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Software and Hardware Implementation of a Graphical User Interface for Solar Power Plants

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***Abstract*—This paper presents the design of a user-friendly graphical user interface (GUI) that monitors and controls the real time parameters of a data logger placed in a solar power plant. To obtain the plant parameters in real time, some hardware such as PLC, energy analyzer, inverter and sensor groups are used in the study. Modbus TCP/IP port of the PLC is connected to internet protocol (IP) channel of the energy analyzer for transferring the data from the PLC to the analyzer. Inverter and sensor groups communicate with the PLC via RS485 channel. Thanks to the system achieved, all data are transferred from the PLC to cloud and also saved into a MS-SQL database. Thus, all data of the plant such as current, voltage, power, energy, irradiation, temperature, wind values and operating statuses of the devices is presented to operators both graphically and numerically in order to make the monitoring and controlling operation easily from anywhere at any time.**

***Keywords*—Solar Power Plant, Graphical User Interface, Monitoring and Controlling, Modbus TCP/IP**

I. Introduction

Because of depletion of fossil fuels, using the renewable energy sources are increased nowadays. Among them, the solar energy systems are the best one because of their free primary energy source, clean and environmentally friendly structures [1], [2]. However, the solar plants are affected easily from irradiation, temperature, weather conditions and many other factors. This is the reason why the monitoring these systems are crucially important [3].

If protection and monitoring functions of on-grid solar power plants are insufficient, they can easily affect whole grid [4]. Thanks to the use of monitoring system, fault detection alarms of the plants can be easily provided and negative effects of the system can be eliminated. In order to make this more clear, the recent studies [5] and [6] are good examples where irradiation, temperature, current and voltage values of the solar systems are monitored successfully.

Besides monitoring the real time data of the solar plants, it can also be stored in databases to analyze it later. For this purpose, data logger devices are preferred in general [7].

Since observing and storing the data is an important factor for real time operation and fault detection in solar power plants as mentioned above, this study deals with a data monitoring system that is applied on a 1 MW real solar plant. Data transfer operations from string inverters, energy analyzer and the weather station to the PLC are provided by using different communication protocols. Obtained data is also transferred to cloud to access and monitor it via internet.

The realized study is explained in Section 2 where technical specifications of the data logger system are given in tables. This section also gives some brief information about communication protocols used in the system and presents some screenshots of the designed WEB portal. As the final section, Section III concludes the results obtained.

II. Design and Implementation

Principal structure of the data transferring operations is seen in Fig 1. PLC is used as the main CPU in the proposed system and it collects data from field devices. While the blue lines connecting the inverters to CPU belongs to Modbus RTU, the orange line belongs to Modbus TCP and the green line is transfers all data to the internet.

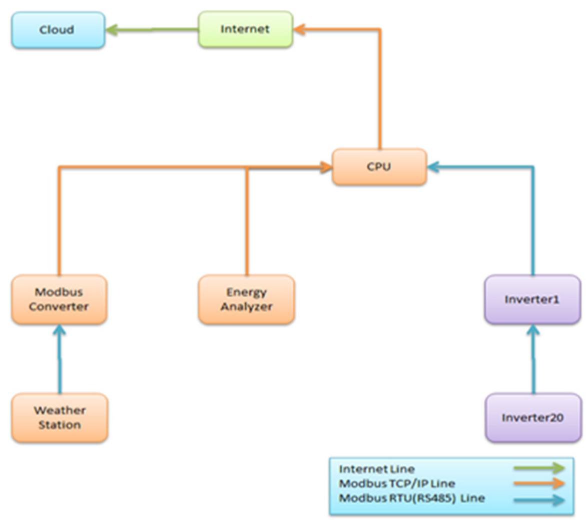

Fig. 1. Principal structure of the data transferring operations

As shown in Fig 1, the data logger device collects the data of inverters, energy analyzer and weather station of the power plant. In the study, since a 1 MW solar power plant is selected for case application, it consists of 20 string inverters each has 50kW power capacity. Each inverter has the same capacity and all of them are connected in parallel to Modbus RTU communication line. DC characteristics, AC characteristics and communication specifications of the inverters are given in Table 1, Table 2 and Table 3, respectively.

RS485 communication port is used for transferring the inverter data to CPU. The collected data from the inverters can be seen in Table 4.

All of the collected data from the inverters are monitored on the designed web portal by updating every 5 minutes. As seen in Fig 2, the table on the WEB portal consists of three columns as data, value and unit. The same table is used for observing the inverter data.

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TABLE I. DC CHARACTERISTICS OF THE INVERTERS [8]

DC Electrical Specifications	50kW Inverter
DC max. input voltage (V DC)	1000
DC peak power operating range (MPP) (V DC)	480 to 850
DC operating range (V DC)	200 to 850
DC min start voltage (V DC)	250
DC max operating current per channel (A DC)	108 (M1) / 36 (M3)
DC max short circuit current per channel(A DC)	165 (M1) / 55 (M3)
Max input source backfeed current (A DC)	0
DC input overload production	Voltage and current limiting during operation
DC input terminals / conductor size per channel A – B	1 Pos and 1 Neg / 8-14 AWG CU
DC polarity safeguard	Short circuit diode
Numbers of MPP-tracker	M1 (1 MPPT) / M3 (3 MPPT)

TABLE II. AC CHARACTERISTICS OF THE INVERTERS [8]

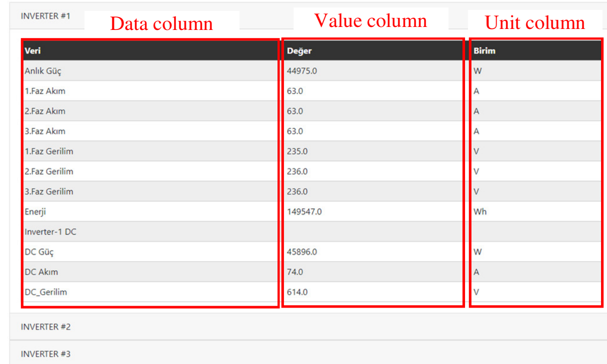
AC Electrical Specifications	50kW Inverter
AC max. continuous output power [VA]	50000
CE weighted eff . [%]	97.5
AC nominal voltage / operating range L to Neutral (V AC)	480 / 243 to 304
AC Continuous output current (A) 480 / 600	60
Frequency nominal / range (Hz)	60 / 60.5 to 59.3 (For Turkey 50 Hz)
Power factor	> .99
Total harmonic distortion %	<5%
Standby losses (W)	< 1.5
Internal consumption standby (W)	30
Feed In Starts (W)	120
AC branch circuit protection	Current limiting inverter, OCPD provided by branch circuit breaker
AC input terminals and conductor	4 / 2-10 AWG AL CU
AC max output fault current (A), RMS, and duration ms	625 A (P-P), 18.25 A (RMS), 36.5ms

TABLE III. COMMUNICATION SPECIFICATIONS [8]

Communication Specifications	50kW Inverter
User interface	Graphical user interface with 3 LED status indicators
Connectivity	Ethernet (Modbus (TCP IP)), USB, RS485, S0 output

TABLE IV. THE COLLECTED DATA FROM THE INVERTERS

No	Value
1	Total Current
2	AC Phase 1 Current
3	AC Phase 2 Current
4	AC Phase 3 Current
5	AC Phase U12 Voltage
6	AC Phase U23 Voltage
7	AC Phase U31 Voltage
8	AC Phase U10 Voltage
9	AC Phase U20 Voltage
10	AC Phase U30 Voltage
11	AC Active Power
12	Frequency
13	AC Apparent Power
14	AC Reactive Power
15	AC PF
16	AC Energy
17	DC Current
18	DC Voltage
19	DC Power
20	Inverter Situation



Veri	Değer	Birim
Anlık Güç	44975.0	W
1.Faz Akım	63.0	A
2.Faz Akım	63.0	A
3.Faz Akım	63.0	A
1.Faz Gerilim	235.0	V
2.Faz Gerilim	236.0	V
3.Faz Gerilim	236.0	V
Enerji	149547.0	Wh
Inverter-1 DC		
DC Güç	45896.0	W
DC Akım	74.0	A
DC_Gerilim	614.0	V

Fig. 2. Inverter data table on WEB portal (In Turkish)

Figure 3 shows a more detailed information about inverters where the first column presents the inverter number, the second column gives the last update time, column 3 presents the instantaneous power and columns 4 and 5 gives its value and unit, column 6 presents the total energy and columns 7 and 8 gives its value and unit, and finally columns 9 and 10 presents the inverter status and status code, respectively. Data on this table can be updated in any desired time interval.

All the inverter data is uploaded to the database on the cloud. These actions realized in every 5 minutes.


RENDA GES INVERTER GÜÇ & STATUS DEĞERLERİ

Inverter	Tarih	Veri	Değer	Birim	Veri	Değer	Birim	Status	Değer
Inverter#1	27/05/19 12:00:00	Anlık Güç	49263.0	W	Enerji	152585.0	Wh	MPP	4.0
Inverter#2	27/05/19 12:00:00	Anlık Güç	49016.0	W	Enerji	154161.0	Wh	MPP	4.0
Inverter#3	27/05/19 12:00:00	Anlık Güç	49008.0	W	Enerji	152640.0	Wh	MPP	4.0

Fig. 3. Inverter status table on the web portal (In Turkish)

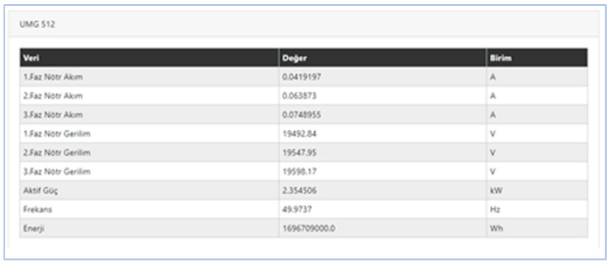
The energy analyzer placed in the power plant has Modbus TCP port. Thus, the device is able to receive the data of CPU via Modbus TCP/IP protocol. The data measured by the analyzer is shown in Table 5.

TABLE V. DATA MEASURED BY THE ENERGY ANALYZER

No	Value
1	Phase-Neutral Voltages
2	Phase-Phase Voltages
3	Phase Currents
4	Total Currents
5	Active Power
6	Reactive Power
7	Apparent Power
8	Power Factor
9	Frequency
10	Phase Rotation
11	Total produced energy

As seen in Figure 4, data of the energy analyzer can be monitored on the web portal as table format.

Similar to the energy analyzer and the inverters, data of the weather station can be read via RS485. However, its baud rate is different from the inverters. Therefore, Modbus RS485 to TCP converter is used. After this conversion, the data read from the weather station is presented in Table 6. The weather station data is shown as widget table at the top of the main web portal as seen in Figure 5.



UMG 512

Veri	Değer	Birim
1.Faz Nötr Akım	0.0419197	A
2.Faz Nötr Akım	0.063873	A
3.Faz Nötr Akım	0.0748955	A
1.Faz Nötr Gerilim	19492.84	V
2.Faz Nötr Gerilim	19547.95	V
3.Faz Nötr Gerilim	19598.17	V
Aktif Güç	2.354506	kW
Frekans	49.9737	Hz
Enerji	1696709000.0	Wh

Fig. 4. Energy analyzer data table on the web portal (In Turkish)

TABLE VI. THE DATA READ FROM THE ENERGY ANALYZER

No	Value
1	Wind Speed
2	Irradiation
3	Temperature
4	Panel Temperature

Fig. 5. Weather station data on web portal

Figure 6 shows the flowchart of the CPU software that collects the data of all 20 inverters located on the plant. The software loop in this flowchart is repeated in every 5 minutes unless there is not any communication fault. If a communication fault is occurred, the data read from the devices is written to a SD card. When the communication fault is resolved, data collected on the SD card is transferred to FTP server on the cloud and then inserted to the databases.

As seen in Figure 7, the collected data of the plant can be monitored as trend graphics. In addition to the total energy measured by the energy analyzer, daily total produced energy of the inverters, current and voltage parameters can be selected from the portal plot them graphically according to a desired date range.

For an example, part A in Figure 6 shows the total energy data belonging to dates between 26/04/2019 and 25/05/2019. For the same date range selected in part A, part B presents the daily production. Thus, daily production of the plant can be evaluated for further analysis such as the effect of daily weather on energy generation.

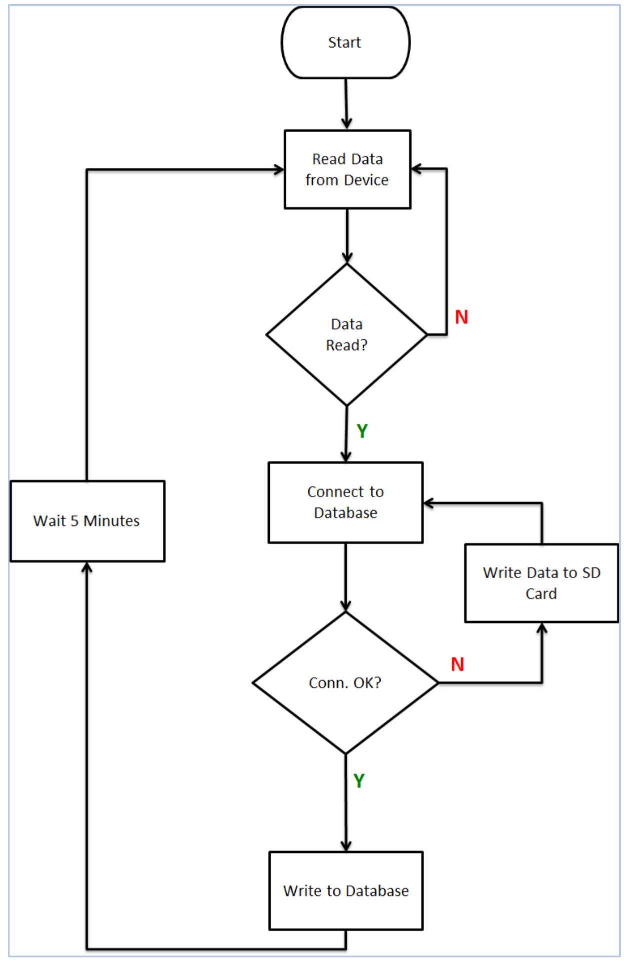


Fig. 6. Flowchart of the CPU software

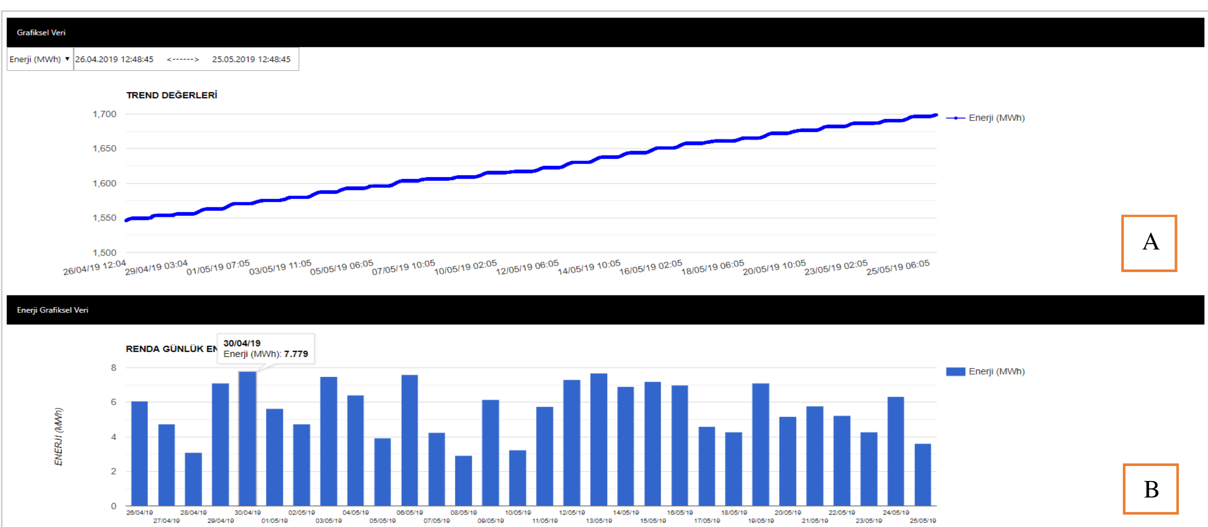


Fig. 7. Trend graphs for monitoring (In Turkish)

III. Conclusion

Hardware and software development of an interactive monitoring and controlling system is achieved for a real solar power plant that have 1MW-installed power. Almost all types of data is measured and saved to the databases on the cloud.

By using the monitoring system, all devices employed in the plant can be tracked in real time in order to detect the negative situations instantly. Furthermore, the system can be used for comparing the efficiency of the inverters and thus it is possible to determine the faulty ones. The data read from the weather station can be utilized to analyze the effects of the environmental conditions on the energy generation.

The developed system can be easily adopted to different platforms such as hydro power plants, geothermal plants and industrial factories, communication protocols of which have ability to communicate with cloud applications like web platforms, mobile applications or etc. Furthermore, the measured data can be used in some critical operations such as fault estimations and determination of maintenance periods.

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