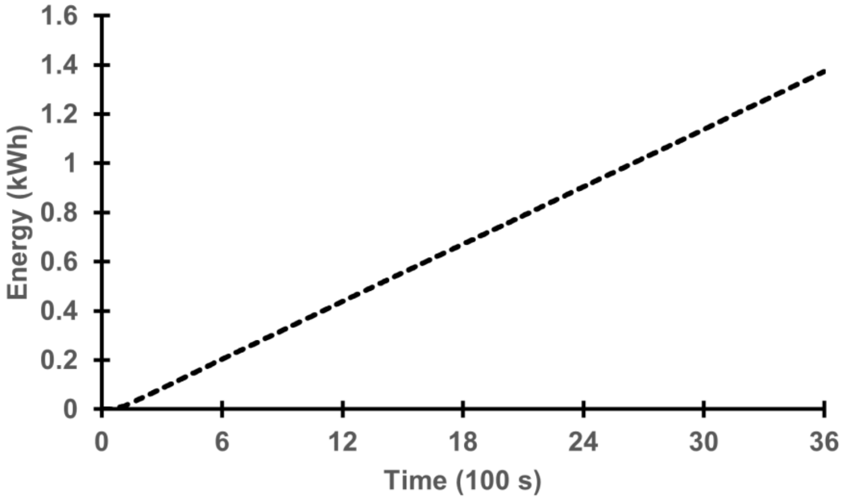

Figure 7. Energy Consumption Profile of the Split Inverter Air Conditioning (Ac) System under at an 18 °C Temperature Setpoint

Figure 8 shows the frequency profile of the split inverter air conditioning (AC) system under at an 18 °C temperature setpoint. It can be observed that the inverter maintains a frequency of approximately 50 Hz for the majority of the investigation, which is the expected standard frequency for AC power. No substantial fluctuations in frequency were detected across the different time points during the investigation. The average frequency calculated based on the data points was found to be 50 Hz, matching the desired output specification. At the times of 1,516 s, 2,863 s, and 3,575 s, the measured frequency decreased slightly to around 49.9 Hz, representing a minor 0.1 Hz drop from the prevailing 50 Hz value. However, this small decrease in frequency is considered acceptable and within normal operating limits for the inverter [10]. The stability of the output frequency at 50 Hz (±0.1 Hz) indicates steady and controlled operation of the inverter to generate the standardized Alternating Current power waveform [8].

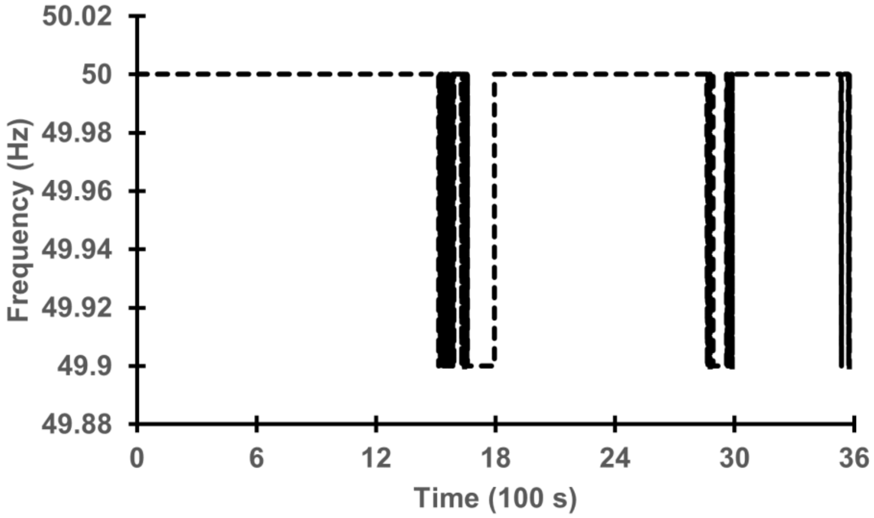

Figure 8. Frequency Profile of the Split Inverter Air Conditioning (Ac) System under at an 18°C Temperature Setpoint

4. Conclusion

In summary, this study analyzed the cooling performance and electrical parameters of a 8,525 Btu/h capacity split inverter air conditioning system controlled by microcontroller technology. Experiments confirmed stable operation within expected technical benchmarks, including T_{supply} 17 °C lower than T_{return}, aligning with the minimum 8 °C differential requirement. Though minor voltage fluctuations from 220 V to 240 V occurred, power draw remained steady at 750 W matching the 1 PK

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rating. An inverse relationship between power consumption and supply temperature confirmed thermodynamic principles. Energy usage reached a maximum of 1,373 kWh without fluctuations. Overall, the microcontroller-regulated split inverter AC demonstrated satisfactory capabilities for maintaining key parameters within nominal ranges. Real-time monitoring and adjustment of operating conditions enabled by the microcontroller represents a promising approach for optimizing efficiency and stability. Further research can build upon these initial findings to continue advancing microcontroller-based control strategies for split inverter air conditioning systems. In addition, this investigation provides evidence that microcontroller integration is a viable technique for enhancing AC performance monitoring and management.

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