ARTIFICAL INTELLIGENCE IN RENEWABLE ENERGY SYSTEMS BASED ON SMART ENERGY HOUSE [1]

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Abstract: This paper develops a feasibility study to identify the problem regarding energy efficiency house and implementation of the home automation system in that. Therefore, the possibilities were profoundly analyzed to determine the key points which were necessary to that project. Energy efficiency can play a significant role in reducing electrical cost, and the attachment of Smart Energy House made the idea more unique and challenging to implement it. Furthermore, the possibilities were analyzed and successfully demonstrated to reduce the temperature impact and minimize the effect in the power source by controlling the connected load into the system.

Key words: smart energy house, real-time, monitoring, networking, MQTT, Raspberry Pi, IoT.

1. INTRODUCTION

The management of energy resources is an issue for smart homes. It is possible to put on standby the devices that are not in use when the users are absent, or automatically adapt the use of electrical resources according to the needs of the residents to reduce the wastes of energy resources [1]. This project involves the realization of an intelligent system to control the home using the sensors' data. The controller (Raspberry Pi) is the main component of the home automation system; it has the essential role of implementing mechanisms necessary to actively responding to the needs of the user.

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Internet of Things (IoT) is a concept that encompasses various objects and methods of communication to exchange information. Today IoT is a more descriptive term for a vision that everything must be connected to the internet [2]. In this project, various environmental data related to the water level, humidity, and temperature were collected through low-cost sensors and analyzed to reduce, among others, the thermal effects on the photovoltaic panels. Furthermore, the electrical load connected to the system has been monitored. According to the load calculation, the total requirements were 3556 Wh/day and served by a 1 KW system. After the theory and the practical studies, it was possible to match the loads to the automation. The financial analysis confirms that the system's cash flow model is beneficial to implement. This prototype was designed in a modular way so that it can easily enhance with other new technologies relevant to renewable energy and energy efficiency.

2. RELATED WORK

Various intelligent home systems have been developed, and they can communicate via the Internet [3] or short message services (SMS) [4]. These systems consist of a home network unit and a gateway [5]. In the past decades, diverse issues concerning intelligent systems have attracted attention, but the installation cost is still high, so design optimization is required. Besides, Artificial Intelligence (AI) can be a great opportunity in Renewable Energy (RE) field by predicting future values using data that is getting from different sensors or open data from other resources [6]. A data acquisition node/system uses various sensors, dedicated hardware, and respective software to measure and store physical signals like the voltage, temperature, pressure, etc. The present report describes the design of a real-time data acquisition system, using self-programmed algorithms implemented on a low-cost, credit card-sized microcomputer known as a Raspberry Pi (RPi) for further analysis and predictive model development [7]. The central gap of competence was bringing all the possibilities together, such as automation and cost analysis. Database management systems such as InfluxDB or PostgreSQL were used for collecting and storing the data. The performance, simplicity, and portability of the resources were improved by using the Representational State Transfer Technology (REST) in a combination with an interactive visualization web interface such as Grafana. The real-time communication between the single system components and the data synchronization was based on the Message Queuing Telemetry Transport (MQTT) protocol. The collected data were further analyzed to predict the upcoming production of solar energy and global solar horizontal irradiation.

2.1. Methodology of the system

The project's purpose was to implement a zero-emission house and put clay instead of brick for better insulation. The clay block walls ensure a balanced indoor climate and protect against sudden temperature changes, which allow the owners to control all the parameters affecting their comfort and optimum management of the maintenance cost. The net passive house is a structural element. The photovoltaic (PV) thermal panel will be installed on the rooftop of the house, which will supply electricity. The PV-T board will provide thermal energy and can also be connected directly to the water pump system. The primary function is to deliver the water by a DC pump and the rated capacity of about 70 watts. The pipe for providing the water into the house has an inner 12 mm and outer 16 mm diameter. Its length should be around 240 m. One hot water pump will be used as a submersible device with a rated capacity of 40 watts. This solar pump is directly run by the DC of PV or the battery. The hot water stored in the tank will be supplied on demand into the house.

The automation process was necessary for this project to maintain the load balance, as well as to determine the future needs by predicting solar irradiation, temperature, and humidity. It shows also how the AI model can be helpful by time series forecasting. Time series forecasting is a powerful AI tool for foretelling future business case and production opportunity analysis. It can be used alongside the automation process of the prediction analysis by ARIMA and persistence model. Due to the substantial increase in solar power generation, the monitoring and analysis of incoming solar energy are too important and necessary to predict the amount of energy need to be produced.

2.2. Technical design of the system based on automation

The control system uses a combination of various electronic devices that are related to each other in a certain way. According to the function of the components, those can be classified into the group of sensors and actuators. The sensors measure the physical and environmental parameters such as temperature, humidity, and distance in the form of an analog signal (voltage, resistance, current). The analog signal is being converted into a digital signal and sent to the central unit. Once the measured data are analyzed, the control unit provides the output signal to the actuators. In this way, for instance, the relay (actuator) will stop the water pump based on the measured water level by the ultrasonic sensor. All components continuously communicate with the central unit, Raspberry Pi (RPi), through the MQTT network protocol.

DHT-11 is an ultra-low-cost capacitive digital sensor that was used for measuring the humidity in the range of 20-80% with an accuracy of ±5% and the temperature in the range of 0-50ºC and accuracy of ±2ºC. The sensor uses a single pin for the data transfer and another two for the power supply of 3-5.5V and ground connection. It is simple to implement but requires careful timing to obtain data [8]:

Figure 1 illustrates an example circuit diagram of the DHT11 sensor that is connected to Raspberry Pi Zero W (client) at pin 1 (VDD), 7 (DATA), and 6 (GND). The sensor measures continuously the temperature and humidity values. The running processes on the microcomputer collect and forward the digital information to the database on the central unit (host). In this particular example, the four-channel relay is wired to the Raspberry Pi Zero W as well and can be controlled remotely by the requests from Raspberry Pi B (host) since both devices are communicating over the network.

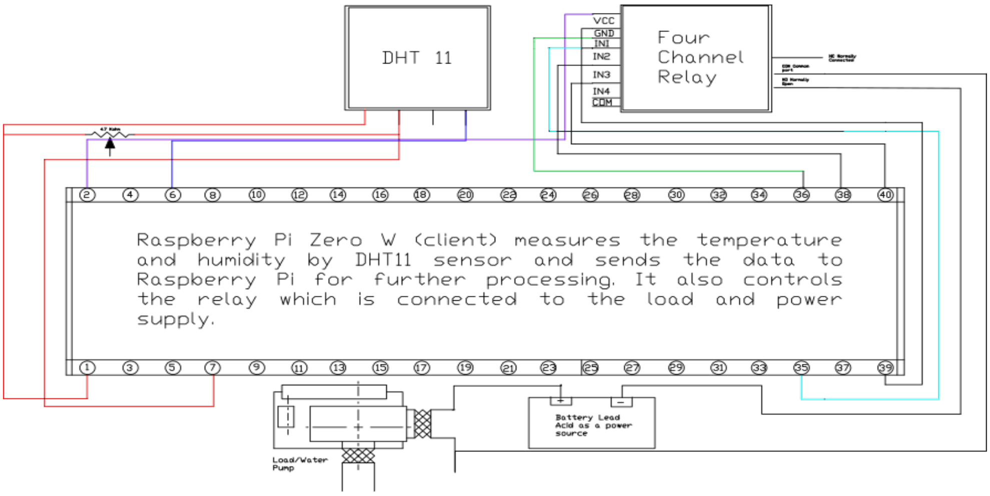

Fig. 1. Circuit Diagram of the DHT 11 sensor with relay

The water level is being detected using two different measuring methods. Both methods were implemented in this project due to mutual redundancy.

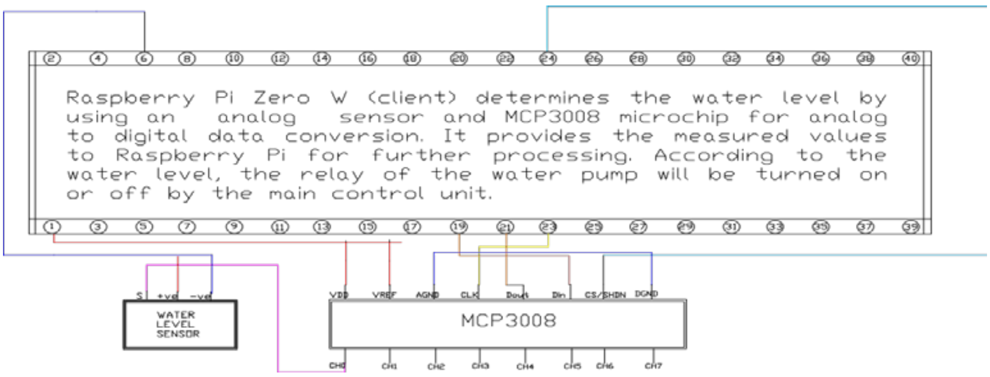

Fig. 2. Client connection with the Water level and the A/D converter

The first technique uses a combination of two analog water sensors that are placed in the upper and lower part of the tank defining the minimum and maximum water level. The sensor uses a single pin for the analog voltage output and two pins for power supply and ground. It returns the highest analog value whenever water or another fluid is covering the board, otherwise, the output is null. Since RPi devices can only process digital signals, an analog to digital converter (ADC) is required. For instance, the MCP3008 10-bit ADC converts the highest output signal into the digital value of 1023. Due to the simple and robust functionality, both sensors operate as on/off switches. All values above the predefined threshold will be interpreted as logical True, the rest as logical False. The first detector (minimum) controls the start position, and the second sensor controls the stop position (maximum) of the water pump. A possible implementation is demonstrated in Figure 2. Raspberry Pi Zero W determines the water level and provides the measured values to Raspberry Pi for further processing. According to the amount of water in the tank, the relay and then the pump will be turned on or off by the main control unit.

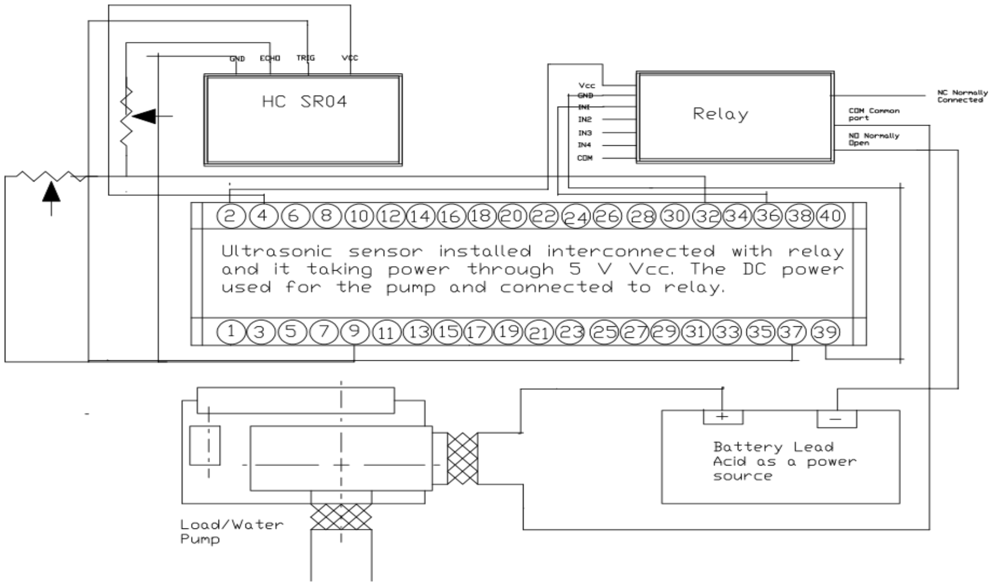

Fig. 3. Automation of water pump and relay

The second technique for controlling the automation of the water pump is the measurement of the fluid height with a help of a digital ultrasonic sensor. The sensor uses a single element for emission and transmission of the ultrasonic waves. The distance based on the measured travel-time can be calculated with the following formula: $L = \frac{1}{2} \cdot T \cdot C$ [9], where L is the distance, T is the travel-time between the emission and reception, and C is the sonic speed.

The time needs to be divided by two, due to the go-and-return distance. According to the measured height of the tank, the maximum water level has been defined and included in the programming part for the automation. The pump will not operate when the water reaches the predefined limit. Unlike the first method, only one sensor in the upper part of the tank is required. Furthermore, a real-time monitoring of the refilling process instead of the basic empty/full status is possible. The current tank fullness is continuously represented by a percentage value. The lower limit for turning the water pump on can be defined by the user in the program configuration. Figure 3 illustrates an example implementation including relay connection. In case of insufficient solar radiation and low battery level the connection of the load (water pump) should be terminated, otherwise, the PV array will be unable to recharge the battery and to give enough power to the pump.

3. COMMUNICATION

A fundamental part of the system is the Message Queue and Telemetry Transport (MQTT) protocol. It was developed especially for applications in networks with low bandwidth. Thus, it is very lightweight and suitable for devices with limited resources. The protocol works with both TCP/IP and non-TCP/IP networks, such as ZigBee [10]. In this project, the MQTT protocol was implemented for TCP/IP-based communication and data transmission.

MQTT implements the publish/subscribe communication concept, an event-based model between transmitters and receivers. A device (client) can publish a message on a topic, or it can be subscribed to a particular topic to receive the messages. The message simply represents the information that one client wants to exchange with other devices. It could be a measured value coming from a sensor or a request going to an actuator. The topic is assigned to every message and it is represented with strings separated by a slash. Each slash indicates a topic level, specifying the type and source of the content. For instance, the following topic: */relay/ch1/on* is enabling the first channel of the relay and consequently turning on the pump. Once the topic name matches a topic pattern, the event is forwarded to the subscribed client. This publish/subscribe process is controlled by a central unit, the broker (server). The broker is responsible for receiving and storing published messages, filtering the topic names of incoming messages according to the topics of the subscribers, and publishing (forwarding) the messages to the interested clients. The broker also handles the authentication process of the clients if required.

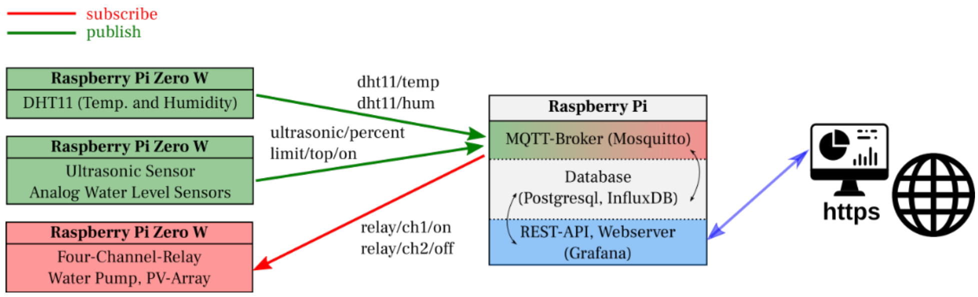

Fig. 4. MQTT publish/subscribe communication model.

Figure 4 presents the technical implementation of the smart energy house system. The server, Raspberry Pi, is a primary part and the main unit of the entire monitoring system, that runs different services for data transmission, collection, processing, and visualization. The transmission of the sensor data and the control of the actuators is done through the MQTT protocol. The Mosquitto broker was installed on the Raspberry Pi. The temperature, humidity, and the water level detected by the analog and digital sensor are sent to the MQTT broker. The measured data are being stored in the database systems, such as PostgreSQL or InfluxDB for further analyzing processes. According to the measured values Raspberry Pi is controlling the channels of the relay and consequently starting and stopping the water pump or the connection between the battery and PV array. Finally, the current status of the monitoring system can be accessed directly in the browser. The self-programmed REST-API used with the web-based platform Grafana offers secure data access and visualization. The system can be controlled and reconfigured from any device, such as a laptop, smartphone, or tablet.

4. PREDICTION ANALYSIS

Information about the global horizontal irradiance, solar production, temperature, and specific yield have been collected according to the location and processed with Homer Pro Software using different prediction models for datasets of 365 days. An Autoregressive Integrated Moving Average (ARIMA) model has been implemented (Figure 5). This method depends on three parameters: p, d, and q, where p is the number of lag observations included in the model, also called the lag order, d is the order of differentiation, the number of times that the raw observations are differentiated, also called the degree of difference, and q is the moving average, the size of the moving average window also called the order of moving average. For the future value analysis based on the previous data, the prediction is represented by Y = (Auto-Regressive Parameters) + (Moving Average Parameters) [11].

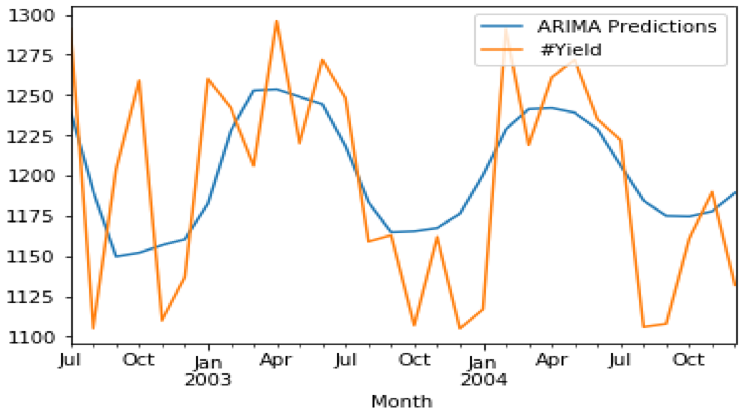

Fig. 5. Autoregressive Integrated Moving Average (ARMA) model

In Figure 6 the approximate prediction for the next 5 years is illustrated by using different tools of forecasting. The model can be modified by changing different parameters. For instance, the input variable for the start (minimum) and end (maximum) limits can be configured. The root-mean-square value should be smaller than the mean value of the test set. If the dataset is not stationary the rest of the parameters: p, d, and q need to be adjusted to get the best possible model.

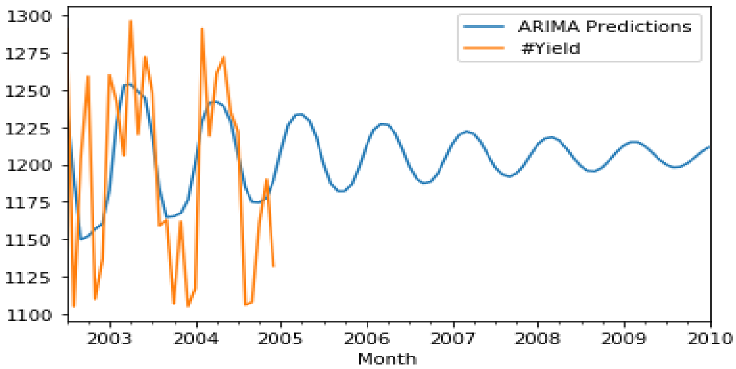

Fig. 6. Prediction model using previous historical data

Table 1 presents an approximate cost comparison of the equipment used in the project and the electricity prepared in the Homer Pro Software. Figure 7 illustrates the amount of time needed to achieve the breakeven point.

Table. 1. Economic analysis after extracting the information from software

Investment Costs €/kWp / Capital Cost Multiplier-Homer	Focus 1kW 800 / 1.0 (With optimum CAPEX)	High 1kW 1200 / 1.5 (With a High CAPEX)
Project IRR (before tax)	19.4%	12.1%
Simple Payback Time (yr)	5.05	7.57
PV LCOE (EUR ct/kWh)	0.036	0.052

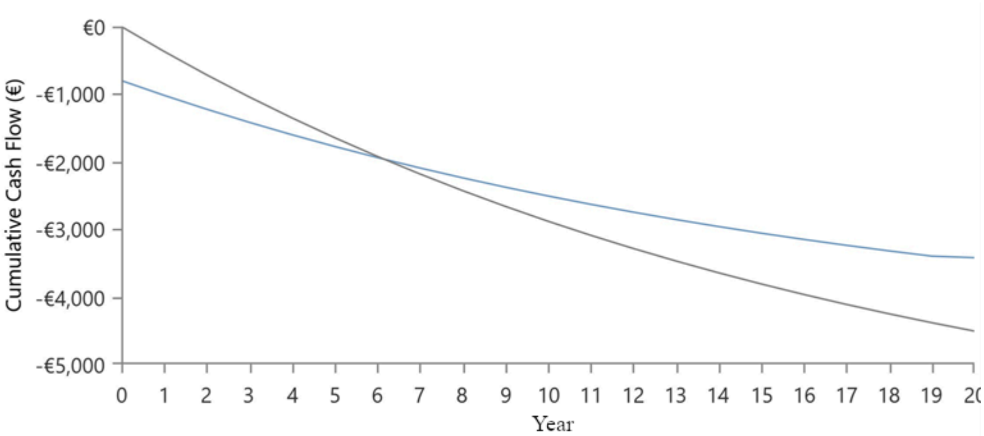

Fig. 7. Cash flow model by using Homer Pro software

In the current system, renewable energy resources are not included. The operation and maintenance cost and the cost of the converter have been considered. An additional calculation for analyzing the capital expenditure including electronic devices showed that the total energy requirement for a small system is 3.56 KWh/day with a demand of 0.17 KW peak. The system is connected to the grid whereas the sell back price is included. The return of investment of the project is 15.8% and the internal rate of return is 19.4% according to the inputs parameters (Formula 1) [12].

$C_{i,ref}$ = Nominal annual cash flow for base (reference) system
C_i = Nominal annual cash flow for current system
R_{proj} = Project lifetime in years
C_{cap} = Capital cost of the current system
$C_{cap,ref}$ = Capital cost of the base (reference) system

$$ROI = \frac{\sum_{i=0}^{R_{proj}} C_{i,ref} - C_i}{R_{proj}(C_{cap} - C_{cap,ref})} \qquad (1)$$

5. CONCLUSION

The improvement of energy consumption and consequently the reduction of the total costs were the focus of our project. The simulation of the cash flow model (Figure 7) including all the capital expenditures for measuring components, actuators, and panels confirms the feasibility of the system. This project idea might play a significant role in terms of a sustainable house with an automation system. Furthermore, the electricity costs including renewable energy resources were optimized based on the total initial cost of the system and the production. A major benefit of this concept is the analytical part. By using different algorithms and methods the amount and costs of production can be predicted for the next several years. It is a huge optimization criterion in the renewable energy field. This project aims at a prototype conception for a small system, but it can be easily extended for more complex targets.

REFERENCES

[1] *Energy-Saving Through Smart Home Concept: Rabea Cheggou*, El-Hadi Khoumeri, and Kamila FerhahL TI Laboratory, Ecole Nationale Supérieure de Technologie, ENST, Algiers, Algeri{rabea.cheggou,elhadi.khoumeri,kamila.ferhah}@enst.dz.

[2] Yoon, D., Bae, D., Ko, H., Kim, H. Implementation of home gateway and GUI for control the home appliance. In: *The 9th International Conference on Advanced Communication Technology*, 2007, pp. 1583–1586.

[3] Yan, M., Shi, H. Smart living using Bluetooth-based Android smartphone. *Int. J. Wireless Mobile Networks*, **1** (vol. 5), 2013, p.65.

[4] Elkamchouchi, H., ElShafee, A. Design and prototype implementation of SMS based home automation system. In: *2012 IEEE International Conference on Electronics Design, System and Applications (ICEDSA)*, 2012.

[5] Kushiro, N., Suzuki, S., Nakata, M., Takahara, H., Inoue, M. Integrated home gateway controller for home energy management system. In: *IEEE International Conference on Consumer Electronics*, 2003, pp. 386–387.

[6] *Predicting Solar Energy Production with Machine Learning*; Evan Bakker, available from: https://medium.com/@evanbaker/predicting-solar-energy-production-with-machine-learning-19fcab295e58

[7] R. Tuna Balkan, *Data Acquisition Handbook*, 3rd ed, Measurement Computing Corporation, 2012, Chap. 1.

[8] Davinder Pal Sharma, et al. Raspberry Pi Based Real Time Data Acquisition Node for Environmental Data Collection, *Journal of Basic and Applied Engineering Research* **4** (vol. 4), Apr-Jun 2017, pp. 307-312.

[9] S*ensor Basics: Understanding fundamental principles and features*, Keyence, 2019, available from: https://www.keyence.com

[10] *Oasis*, MQTT Version 3.1.1 Oasis Standard (2014).

[11] Jason Brownlee, *Introduction to Time Series Forecasting with Python*, Machine Learning Mastery (eBook), 2017, 367 p. 182-248; available at: https://machinelearningmastery.com/introduction-to-time-series-forecasting-with-python/

[12] https://www.homerenergy.com/products/pro/index.html

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