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Downtime Measurements of Generator-Powered Microgrid During Planned and Unplanned Transfer to Island Mode

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***Abstract*—Growing popularity of distributed generation is drawing special attention to communication technologies in smart power grids. This paper provides a detailed overview of the communication protocols utilized in the modern distributed grid laboratory. It describes both wired and wireless technologies used in Smart Grid and presents the remote operation of switching the subsystem from grid mode to island mode operating under nominal conditions. It shows the duration of power outages during a transfer to island mode with diesel generator running on idle - which simulates planned islanding and diesel generator stationary, which simulates unplanned islanding. Latency between registration of disturbance and executing control command is measured. The results obtained are compared with current legislation. The consequences to the power system that are possible in both scenarios are highlighted. Obtained results and description of the communication technologies can be useful for the design of distributed power grids, island-mode power grids, and Smart Grids, as well as for further research in the area of using combustion fuel generators as a primary power supply in the microgrid.**

***Keywords*—islanding; Smart Grid; power grid communication; power quality; distributed computing**

I. Introduction

THE choice of communication protocols is crucial to the efficiency of the energy management system [1]. The use of popular and general purpose communication technologies could be beneficial for such projects, as it can result in a lower price for the investor and can facilitate the integration of the system with other systems [2]. The use of less popular and more specific communication protocols can result in a more individualized communication system that can offer greater safety, security, reliability, faster transmission, or management of communication channels that better meet the requirements of the system design [3], [4]. One of the goals of the RELFlex project was to examine the communication protocols that could be the best fit for the distributed generation system and modern energy management systems 5. The communication system was tested in terms of its suitability to control the remote system in the event of an emergency power outage. Some of the power subsystems cannot be operated locally because their switch to island mode may influence the operation of other subsystems within the same macrogrid, causing large-scale disruptions. Various countries do not legally allow the operation in island mode without informing the electric utility company. The exchange of information on the state of the systems is a crucial part of a smart grid management strategy. The effective flow of information describing the state of subsystems is critical for the execution of defensive actions to maximize the percentage of the grid that remains powered in the case of cyber or military attack. Implementing centralized control systems may also be a method to reduce the cost of managing island systems.

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II. System Architecture

The RELflex project consists of three subsystems. The architecture of the communication system implemented in the RELflex laboratory is presented in 1 with every element described in I. The first and most complex system is the laboratory that performs a role of a center of management for renewable sources and different types of load that are located within the building site and the remaining two sub-sites [6]. The remaining two systems are located at sites geographically remote from the laboratory and each other. They both consist of hotels which are the grid load and diesel generators that can be used both as an emergency power supply or as an auxiliary power supply to generate electrical energy when it is profitable. Distribution and complexity require the application of a variety of protocols to fulfill the objective of the project - which is to monitor and observe the possibilities for the development of distributed generation and consumption of energy [7]. Communication of sensors with supervisory controllers provides an overview of the state of the grid, which aids making decisions. Distributed measurements are the only way to react appropriately to the disturbances present in the grid [8]. One of the main purposes of the communication system is providing the ability to quickly pass information about power outages. In order to be useful, the remote controller needs to the react to power outage with a proper control strategy in a short time, since the lack of control signals may result in delayed reaction from the subsystem and a prolonged period of time without power. The suitability to control remote site with this infrastructure will determine the usefulness of the system as a supervisory control for Smart Grid with islanding capability.

III. Power quality meters and generators

The energy meters used in this laboratory communicate via the Ethernet, since it is the standard communication protocol for the model used [9] SIEMENS SENTRON PAC5100 and PAC5200 [10] (the devices are equipped with an RJ45 connection socket) [11]. The protocol used to integrate with external systems is Modbus TCP [12]. Depending on the settings, getting a good view of the quality of the power often requires a transfer of large amounts of data. These devices can provide data transfer rates at a maximum level of 100 Mbit/s.

The power quality meters installed in remote subsystems communicate through an Ethernet connection with the GPRS module, which is used for wireless communication with the computer that has the function of controlling the whole system [13]. The same GPRS module communicate over the RS485 protocol with the HMI Panel of the generator controllers. RS485 protocol (also called RS-485 or EIA-485) uses differential signaling sent over the twisted pair, and using that method of communication makes this protocol resistant to electromagnetic disturbances, which could be a frequent and severe occurrence in the environment consisting of power transformers, switchgear, cables, and buses that conduct a high-value current or a large number of consumer electronics that hotel guests use [14]. RS485 provides data transfer at the level of 10 Mbit/s in short-distance applications, which is a sufficient and economically efficient solution for communication between the GPRS module and the HMI Panel.

Communication between the GPRS modules installed at the two remote sites and the supervisory control system in the laboratory needs to be wireless due to the significant distance between transmitters and receivers. The choice of GPRS communication, in addition to economical efficiency, also fulfills one of the main goals of the projects, - it provides flexibility [15]. Defined not only as the ability to modify the profile of power consumption or generation, but also as the possibility of expanding the system with other energy clusters, the GPRS standard allows adding new nodes to the grid in an easy and cost-effective way [16].

Reliable wireless communication is crucial for proper fault classification in a distributed power system [8]. High latency, packet loss, low signal-to-noise ratio can prevent efficient Smart Grid operation, even if all other system components are functioning properly. Both false negatives and false positives can result in operating the grid under non-optimal conditions or even destabilization of the whole macrogrid.

IV. Communication within the laboratory

RELflex laboratory is a separate part of the larger laboratory (as presented in 1) that contains other electrical power equipment, which, together with the devices that make up the RELflex setup, can be a source of EMC disturbances [17]. For this reason, the main communication technologies used in the laboratory needed to be resistant to electromagnetic interference. The computer, which is the supervisory control unit, is connected to the laboratory system via the Ethernet protocol. At the lowest - physical ISO/OSI layer is a twisted pair, which is an effective solution to cancel EMC disturbances

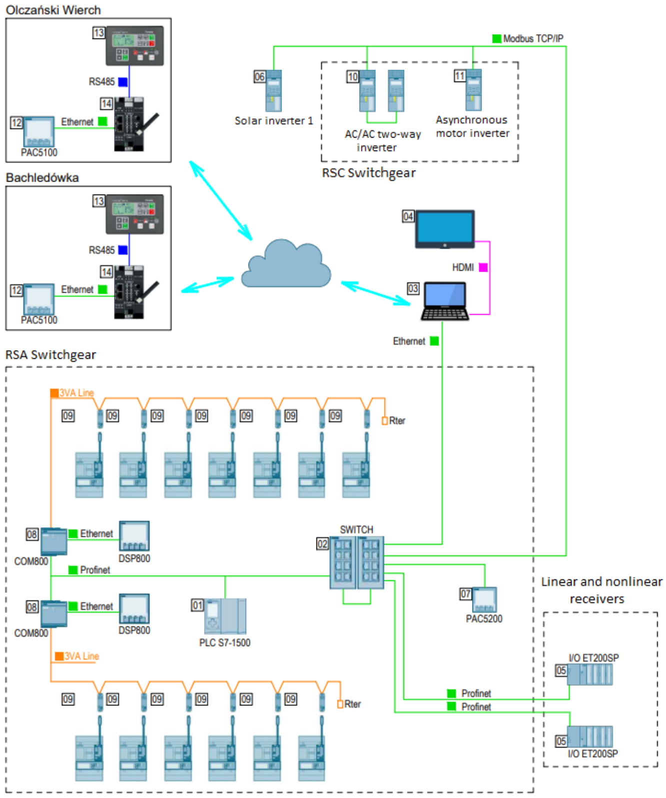

Fig. 1. System architecture

TABLE I. List of systems components

№	Model	Producer	Description
01	S7-1500	Siemens	Controller / Data gateway
02	EDS-208A-MM-SC	Moxa	Switch
03	HP Pro Book 650 G8	HP	Laptop with SCADA
04	-	-	Computer display
05	ET 200SP	Siemens	Island I/O
06	GEN24 Plus 6kW	Fronius	Solar inverter
07	PAC5200	Siemens	Power quality meter
08	COM800	Siemens	3VA switches data server
09	3VA	Siemens	Switch
10	Vacon NXI	Danfoss	AC/AC inverter
11	Vacon NXP	Danfoss	Motor inverter
12	PAC5100	Siemens	Power quality meter
13	AMF25	ComAp	Generator controller
14	AMF25	ComAp	Generator controller

occurring during transmission of the data. Ethernet was chosen as the most universal solution to this application because it offers:

- suitable data transfer rate
- backward compatibility (for a future expansion of the laboratory using newer technologies)
- possibility of integration with other protocols that are based on Ethernet and using it on the transportation levels (such as Profinet or Modbus).

Ethernet is used to connect the supervisory control unit to the subordinate control systems via a switch. Siemens Simatic S7-1500 was selected as a laboratory grid PLC controller due to the fact that it offers a rapid CPU calculation time (less than 1 ns). Short reaction times of the computing unit facilitate measurement in the laboratory because they add less time bias to the samples. The Simatic controller is responsible for controlling the linear energy receiver and the non-linear energy receiver. Communication between the PLC controller and the energy receivers is done using the Profinet protocol [18]. Profinet is also used to provide communication with Siemens data concentrators COM800, which act as a data server for series of 3VA Siemens circuit breakers. Data concentrators communicate with displays using the Ethernet protocol, which is suitable due to cost-efficiency in low-distance connections. Siemens data concentrators are used as data brokers for the lines of 3VA circuit breakers, and they are communicated using the 3VA Line industrial communication standard designed by the Siemens company. This standard was designed to facilitate the expansion of the main communication line for each additional 3VA circuit breaker added.

The system also contains three inverters:

- One-way inverter used to input the energy from photovoltaic arrays into the grid
- one-way inverter used to supply the power to the asynchronous motor, which is used as another form of load
- two separate inverters, configured in a way to be used as a two-way inverter, that are used to control power flow to and from the AC/AC converter, which is made up of a set of induction motor and induction generator.

These inverters are a part of a system that can function as both energy consumption and generation. All inverters in the laboratory power grid communicate through a single bus of the Modbus TCP/IP protocol. The main bus is connected to the switch, so that it can exchange data with supervisory controls, such as a computer or a Siemens Simatic controller.

V. Measurements Setup

The laboratory setup had to be tested to examine how well it resembles the real-life distributed power grid, as well as how dependent the emergency power supply can be. The generator controller was supplied with two signals:

- $K3$ - signal being used to turn on the generator and keep it on idle. It does not start supplying the power from the generator to the grid. It can be used to prepare the generator to take over the supply of the powered object in case power disruptions are expected or to run the generator in idle mode for diagnostics of the system and maintenance of the mechanical parts purposes.
- $K4$ - signal used to simulate a loss of voltage in one phase (phase A in the described system). This relay is used to test the detection of a lack of power supply by the emergency supply system.

The signal U_a is used as a feedback. This signal is the instantaneous value of the voltage between phase A and the ground. The sampling frequency of the voltage signal is equal to $1s$.

The route that must be traveled to deliver a signal with detection to the supervisory control and back to the PLC that governs the generator (which performs the role of an actuator in the control system) is presented in 2.

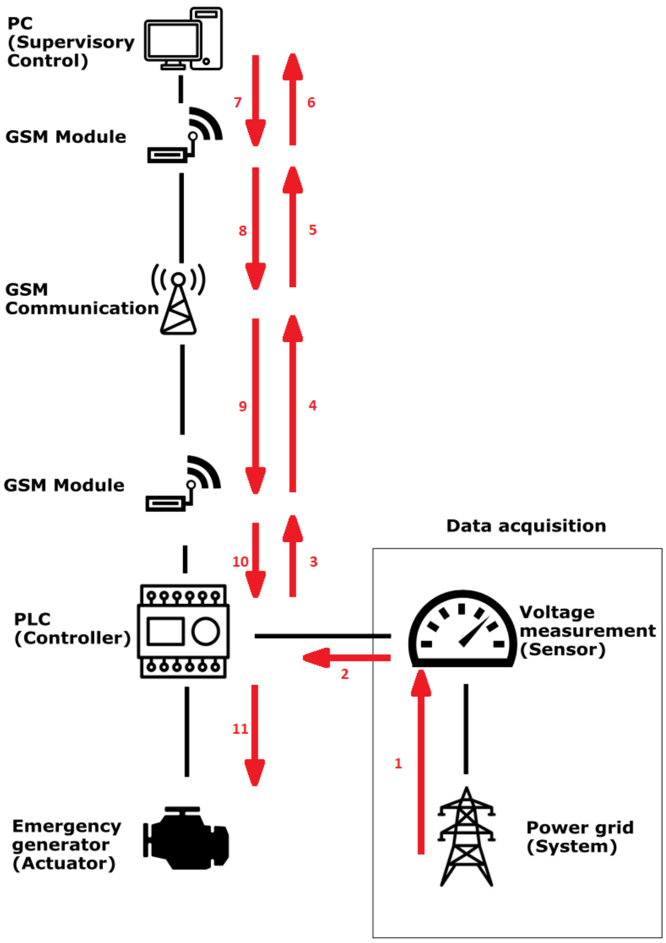

Fig. 2. Route that measured data needs to travel. The distance between supervisory control computer and remote subsystem is approximately 100km.

VI. Measurements Results

Two tests have been conducted. The objective of the tests was to determine the time between the appearance of a voltage failure in the supplying network and the achievement of the nominal voltage level of the diesel engine generator to switch the subsystem operation to island mode. The whole experiment was conducted remotely, in the laboratory 100 km from the measured grid. Two scenarios of possible operation were examined:

- Operation $K3$ ON $->$ $K4$ ON $->$ $K4$ OFF $->$ $K3$ OFF was performed to examine the scenario in which the switch to island mode from grid mode was planned and, therefore, the generator was running at the time of the voltage cut. The simulation of this event is presented on 3. Such a scenario could happen for example in a situation of a planned change to island mode (due to the purposes of utilizing cheaper energy or providing continuity of

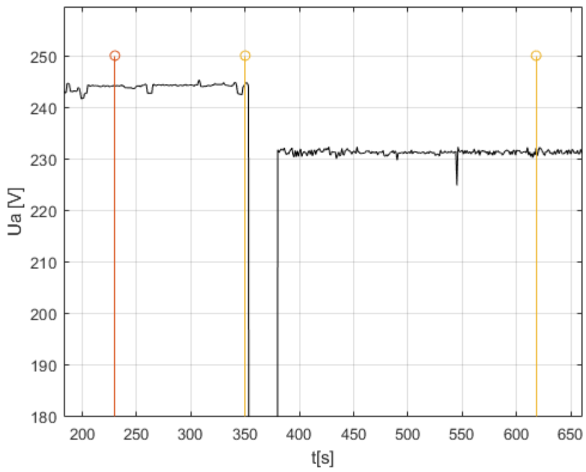

Fig. 3. Measurement of voltage in the situation of a planned switch to island mode. Switching of K3 relay is marked with orange marker and switching of K4 relay is marked with yellow marker.

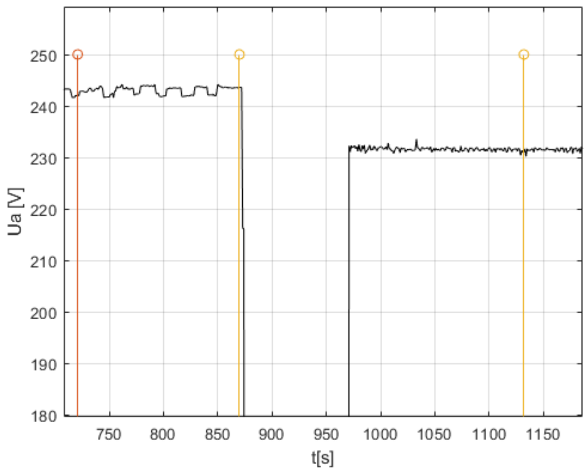

Fig. 4. Measurement of voltage in thr situation of an unplanned switch to island mode. Switching of K3 relay is marked with orange marker and switching of K4 relay is marked with yellow marker.

power supply) or in a situation where voltage disruptions can be predicted (for example, using historical data, algorithm or neural network based methods)

- Operation $K4$ ON $->$ $K4$ OFF was performed in order to examine the scenario in which the switch to island mode was not scheduled. In this scenario, the generator was stationary at the time of the occurrence of a voltage breach. The simulation of this event is presented on 4. This scenario is possible in the event of a grid failure or a lack of communication from the power supplier about the scheduled power outage.

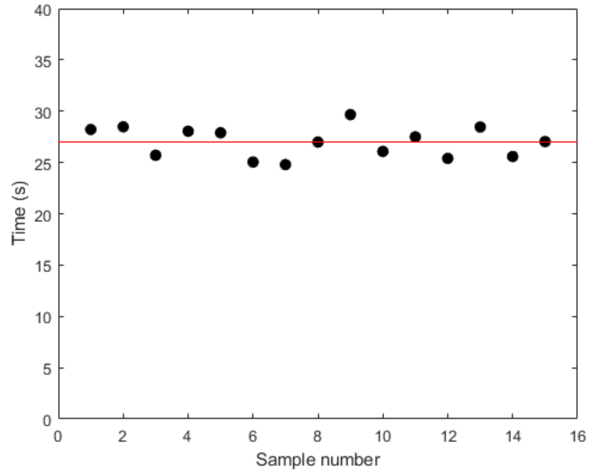

Fig. 5. Distribution of the samples in the situation of a planned switch to island mode

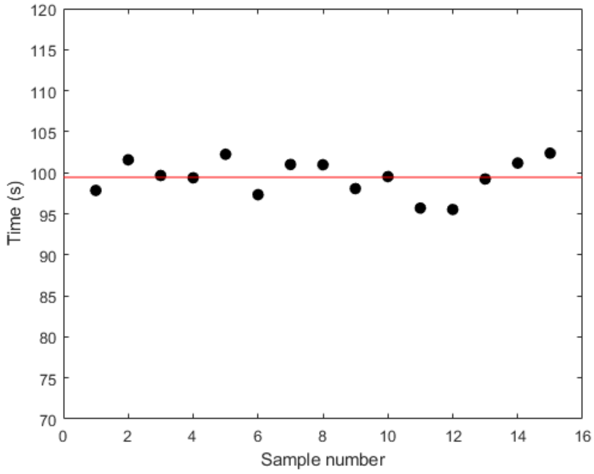

Fig. 6. Distribution of the samples in the situation of unplanned switch to island mode

VII. Discussion

The measurements have shown that the voltage was disconnected for 26.9909 seconds on average in the case where the generator runs on idle, which simulates the situation of expected islanding. In the second case, the voltage was disconnected for 99.4438 seconds on average. The voltage waveforms registered in both of these scenarios are presented in 3 and 4. Both figures show that the voltage levels are different after switching to island mode. The voltage level during connected operation is dependent on a variety of factors, such as the location of the common coupling point, the balance between supply and demand, or the transformer ratio configuration. When the microgrid is powered by a diesel generator, the voltage level depends on the configuration of the generator system. The different shape of the voltage waveform after transfer to the microgrid mode can also be observed. The cause of this change can be the fact that the generator has a smaller short-circuit power; therefore, it is not able to withstand the changing demand as well as the macrogrid. This phenomenon can be reduced by using filters, adding some kind of inertia to the system, or introducing compensation devices. It is also important to take this change in voltage quality during islanding mode into consideration during the design process in order to prepare the system to work in such conditions.

This experiment has shown that both operation modes create short voltage breaks. Short voltage breaks are defined in the EN 50160 standard [19] as a situation in which:

$U_a \leq 0.1U_n$
for:
$10ms \leq t \leq 180s$
where:
U_a - measured voltage value,
U_n - nominal voltage value,
t - duration of the event.

This type of system can be utilized for microgrids that can withstand short voltage failures [20]. If the system cannot withstand breaks of this duration, this setup could be equipped with power storage devices with faster reaction time [21], such as super capacitors or lithium ion batteries to supply the voltage for the time needed to synchronize the generator [22]. Measurements have also shown that the application of voltage disturbance prediction techniques can reduce the time needed to prepare the generator to supply the power to the system by 70% [23]. The experiment has also shown that to achieve the minimum time required for the generator to prepare to power the grid, the voltage breach must be predicted at least 72 seconds before the actual event [24] (in the case presented the precise difference between the mean values is 71.9773). Times that long cannot be acceptable for most of the systems but can be accepted in grids supplying non-critical devices or as an emergency power supply.

Measurements were carried out on the operating power grid and 15 samples were taken for both scenarios. The distribution of consecutive samples is presented in 5 and 6. The measurements carried out were invasive, since they have caused disturbance to the power grid. The 30 repetitions were negotiated with the electric utility company, so it was not possible to collect more samples.

The experiment also shows that the operator can make a decision to run the generator on idle to trade energy used to keep the motor running for the reduced downtime in the case of switching to island mode.

VIII. Summary

The full name of the RELflex project is "Renewable Energy and Load Flexibility in Industry", so the laboratory is supposed to resemble an industrial power grid with a variety of loads and power sources. Selecting appropriate communication technologies for such a setup is a challenging task, due to:

- diversity of appliances used in a grid
- reliability of measurements
- large number and different types of data being sent through the communication protocols
- reliability of the system, since it does not only serve research purposes, but the goal of this project is to also operate the subsystem in a way that could reduce costs of energy used by the business partners or amplify the profits gained from supplying energy to the grid
- geographic dispersion of the subsystems making up the system
- need to use cost-efficient solutions, to closely imitate the communication systems used in modern industry
- lack of similar systems that could be used as a model for designing the communication system
- possibility of further development of the RELflex project in the future, which calls for a communication system that will be backward compatible and easy to expand

The communication system was tested to control whether the set-up could counteract a sudden breach of voltage. Tests have shown that latency that comes from delay in signal transmission as well as the time required to start the generator (which consists of time needed to process signals received by the controller and time to start and synchronize the machine) allows effective supervision and control of the system from the laboratory 100 km away [25]. The robustness of the communication system in the power grid is crucial to the success of the project, because it not only provides a reliable way to control devices that are part of a system, but also provides high-quality measurement data transmission, so that the system can be precisely controlled using the Supervisory Control And Data Acquisition (SCADA) system [26], [27]. A good representation of the system allows operators to make adequate decisions and makes analyses of the phenomena happening in the system more credible. The variety of applied protocols is useful to conducting measurements and analyses on how to utilize certain protocols in industrial and distributed power systems. It can also provide useful information about the benefits and challenges of integrating different communication technologies.

Conducted measurements have shown that distributed systems that are based on operating independently of the macrogrid using generators must be prepared for voltage breaks during switching to microgrid operation. Designers can address this situation in advance and equip the microgrid with some intermittent power supply such as fast-reacting energy storage systems.

This paper contributes to the design of communication systems in Smart Grids, presents challenges for distributed data acquisition and control and time constraints for using diesel generator as a main energy source in the microgrid.

References

[1] B. Zhang and J. Baillieul, "Communication and control protocols for load networks in the smart grid," *IFAC Proceedings Volumes*, vol. 47, no. 3, pp. 11 250–11 256, 2014, 19th IFAC World Congress. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S147466701643404X

[2] N. Gai, K. Xue, B. Zhu, J. Yang, J. Liu, and D. He, "An efficient data aggregation scheme with local differential privacy in smart grid," *Digital Communications and Networks*, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2352864822000049

[3] M. Z. Gunduz and R. Das, "Cyber-security on smart grid: Threats and potential solutions," *Computer Networks*, vol. 169, p. 107094, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1389128619311235

[4] K. Kimani, V. Oduol, and K. Langat, "Cyber security challenges for iot-based smart grid networks," *International Journal of Critical Infrastructure Protection*, vol. 25, pp. 36–49, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1874548217301622

[5] "http://relflex.eu/about/."

[6] A. Rosini, A. Labella, A. Bonfiglio, R. Procopio, and J. M. Guerrero, "A review of reactive power sharing control techniques for islanded microgrids," *Renewable and Sustainable Energy Reviews*, vol. 141, p. 110745, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1364032121000411

[7] M. A. Judge, A. Khan, A. Manzoor, and H. A. Khattak, "Overview of smart grid implementation: Frameworks, impact, performance and challenges," *Journal of Energy Storage*, vol. 49, p. 104056, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2352152X22000950

[8] X. Xia, X. Liu, and J. Lou, "Smart substation network fault classification based on a hybrid optimization algorithm," *International Journal of Electronics and Telecommunications*, vol. 65, pp. 657–663, 2019.

[9] A. Hassan, H. N. Afrouzi, C. H. Siang, J. Ahmed, K. Mehranzamir, and C.-L. Wooi, "A survey and bibliometric analysis of different communication technologies available for smart meters," *Cleaner Engineering and Technology*, vol. 7, p. 100424, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2666790822000295

[10] "https://assets.new.siemens.com/siemens/assets/api/uuid:884edaea-4708-40cb-833d-c30e282a74f3/sentron-pac-5100-ja-5200-kasikirja.pdf."

[11] L. A. Kumar, V. Indragandhi, R. Selvamathi, V. Vijayakumar, L. Ravi, and V. Subramaniyaswamy, "Design, power quality analysis, and implementation of smart energy meter using internet of things," *Computers & Electrical Engineering*, vol. 93, p. 107203, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0045790621001993

[12] S. Mackay, E. Wright, D. Reynders, and J. Park, "7 - modbus overview," in *Practical Industrial Data Networks*, S. Mackay, E. Wright, D. Reynders, and J. Park, Eds. Oxford: Newnes, 2004, pp. 96–114. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780750658072500315

[13] I. Duncan, J. Hoy, A. Fahey, R. Morgan, S. Nakhaeizadeh, and J. French, "An investigation into the accuracy of follow-on gprs/mobile data cdrs," *Science & Justice*, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1355030622000211

[14] O. Rholam, M. Tabaa, and F. M. et Abbas Dandache, "Smart device for multi-band industrial iot communications," *Procedia Computer Science*, vol. 155, pp. 660–665, 2019, the 16th International Conference on Mobile Systems and Pervasive Computing (MobiSPC 2019),The 14th International Conference on Future Networks and Communications (FNC-2019),The 9th International Conference on Sustainable Energy Information Technology. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1877050919310105

[15] C. Rocha-Osorio, J. Solís-Chaves, I. R. Casella, C. Capovilla, J. Azcue Puma, and A. Sguarezi Filho, "Gprs/egprs standards applied to dtc of a dfig using fuzzy – pi controllers," *International Journal of Electrical Power & Energy Systems*, vol. 93, pp. 365–373, 2017. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0142061517303514

[16] R. Nale, M. Biswal, and N. Kishor, "A passive communication based islanding detection technique for ac microgrid," *International Journal of Electrical Power & Energy Systems*, vol. 137, p. 107657, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0142061521008887

[17] A. N. Akpolat, E. Dursun, and P. Siano, "Inverter-based modeling and energy efficiency analysis of off-grid hybrid power system in distributed generation," *Computers & Electrical Engineering*, vol. 96, p. 107476, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0045790621004316

[18] P. Ferrari, A. Flammini, and S. Vitturi, "Performance analysis of profinet networks," *Computer Standards & Interfaces*, vol. 28, no. 4, pp. 369–385, 2006. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0920548905000528

[19] "En 50160:2010 voltage characteristics of electrity supplied by public electricity networks."

[20] R. M. Kamel, "Distributed generators as reactive power providers and their impacts on standalone micro-grid performance during both symmetrical and unsymmetrical faults," *Renewable Energy Focus*, vol. 35, pp. 159–170, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1755008420300545

[21] R. V. A. Neves, E. J. Agnoletto, G. B. Reis, R. Q. Machado, and V. A. Oliveira, "Analysis of the maximum available time to switch the operation control mode of a distributed generation during an islanding occurrence," in *2015 IEEE Eindhoven PowerTech*, 2015, pp. 1–5.

[22] H. Xianlai, D. Yunlong, and L. Zhiguo, "Strategy of ac-isolated island detecting and control mode switching over in zhoushan project," in *13th IET International Conference on AC and DC Power Transmission (ACDC 2017)*, 2017, pp. 1–6.

[23] Y. Chen, "Voltages prediction algorithm based on lstm recurrent neural network," *Optik*, vol. 220, p. 164869, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0030402620307051

[24] J.-H. Menke, N. Bornhorst, and M. Braun, "Distribution system monitoring for smart power grids with distributed generation using artificial neural networks," *International Journal of Electrical Power & Energy Systems*, vol. 113, pp. 472–480, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0142061518320805

[25] M. W. Khan, M. Zeeshan, A. Farid, and M. Usman, "Qos-aware traffic scheduling framework in cognitive radio based smart grids using multi-objective optimization of latency and throughput," *Ad Hoc Networks*, vol. 97, p. 102020, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1570870519304937

[26] A. Jolfaei and K. Kant, "A lightweight integrity protection scheme for low latency smart grid applications," *Computers & Security*, vol. 86, pp. 471–483, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S016740481831126X

[27] O. Selinger-Lutz, R. Brandalik, I. Katz, and R. Hollinger, "Insights from a field test implementation of a robust smart grid concept based on ripple control," *Sustainable Energy, Grids and Networks*, vol. 18, p. 100210, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2352467718303308