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INTEGRATED SMART DC AC ENERGY METER SUPPORTED IN IoT NETWORK

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Abstract. Energy measurement and the processing data in industrial plants have become an area in which the contribution of electronics is significant. Recent advances in electronic hardware and software solutions have been implemented for more efficient monitoring and management of industrial processes. These technologies allow process data to be measured, processed, stored, visualized, and distributed within industrial systems. In the contemporary measurement system, there is a strong tendency towards digital signal processing of measured quantities, although some solutions still incorporate elements of analogue processing. For effective process management, it is essential that users have timely and accurate information about measurement data within their industrial facilities. Driven by the need for reliable measurement, visualization and storage of process parameters, modern electronic systems enable on-site processing and storage, as well as transmission of measurement data through GSM and IoT network. The application of advanced electronic systems is evident not only in power plants, but also in industries related to healthy and high-quality food production, particularly in agriculture. This trend is largely due to the increasing number of independent agriculture facilities that are often located in remote areas and require autonomous power supply along with long-distance transmission of process data. Motivated by these requirements, this paper presents the design of an electronic system that provides a solution for supplying electricity to such facilities. The proposed system provides a solution for measurement of two key components of energy systems, namely DC and AC energy. In addition to the measurement, the system provides visualization and storage of measurement data, as well as the capability to transmit the data to an IoT network. The measured DC and AC energy values are displayed locally on LCD screens and stored on an SD card, while also being remotely transmitted to the IoT network for visualization on a mobile device.

1. Introduction

Modern industrial plants typically include both AC and DC energy consumers. The configuration of the power supply system depends on the facilities' location and access to the electrical power grid. For independent locally remote standalone plants without grid access, there is a need for energy- independent power supply system. Such systems are commonly based on renewable energy sources, particularly solar and wind generation systems [1]-[3]. Figure 1 illustrates the power supply of a stand-alone industrial plant using green energy generated from solar and wind sources. This independent system integrates photovoltaic panels or wind turbines as primary energy sources. To convert DC energy into AC energy, the system includes a voltage controller and an inverter. The excess DC energy is stored in batteries for later use. The plant has both DC and AC consumers, which are connected to the corresponding DC and AC terminals. In accordance with modern standards and energy management protocols,

Keywords: Agro-industrial facility, Process parameters, Controller, GSM, SIM, Data log file

these independent energy systems are equipped with DC and AC energy metering stations, [4], [5]. With the implementation of advanced electronic solutions, such independent energy systems are increasingly enhanced with measurement stations capable of real-time visualization, data storage, and remote transmission of measurement data [6]-[9].

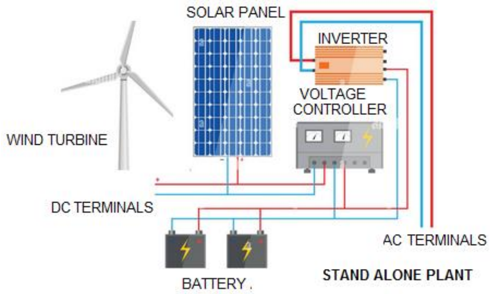


Figure 1. *Standalone industrial plant supplied by green energy from solar and wind sources*

LCD displays, personal computers or SD cards are commonly used for visualization and storage of measurement data, depending on the requirements and technical capabilities of the plant. For remote transmission of measurement data, communication technologies such as RF, GSM, and IoT networks are widely used. These solutions contribute to safer and more efficient operation, particularly for operations that are directly responsible for monitoring the proper function of the entire industrial process. This approach is facilitated by smart electronic devices that, among other functions, generate data log files containing measurement data [10], [11]. On the other hand, a modern controlled system of an industrial process is fully rounded if it is connected to an IoT or GSM SIM network [12], [13], [14]. Such a concept enables process data to be transmitted to any location, visualized in real-time, and stored on a personal and cloud computer.

The choice of remote transmission of measurement process data via RF, IoT, or GSM SIM connection depends on the location of the specific industrial facility, the type, and quantity of measurement data. Each of these transmission media has advantages and disadvantages. In the case where RF connection is used, the transfer is limited in scope and is most often used when a standalone industrial facility needs to be connected to a master station of a complex industrial facility. The connection in the IoT network requires a reliable and secure internet network and a secure and inexpensive cloud platform. It should be also noted that cloud platforms developers periodically release new versions which may require updates and modification to the program codes. This results in additional time and cost constrains. Considering the limited range of the RF connection and high and variable cost of cloud platforms, the use of GSM SIM networks is a practical solution for small standalone industrial facilities.

In this paper, a prototype of smart electronic system is designed to provide a solution for measuring both components of energy systems, namely DC and AC energy. In addition to on-site measuring, visualisation and data storage, the system also enables data transmission to an IoT network. The measurement data for both DC and AC energy are visualized locally on LCD screens, stored on an SD card, and remotely transmitted to the IoT network, where they can be accessed and visualized on a mobile device.

Guided by the functional requirements of the electronic system, the following section outlines the fundamentals of DC and AC energy measurement. Power analysis involves a range of measurements, terms, and calculations that may be unfamiliar or challenging for engineers and technicians new to the field. Moreover, modern power-conversion equipment often generates complex voltage and current waveforms, requiring more advanced measurement approaches than those used for simple sinusoidal signals. These quantities are well established in basic electrical engineering and are therefore not discussed in detail here [15]. With regard to the principles of DC and AC energy measurement and the associated parameters, it can be noted that circuit implementation depends on the level of advancement of electronic components. However, a common feature across all solutions is that the measurement system interfaces with the energy source through two branches: the voltage branch and the current branch. As the focus of this paper is the design of a prototype smart power meter, the basic circuit configuration—based on a microcontroller platform—is presented in the following section [16].

a.) Background for measuring DC energy

DC metering is used in specialized applications to measure, collect, and store real-time data in DC power systems. Energy professionals use DC meters to monitor power generation and consumption, detect system faults, achieve performance targets, reduce cost, and ensure energy integrity within their facility. Such systems are widely used in industries including solar energy systems, EV charging stations, battery energy storage systems (BESS), telecommunication infrastructures, data centres, and light rail transportation [17], [18]. The key measurable quantities in a DC system include DC voltage *VDC*, current *IDC*, active power *PDC*, and active energy *E*. In Figure 2 the basic circuit configuration is shown for DC energy measurement based on microcontroller platform.

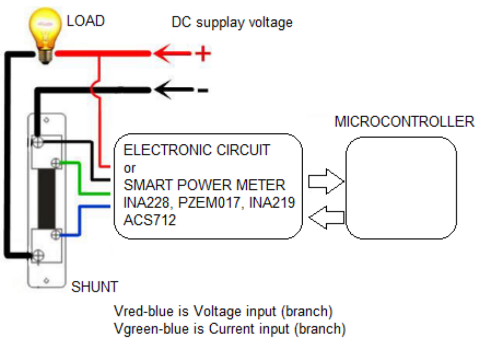


Figure 2. *Basic circuit for DC energy measurement based on microcontroller*

In a DC power meter, the voltage signal is typically obtained from the output of a voltage divider, while the current signal is usually measured using a shunt resistor. In some configurations, a Hall-effect sensor (e.g. ACS712) or DC current sensors such as INA228, INA 226, and INA 219 are used. The program code is adjusted according to the specific hardware implementation.

b.) Background for measuring AC energy

Figure 3 shows the basic circuit configuration for AC energy measurement based on microcontroller.

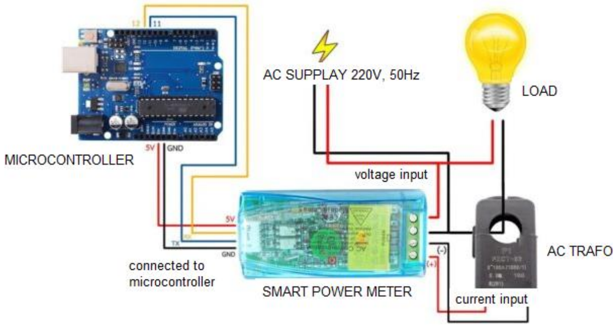


Figure 3. *Basic circuit for AC energy measurement based on microcontroller*

The circuit consists of a power meter, a load and a microcontroller and it is powered by an AC voltage of 220V 50Hz [19]. The power meter has an input for measuring voltage and current. The current signal is obtained through a current transformer with a defined transmission ratio, while the voltage signal is measured directly by the input voltage supply. The power meter, using a defined number of input/output lines, is connected to the microcontroller. In addition to the hardware components, the microcontroller also has an appropriate built-in code according to the defined task. The measurable and relevant quantities in an AC system include voltage *V*, current *I*, active power *P*, active energy *E*, power factor *PF,* and frequency *f*. By extending the program code, data can be obtained for other quantities relevant to the AC system, such as apparent power S, reactive power Q_r, reactive energy Q_{re}, and phase angle φ.

2. Design of an Integrated Smart AC DC Energy Meter Supported in IoT Network

The prototype electronic system presented in this paper is designed for measurement, visualization, store and transfer of both DC and AC electrical energy parameters. The designed system will receive input signals for the consumed DC and AC energy by connecting the AC and DC terminals in Figure 1. Figure 4 shows the block diagram of the electronic system. The electronic system consists of both DC and AC energy modules, two LCD displays, and a master module. The DC and AC modules are actually DC and AC energy meters with appropriate hardware equipment. The two LCD displays visualize the current values of the measured quantities for DC and AC energy. The DC LCD display visualizes the shunt voltage *SV*, the DC bus voltage *BusVoltage*, the voltage the DC load *LoV* which is actually the voltage at the DC terminals, the DC current *current*, the power *P,* and the energy *E*. The AC LCD display visualizes the AC voltage *V*, the AC current *I*, the active power *P*, the active energy *E*, the apparent power *S*, the reactive power Q_r, the reactive energy Q_{re}, and the power factor *PF*.

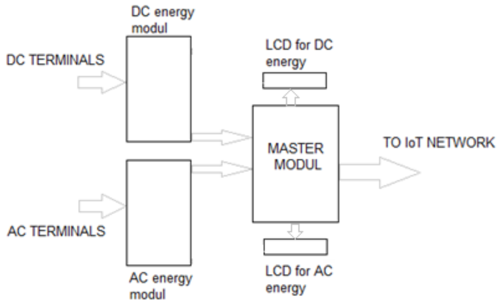


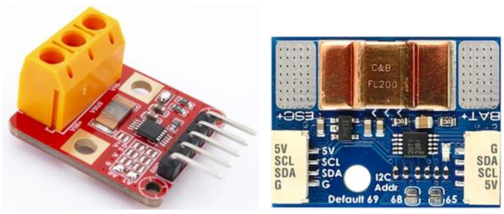
Figure 4. *Block diagram of electronic system build-in standalone energy plant*

The master module receives signals from the DC and AC modules, processes them, stores them on an SD card, and transfers them to the IoT network. It contains an IoT microcomputer, an SD module, a clock module, and other appropriate hardware components. The IoT microcomputer is connected to the two LCD displays for visualization of AC and DC energy parameters. It has a built-in Wi-Fi interface for connection to the IoT network. The measured values of the DC and AC energy parameters are stored on the SD card. The clock module synchronizes the operation of the master module with the time stamping required for compliance of the stored parameter values.

2.1 Design on Energy module

a.) *Design of DC Energy Module*

The DC power module design uses the INA228 power module, a product of Texas Instruments, [20]. Figure 5 shows this DC module.



a.) b.)

Figure 5. *INA228 power meter: a.) module for 85VDC, 40ADC and b.) module 85VDC, 208ADC*

The module in Figure 5 a.) is for DC voltage 85V and current 40A, while the module in Figure 5 b.) is DC voltage 85V and current 208A.

The INA228 module is a precise, low-power bidirectional current and power monitor. It measures current by sensing the voltage across an external shunt resistor, while simultaneously measuring the bus voltage up to 85V to calculate instantaneous power.

With its excellent voltage accuracy of ±0.25% and low operating current of 330µA, it is an ideal choice for power supply monitoring, server load management, and industrial automation equipment where reliable, efficient performance is required.

Features

- **Bidirectional Current Sensing:** Measures both source and sink currents with high accuracy (±1% typical).
- **Wide Operating Ranges:** Modules support bus voltages from 85V, powered by a simple 2.7V-5.5V supply.
- **High-Resolution Measurement:** Features 20-bit (INA228) analogue-to-digital converters for detailed data.
- **Flexible I2C Interface:** Includes 16 configurable I2C addresses set via solder jumpers, enabling multiple units on a single bus.
- **Integrated Design:** Comes with a pre-soldered 0.15mΩ shunt resistor, calibrated for measurements up to 208 A continuous current (at 85V bus).
- **Compact and Ready-to-Use:** Standard pin-header footprint for easy integration with development boards and ESP32.

Product Specification

- **Communication Interface:** I2C
- **Module Supply Voltage:** 2.7V - 5.5V
- **Configurable I2C Addresses:** 16
- **Shunt Resistor:** depending on the required power application

b.) Design of AC Energy Module

For AC energy meter PZEM004t V3.0 is used. This energy module is mainly used for measuring AC voltage, current, active power, frequency, power factor, apparent energy, active energy, reactive power, and reactive energy. The module is without a display function, while the data could be read through the TTL interface. PZEM-004T-10A built-in shunt has a measuring range of 10A, and PZEM-004T-100A with external transformer has a measuring range of 100A [19]. Figure 6 represents the board of the PZEM-004T power meter.

Figure 6. *The board of PZEM-004T power meter*

The current signal is connected to the power meter on the terminals NIN and NOUT, and the voltage is connected to the terminals LIN and LOUT. The power meter is supplied with 5 VDC voltage. The terminals TX and RX are for serial communication.

2.2 Design of Master Module

As mentioned above, the Master module receives the signals for DC and AC energy consumption from the energy modules, visualizes them, stores and transfers them to the IoT network. Figure 7 shows the electrical diagram of the master module.

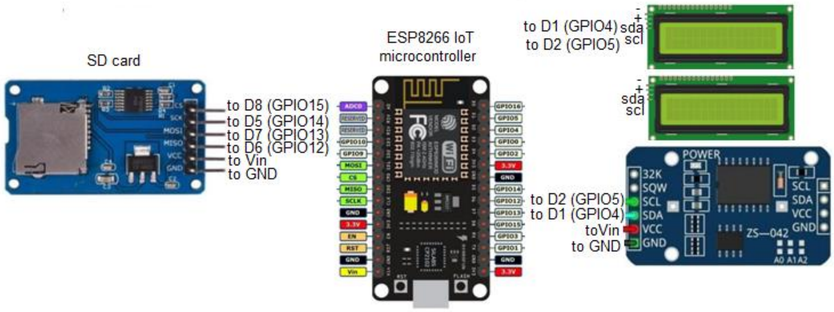
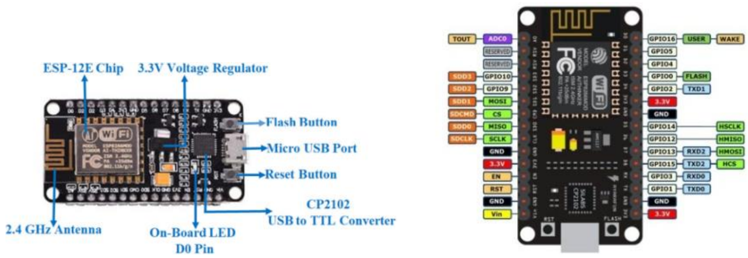


Figure 7. *Electrical diagram of the master module*

Below is a brief description of the hardware components used in the master module.

a.) ***Microcomputer NodeMCU ESP8266***

The NodeMCU ESP8266 development board comes with the ESP-12E module containing an ESP8266 chip having Tensilica Xtensa 32-bit LX106 RISC microprocessor [21]. This microprocessor supports RTOS and operates from 80MHz to 160 MHz adjustable clock frequency. NodeMCU has 128 KB RAM and 4MB of Flash memory to store data and programs. Its high processing power with built-in Wi-Fi / Bluetooth and Deep Sleep Operating features makes it ideal for IoT projects. NodeMCU can be powered using Micro USB jack and VIN pin (External Supply Pin). It supports UART, SPI, and I2C interface. Figure 8 shows NodeMCU ESP8266 and its pinout.



a.) b.)

Figure 8. a.) *NodeMCU ESP8266 and b.) pinouts*

NodeMCU is an open-source based firmware and development board specially targeted for IoT based applications. It includes firmware that runs on the ESP8266 Wi-Fi SoC from Espressif Systems, and hardware which is based on the ESP-12 module.

b.) ***SD Card Module***

This module provides an SPI interface to connect an SD card module with any microcontroller which supports the SPI communication interface. Using a microSD card becomes very handy for applications where we need to store files or any data. MicroSD card includes accessing information and reading/writing to a file [22]. Storage data including text, video, audio, CSV, HTML, JavaScript, and CSS files can all be conveniently stored in the microSD card. It is one of the most reliable and practical ways to store data in devices such as mobile phones, laptops, and personal computers. The MicroSD card modules are designed to communicate with the MicroSD cards. These connectors provide the required hardware and pinout to connect SD cards with microcontrollers such as ESP32, Arduino, ESP8266, Raspberry Pi, etc. They are compatible with almost all SD cards which are commonly used in cell phones. They can handle a maximum of 16GB capacity microSD cards and only 2GB capacity for standard SD cards. This microSD card module has 6 terminals consisting of SPI and power supply terminals. The pinouts of this module with some description of the individual pins are shown in Figure 9.

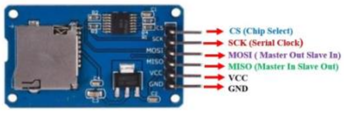


Figure 9. *SD card module*

Table 1 shows the default SPI pins connected on SD module and ESP8266-12E.

Table 1: Pin connected on SD card module and ESP8266-12E

SD card module	ESP 8266-12E
MOSI	D7 (GPIO13)
MISO	D6 (GPIO12)
SCK	D5 (GPIO14)
CS	D8 (GPIO15)
+	Vin
-	GND

c.) ***Clock Module DS3231***

The clock module synchronizes the operation of the master module with the time stamping required for compliance of the stored parameter values [23]. In this paper, a DS3231 real time clock (RTC) module is used shown in Figure 10.

Figure 10. *DS 3231 real time clock module*

The DS3231 is a low-cost, extremely accurate I²C real-time clock (RTC) with an integrated temperature-compensated crystal oscillator (TCXO) and crystal. The device incorporates a battery input and maintains accurate timekeeping when the main power to the device is interrupted. The RTC maintains seconds, minutes, hours, day, date, month, and year information. The date at the end of the month is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with an active-low AM/PM indicator. Two programmable time-of-day alarms and a programmable square-wave output are provided. Table 2 shows the default pins connected on this module with ESP8266.

Table 2: Pin connected on DS3231 time clock module and ESP8266-12E

DS3231 time clock module	ESP 8266-12E
SCL	D2 (GPIO5)
SDA	D1 (GPIO4)
+	Vin
-	GND

Two 2004 LCD displays are used to visualize the measured DC and AC energy on site. The LCD displays are connected to the microcontroller with the I2C bus on the SCL and SDA pins.

3. Experimental Results and Discussion

This section presents the results from the experimental work on the prototype electronic smart DC and AC energy meter support in IoT network. Figure 11 shows the prototype of the designed electronic system.

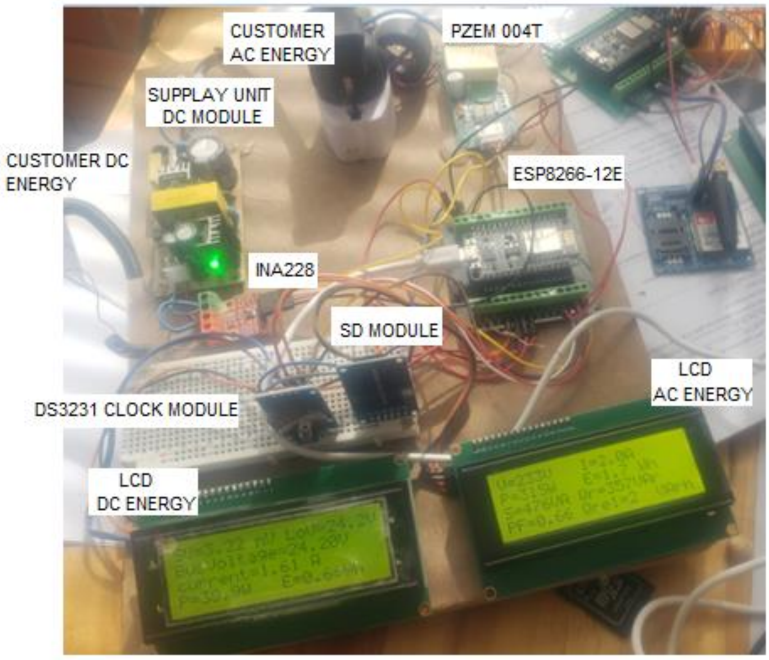


Figure 11. *Prototype of the electronic system*

In Figure 11, the modules used in the prototype are marked. Figure 12 shows the LCD display for visualized parameters of DC and AC energy.

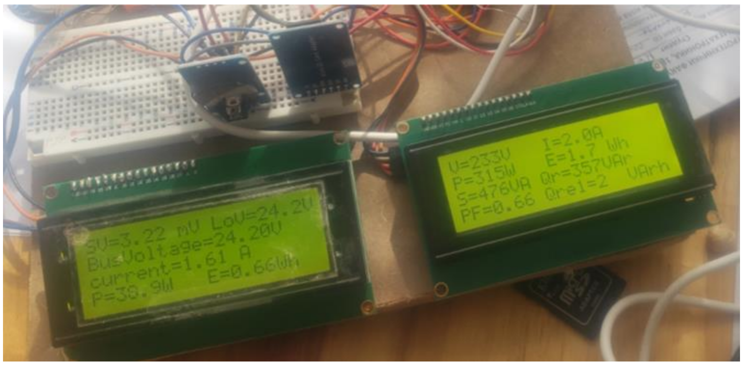
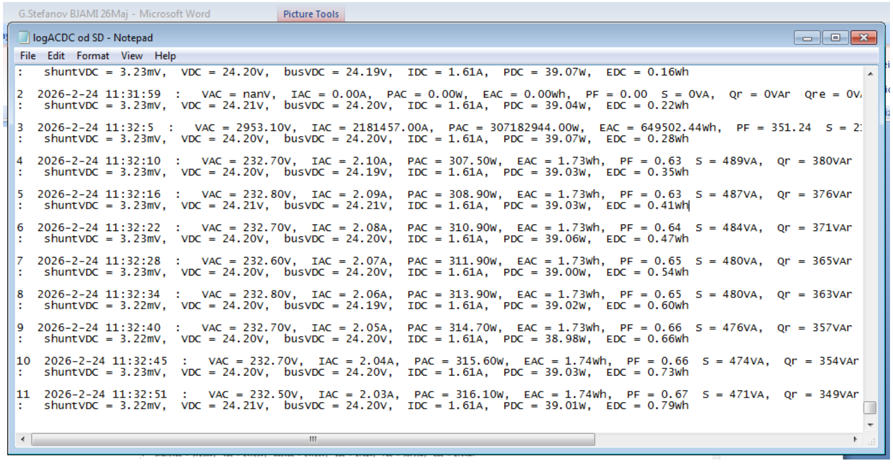


Figure 12. *LCD display for visualized DC and AC parameter energy*

Figure 13 shows a print screen of a data log file on the SD card for monitoring DC and AC energy parameters obtained from the designed system in the paper.



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G.Stefanov BJAMI 26Maj - Microsoft Word    Picture Tools
logACDC od SD - Notepad
File  Edit  Format  View  Help
:   shuntVDC = 3.23mV,  VDC = 24.20V,  busVDC = 24.19V,  IDC = 1.61A,  PDC = 39.07W,  EDC = 0.16Wh

2  2026-2-24 11:31:59  :  VAC = nanV,  IAC = 0.00A,  PAC = 0.00W,  EAC = 0.00Wh,  PF = 0.00  S = 0VA,  Qr = 0VAr  Qre = 0V
:   shuntVDC = 3.23mV,  VDC = 24.21V,  busVDC = 24.20V,  IDC = 1.61A,  PDC = 39.04W,  EDC = 0.22Wh

3  2026-2-24 11:32:5  :  VAC = 2953.10V,  IAC = 2181457.00A,  PAC = 307182944.00W,  EAC = 649502.44Wh,  PF = 351.24  S = 2
:   shuntVDC = 3.23mV,  VDC = 24.20V,  busVDC = 24.20V,  IDC = 1.61A,  PDC = 39.07W,  EDC = 0.28Wh

4  2026-2-24 11:32:10  :  VAC = 232.70V,  IAC = 2.10A,  PAC = 307.50W,  EAC = 1.73Wh,  PF = 0.63  S = 489VA,  Qr = 380VAr
:   shuntVDC = 3.23mV,  VDC = 24.20V,  busVDC = 24.19V,  IDC = 1.61A,  PDC = 39.03W,  EDC = 0.35Wh

5  2026-2-24 11:32:16  :  VAC = 232.80V,  IAC = 2.09A,  PAC = 308.90W,  EAC = 1.73Wh,  PF = 0.63  S = 487VA,  Qr = 376VAr
:   shuntVDC = 3.23mV,  VDC = 24.21V,  busVDC = 24.21V,  IDC = 1.61A,  PDC = 39.03W,  EDC = 0.41Wh

6  2026-2-24 11:32:22  :  VAC = 232.70V,  IAC = 2.08A,  PAC = 310.90W,  EAC = 1.73Wh,  PF = 0.64  S = 484VA,  Qr = 371VAr
:   shuntVDC = 3.23mV,  VDC = 24.20V,  busVDC = 24.20V,  IDC = 1.61A,  PDC = 39.06W,  EDC = 0.47Wh

7  2026-2-24 11:32:28  :  VAC = 232.60V,  IAC = 2.07A,  PAC = 311.90W,  EAC = 1.73Wh,  PF = 0.65  S = 480VA,  Qr = 365VAr
:   shuntVDC = 3.23mV,  VDC = 24.20V,  busVDC = 24.20V,  IDC = 1.61A,  PDC = 39.00W,  EDC = 0.54Wh

8  2026-2-24 11:32:34  :  VAC = 232.80V,  IAC = 2.06A,  PAC = 313.90W,  EAC = 1.73Wh,  PF = 0.65  S = 480VA,  Qr = 363VAr
:   shuntVDC = 3.22mV,  VDC = 24.20V,  busVDC = 24.19V,  IDC = 1.61A,  PDC = 39.02W,  EDC = 0.60Wh

9  2026-2-24 11:32:40  :  VAC = 232.70V,  IAC = 2.05A,  PAC = 314.70W,  EAC = 1.73Wh,  PF = 0.66  S = 476VA,  Qr = 357VAr
:   shuntVDC = 3.22mV,  VDC = 24.20V,  busVDC = 24.20V,  IDC = 1.61A,  PDC = 38.98W,  EDC = 0.66Wh

10  2026-2-24 11:32:45  :  VAC = 232.70V,  IAC = 2.04A,  PAC = 315.60W,  EAC = 1.74Wh,  PF = 0.66  S = 474VA,  Qr = 354VAr
:   shuntVDC = 3.23mV,  VDC = 24.20V,  busVDC = 24.20V,  IDC = 1.61A,  PDC = 39.03W,  EDC = 0.73Wh

11  2026-2-24 11:32:51  :  VAC = 232.50V,  IAC = 2.03A,  PAC = 316.10W,  EAC = 1.74Wh,  PF = 0.67  S = 471VA,  Qr = 349VAr
:   shuntVDC = 3.22mV,  VDC = 24.21V,  busVDC = 24.20V,  IDC = 1.61A,  PDC = 39.01W,  EDC = 0.79Wh
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Figure 13. *Print screen of data log file in SD card for monitoring on the DC and AC energy parameters*

Figure 14 shows a screenshot of transferring DC and AC energy parameters on a mobile phone in IoT network via Blynk cloud IoT [24].

Figure 14. *Screenshot of transferred DC and AC energy parameter on a mobile phone in IoT network*

3.1 Analysis of the Results and Discussion

The main task of the paper is to design and implement a prototype electronic system for measuring, visualizing and transferring energy parameters from smart DC and AC energy meter in the IoT network. The verification of the correct operation of the system according to the defined task is illustrated in Figures 11, 12, 13, and 14.

- In Section 2, a prototype of the system for measurement, monitoring, and transferring of the energy parameters on DC and AC energy meter in IoT network was designed and implemented;
- Section 3 gives the results of the experimental work of the solution in the paper;
- The results show that the system measures, visualizes on LCD screens, and stores in a data log file on SD card and sends them in IoT network;
- The screenshot shown in Figure 13 is provided to verify that the solution in the paper stores the data in a data log file on SD card;
- The screenshot from the mobile phone shown in Figure 14 confirms that accurate values of the measured parameters were successfully transmitted.

The paper offers a solution that addresses a problem that is currently relevant in renewable energy sources, solar and wind generators, and self-powered industrial plants. The topicality of the problem to which the results in the paper provide a solution is the subject of [1], [2], [3]. In [4], [5], [6]. [7], [8], [9], the subject of analysis is industrial processes from different aspects and in all of them the commitment to transferring on energy measurement data remotely is clear. In some solutions, RF connections are used, in some cloud platforms, [14]. The way in which this is achieved is different and depends on the capabilities and approach of the authors. In case where an RF connection is used, the transfer is limited in scope and is mostly often used when a standalone industrial facility needs to be connected to a master station of a complex industrial facility. The connection in the IoT network requires a reliable and secure internet network and a secure and inexpensive cloud platform. Also, it should be considered that the designers of cloud platforms periodically release new versions that require reworking of the program codes [24].

4. Conclusion

In this paper, a prototype of an electronic system for measuring energy parameters in self-powered industrial plants is presented. The proposed solution focuses on the development, design, and practical implementation of a smart electronic system capable of monitoring the energy parameters of a standalone industrial facility and data transfer to IoT network. The proposed solution enables visualization of DC and AC energy parameters both locally, through an LCD display, and remotely, via a mobile device connected to IoT network. In addition, the system provides data logging functionality by storing the measured energy parameter values on an SD card for further analysis and monitoring.

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