XVII Simposio CEA de Control Inteligente

27-29 de junio de 2022, León

# Web-based HMI for renewable energies microgrid through Grafana environment

Folgado, F.J.[a], González, I.[a], Orellana, D.[a], Calderón, D.[a], Calderón, A.J.[a,*]

[a] *Departamento de Ingeniería Eléctrica, Electrónica y Automática, Escuela de Ingenierías Industriales, Universidad de Extremadura. Avenida de Elvas s/n, 06006 Badajoz, España.*

**To cite this article:** Folgado, F.J., González, I., Orellana, D., Calderón, D., Calderón, A.J. 2022. Web-based HMI for renewable energies microgrid through Grafana environment. XVII Simposio CEA de Control Inteligente.

## Abstract

Smart Grids and Microgrids require continuous monitoring and visualization of the operational state of its generation and consumption equipment. The use of Internet of Things (IoT) technology for monitoring purposes can solve limitations of traditional solutions. This paper presents a web-based Human Machine Interface (HMI) developed in the IoT software Grafana to visualize in real-time the operation of a Smart Microgrid. Photovoltaic generation is combined with hydrogen production and consumption in the microgrid. The main magnitudes of the components are measured and graphically displayed through a user-friendly web interface. Experimental results are reported to prove the suitability of the developed HMI.

*Keywords:* HMI, Web, IoT, Microgrid, Monitoring, Database, Grafana.

## 1. Introduction

The monitoring and continuous visualization of an automated process is an essential task in all scientific processes. In particular, for renewable energy facilities, its relevance is acquiring an increasing attention from researchers and practitioners, as emphasized in many recent papers. For instance, in (Ferreira et al., 2015) it is asserted that deploying distributed monitoring and control systems is one of the main challenges in the scope of Smart Grids. In a similar sense, for Smart Grids and Microgrids, according to (Vargas-Salgado et al., 2019) and (Portalo et al., 2021), the monitoring task is of paramount importance.

Traditional software suites for process monitoring involve proprietary suites such as LabVIEW of National Instruments, iFix of General Electric, or WinCC of Siemens. In this sense, conventional monitoring and supervisory systems for microgrids are expensive due to the need for data loggers, controllers, sensors and other devices (Vargas-Salgado et al., 2019). Even more, these solutions have high costs and limited options for programming at low level. Additionally, most of monitoring systems for plants involving renewable energies are implemented in LabVIEW over a PC, allowing only local monitoring (Pereira et al., 2018).

The licensing expenditures and restricted local access of classic monitoring systems are limitations that must be overcome in order to stimulate the real implementation of Smart Microgrids (Portalo et al., 2021).

Aiming at addressing these drawbacks, Internet of Things (IoT) software for monitoring tasks is a valuable solution. In general, IoT software is also open-source, which provides the user the ability to modify and customize it at deep level. Indeed, these suites are commonly low-cost or free, which reduces the associated expenses. On the other hand, remote access to real-time data through the network is easily achieved thanks to the native support of online connections provided by IoT software packages.

In fact, a prominent trend in the deployment of monitoring systems relies on using IoT technology (González et al., 2022). Particularly, to support microgrid applications, IoT technologies provide great opportunities for sensing, communication, processing, and actuating (Eltamaly et al., 2021).

Among the available IoT software suites, web platforms that are gaining popularity are ScadaBR, Angular, Thinger.io and Grafana. The latter one is an IoT web environment developed in 2014 that provides an easy-to-use and intuitive environment to deploy web-based dashboards including instant values and time-series. Data is fed from a database, so the user can observe real-time data or historical information.

This paper presents a web-based Human Machine Interface (HMI) developed in Grafana to visualize in real-time the operation of a Smart Microgrid. Such microgrid is a renewable energy facility which combines photovoltaic generation with hydrogen production and consumption. The most relevant magnitudes of the components are sensed and graphically displayed through a user-friendly web interface.

The presence of Grafana in scientific papers demonstrates its versatile and powerful functionalities. For example, Grafana is used as display environment in the CERN, the European Organization for Nuclear Research, one of the world largest centres of scientific research (Beermann et al., 2020). Computation resources and memory consumption are monitored by Grafana for software deployment in the cloud in t et l. 2022 . Resource monitoring via Grafana is reported in (Chan et al., 2022) as part of a cluster-based heterogeneous edge computing system. The visualization of the status and power consumption of automated guided vehicles and drones is proposed in (Tsung et al., 2022). Condition monitoring for industrial autonomous transfer vehicles is solved by means of Grafana in (Gültekin et al., 2022). In the scope of Industrial IoT, this software is used for data query and visualization in (Liu et al., 2022).

Regarding energy-related applications, interesting contributions are found in recent literature. In (Portalo et al., 2021), the temperature of a photovoltaic generator is tracked by means of Grafana. The operation of a photovoltaic array and a Lithium-ion battery for water pumping purposes is visualized through this software in (Gimeno-Sales et al., 2020). A grid-connected photovoltaic plant is monitored via Grafana in (De Arquer Fernández et al., 2021). In (Barroso et al., 2022) Grafana is used to visualize data of water and energy consumption in the context of a SmartCampus.

The structure of the rest of the manuscript is as follows. The second section expounds the main features of the software Grafana. Section 3 describes the smart microgrid where the web-based HMI is applied. Implementation results are shown in the fourth section. Finally, the main conclusions of the work are addressed together with further guidelines.

## 2. Grafana main features

Grafana is IoT software focused on the information monitoring by means of queries in various databases. For this purpose, the environment provides a web-based HMI consisting of panels or dashboard that include graphical elements such as displays or charts to represent instantaneous values or time-series. Its principle of operation is based on communication with multiple data sources, such as InfluxDB, MariaDB, SQLite or MySQL. The Grafana and databases interconnection is carried out simultaneously, offering the possibility to represent different values from different data sources in the same graph. In addition, these databases can be located on devices other than the one running the Grafana web server. Figure 1 illustrates the principle of operation of Grafana, highlighting its connectivity with various data sources.

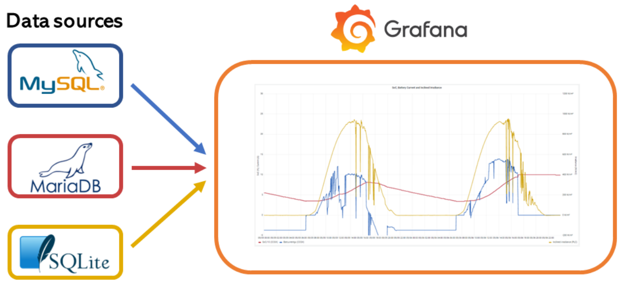

Figure 1: Principle of operation of Grafana. Interaction with databases.

Read data are represented in dashboards, where the graphical elements that contains the information are placed. These panels are characterised for its ease of configuration and user-friendly representation which facilitates the design and implementation of monitoring interfaces for a wide range of applications, as it has been stated in the previous section.

Another outstanding advantage of Grafana is its multiplatform character, offering the possibility of running Grafana on multiple operating systems such as Windows, MacOS or Linux. At the same time, it presents low computational requirements, which promotes its use in devices of diverse specifications such as personal computers, single board computers like Raspberry Pi, or even Android devices through an app that provides a Grafana client. This diversity of available devices and functions is due to its open-source approach, which encourages the development of plugins and additional functions by the Internet community under the Do It Yourself (DIY) philosophy.

Grafana has an intuitive and simple interface that guides the user through all the necessary steps for its operation. First, the connection to the environment is made locally or via Ethernet, depending on where the Grafana server is hosted. Once connected, the user logs in with a username and password. Then, the dashboard or element to be visualised and the specific time range are selected. After this, the program sends the request to the databases and, finally, the values received are represented in the graphical displays. The flowchart in figure 2 summarises the sequence of steps required for the visualisation of values in Grafana.

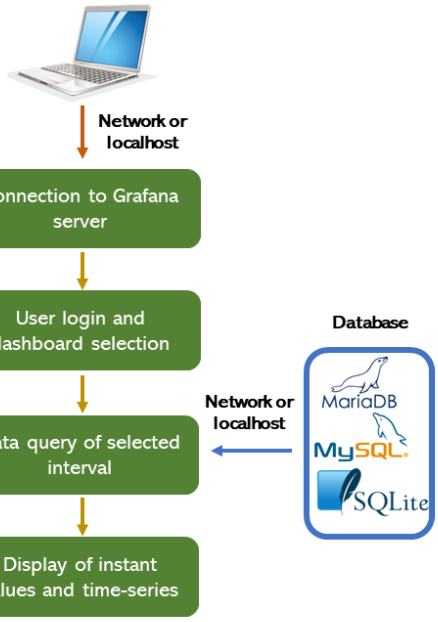

Figure 2: Flowchart of steps required for the visualisation of values in Grafana.

## 3. Smart Microgrid description

The monitored microgrid consists of a hybrid renewable energies system, formed by loads and generators. The Smart connotation refers to the self-management capacity of the system, based on devices dedicated to this function, such as programmable controllers.

As part of the generation subsystem, the microgrid includes an array of interconnected Solar Photovoltaic (SPV) panels controlled by a Maximum Power Point Tracker (MPPT) driver that optimises its operation and maximises current output. In addition, a Membrane-Based Fuel Cell (MBFC) is installed to generate electric current from an input hydrogen flow.

Within the load subsystem, an Electronic Programmable Load (EPL) is used to simulate different energy demand profiles. Also, a Membrane-Based Electrolyzer (MBEL) produces hydrogen by means of an electrical current provided by the SPV array. The stored hydrogen is used to fulfil the gas flow needed for the MBFC operation.

Lastly, a Lithium-Ion battery allows the electrical storage and stabilisation of the DC bus to which the rest of the devices are connected. Figure 3 depicts the interaction between the elements that make up the Smart Microgrid.

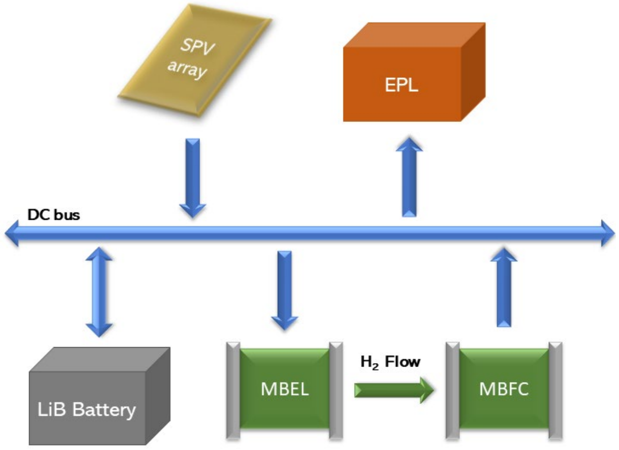

Figure 3: Components of the monitored Smart Microgrid.

Each of the abovementioned elements is accompanied by a set of sensors and actuators to collect information about the operation of the device and to act according to the energy management criteria. Some of these variables, such as the generated current by the SPV panels or the hydrogen flow rate produced by the MBEL, are directly related to the behaviour of the device. On the other hand, to maintain a smooth, efficient and safe operation, it is required to monitor variables associated with the operating status of the devices, such as the temperature of the MBFC or the State of Charge (SoC) of the Li-Ion battery. Figure 4 depicts all the elements involved in the monitoring system and their interactions.

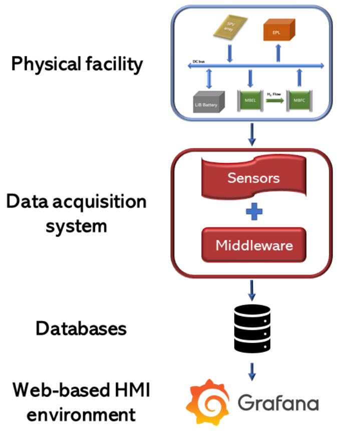

Figure 4: Elements concerned in the monitoring system and interactions.

## 4. Implementation

The developed web-based HMI groups a set of graphs on a single dashboard. This design provides the user with a global overview of the status of the microgrid from a single screen. For this purpose, the used graphs represent multiple variables of the microgrid, which combined analysis provides further information on the state of the system. As an example, Figure 5 shows the evolution, for a selected time frame of the currents from the SPV panels, the battery and the EPL, together with the inclined irradiance measured on the panels.

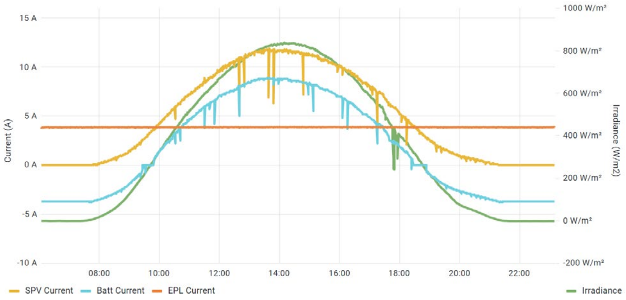

Figure 5: SPV-Batt-EPL current and irradiance for a selected time interval.

The current generation by the SPV array depends on the irradiance, as can be seen in the homomorphism of both curves. The time interval depicted shows the behaviour of the microgrid in an operating case where the EPL does not demand current. Thus, the battery current has the same form as the panel current, whose positive value indicates that the battery is charging.

Other types of used graphs display variables associated with device performance within a nominal and safe range. These parameters determine the overall operation of the microgrid and result in changes in the operating modes of the devices involved through the installed actuators. In this context, a noteworthy feature of Grafana is the definition of alarms associated with variables, detecting deviations from setpoints or operating intervals. Even database disconnections can be detected. The user is warned of these situations graphically so the appropriate actions can be conducted. As an example of this feature, an alarm has been defined for the battery SoC. As previously mentioned, the battery is a critical element in the operation of the microgrid as it performs the functions of energy storage and DC bus stabilisation. Consequently, the rest of the microgrid components depend on the proper state of this device, so it is essential to monitor certain parameters such as the SoC or the current flow of the battery. Due to this importance, a specific curve has been implemented to visualise these variables, as shown in figure 6.

Figure 6: SoC and battery current for a selected time interval.

As shown in the figure, an alarm associated to the SoC variable has been implemented, in order to notify the operator when the value drops below 20%. This setpoint has been selected considering the properties of the installed battery. Li-Ion batteries are intended to operate in a nominal range from 20% to 80% SoC. Discharges below the lower limit are critical as they affect the health of the battery due to degradation effects.

The alarm signal allows the user to detect this unwanted situation and to act accordingly. In this case, it is desired to cut off the current consumption of the battery in order to prevent it from in-depth discharging. By doing so, all the current generated will be stored in the battery, increasing the SoC value to the nominal operating range.

Numerical indicators are used to represent the values of the microgrid in real time. The set of elements that make up the dashboard allows the user to visualise two types of data simultaneously: historical data through the graphs and real-time values by means of the indicators.

Taking MBEL values as an example, two types of indicators are used: simple and with value range. The first type is used for variables whose value is not critical for the system, as in the case of hydrogen flow. On the other hand, the value-range indicators display values such as the working pressure, which should not exceed a maximum limit in order to ensure correct operation of the MBEL. If this maximum is reached, the indicator changes colour to alert the operator. Figures 7a and 7b shows the appearance of the simple and value-range indicator described above.

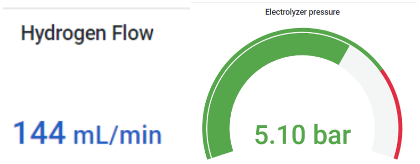

Figure 7a. Simple indicator. Figure 7b. Value-range indicator.

Figure 7. MBEL hydrogen flow and working pressure indicators.

## 5. Conclusions

This paper has presented the development and implementation of a web-based HMI devoted to monitor a renewable energy Smart Microgrid. The IoT software Grafana has been applied to design a dashboard which display in real-time the main magnitudes of the microgrid. Experimental results demonstrate the ability of this HMI to visualize such magnitudes through graphical time-series as well as instant values. Moreover, alarms can be defined for the continuous surveillance of critical variables, warning when values out of the proper range are reached. Future research guidelines deal with including advanced functionalities by means of additional plugins as well as with developing a digital twin of the microgrid components with the acquired data.

## Acknowledgments

This project was co-financed by European Regional Development Funds FEDER and by the Junta de Extremadura (IB18041).

## References

Arquer Fernández, P. De, M. Angel Fernández Fernández, J. Luis, C. Candás, P. Arboleya Arboleya. 2021. An IoT Open Source Platform for Photovoltaic Plants Supervision. Electrical Power and Energy Systems vol. 125pp. 106540. https://doi.org/10.13039/501100011033.

Barroso, S., P. Bustos, P. Núñez. 2022. Towards a Cyber-Physical System for Sustainable and Smart Building: A Use Case for Optimising Water Consumption on a SmartCampus. Journal of Ambient Intelligence and Humanized Computing, no. 0123456789. https://doi.org/10.1007/s12652-021-03656-1.

Beermann, T., A. Alekseev, D. Baberis, S. Crépé-Renaudin, J. Elmsheuser, I. Glushkov, M. Svatos, A. Vartapetian, P. Vokac, H. Wolters. 2020. Implementation of ATLAS Distributed Computing Monitoring Dashboards Using InfluxDB and Grafana. EPJ Web of Conferences vol. 245pp. 03031. https://doi.org/10.1051/epjconf/202024503031.

Chan, Y.-W., H. Fathoni, H.-Y. Yen, C.-T. Yang. 2022. Implementation of a Cluster-Based Heterogeneous Edge Computing System for Resource Monitoring and Performance Evaluation. IEEE Access vol. 10pp. 1–1. https://doi.org/10.1109/access.2022.3166154.

Eltamaly, A.M., M.A. Alotaibi, A.I. Alolah, M.A. Ahmed. 2021. Iot-Based Hybrid Renewable Energy System for Smart Campus. Sustainability (Switzerland) vol. 13 (15), . https://doi.org/10.3390/su13158555.

Ferreira, A., Â. Ferreira, O. Cardin, P. Leitão. 2015. Extension of Holonic Paradigm to Smart Grids. IFAC-PapersOnLine vol. 28 (3), pp. 1099–1104. https://doi.org/10.1016/j.ifacol.2015.06.230.

Gimeno-Sales, F.J., S. Orts-Grau, A. Escribá-Aparisi, P. González-Altozano, I. Balbastre-Peralta, C.I. Martínez-Márquez, M. Gasque, S. Seguí-Chilet. 2020. Pv Monitoring System for a Water Pumping Scheme with a Lithium-Ion Battery Using Free Open-Source Software and Iot Technologies. Sustainability (Switzerland) vol. 12 (24), pp. 1–28. https://doi.org/10.3390/su122410651.

González, I., A.J. Calderón, F.J. Folgado. 2022. IoT Real Time System for Monitoring Lithium-Ion Battery Long-Term Operation in Microgrids. Journal of Energy Storage vol. 51 (March), pp. 104596. https://doi.org/10.1016/j.est.2022.104596.

lte in . E. Cin r . n A. . 2022. Real-Time Fault Detection and Condition Monitoring for Industrial Autonomous Transfer Vehicles Utilizing Edge Artificial Intelligence.

t . A. . Ionit . . Anton . t . 2022. Applied S ien es Analysis of Complexity and Performance for Automated Deployment of a Software Environment into the Cloud.

Liu, C., Z. Su, X. Xu, Y. Lu. 2022. Service-Oriented Industrial Internet of Things Gateway for Cloud Manufacturing. Robotics and Computer-Integrated Manufacturing vol. 73 (February), . https://doi.org/10.1016/j.rcim.2021.102217.

Pereira, R.I.S., I.M. Dupont, P.C.M. Carvalho, S.C.S. Jucá. 2018. IoT Embedded Linux System Based on Raspberry Pi Applied to Real-Time Cloud Monitoring of a Decentralized Photovoltaic Plant. Measurement: Journal of the International Measurement Confederation vol. 114 (January 2017), pp. 286–97. https://doi.org/10.1016/j.measurement.2017.09.033.

Portalo, J.M., I. González, A.J. Calderón. 2021. Monitoring System for Tracking a Pv Generator in an Experimental Smart Microgrid: An Open-Source Solution. Sustainability (Switzerland) vol. 13 (15), . https://doi.org/10.3390/su13158182.

Tsung, C.-K., F.-S. Chang, X.-Y. Liu. 2022. On the Construction of an Edge-Based Remote Sensing Framework: The Applications on Automated Guided Vehicles and Drones. Electronics vol. 11 (7), pp. 1034. https://doi.org/10.3390/electronics11071034.

Vargas-Salgado, C., J. Aguila-Leon, C. Chiñas-Palacios, E. Hurtado-Perez. 2019. Low-Cost Web-Based Supervisory Control and Data Acquisition System for a Microgrid Testbed: A Case Study in Design and Implementation for Academic and Research Applications. Heliyon vol. 5 (9), . https://doi.org/10.1016/j.heliyon.2019.e02474.