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IoT Monitoring System for Applications with Renewable Energy Generation and Electric Drives

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Abstract. Internet of Things IoT developed for monitoring, control, and management of sectors such as Smart Cities, Energy, Environment, Transport, Manufacture, Industrial Automation, Maritime, Healthcare, Education, etc, by interconnecting devices over internet. New sectors emerged in renewable energy systems, industrial motion drives, sensors and actuators. This article presents the design, and development of specific IoT applications for wind energy generating units, and electric drives. IoT technologies in the control systems of electric machines, mainly in applications of motor drives, and wind energy generating systems, contribute to improved monitoring, and management of performance, and to possible savings of energy. The experimental configurations upgrade laboratory infrastructure and offer new teaching and research perspectives to engineering education.

Keywords. Internet of Things, Renewable Energy Generation, Electric Motion Systems, Remote Control, Sensors.

1. Introduction

The Internet of Things IoT developed as a network of interconnected smart physical objects, from different systems, with machine-to-machine communication, remote human monitoring, and control. IoT inter-connects devices in the physical and digital world such as buildings, installations, vehicles, equipment, etc. Components are embedded with electronics, sensors, actuators, and software, which enable the collection, storage, retrieval, analysis, process, and exchange of data. *Cloud computing* analyzes and stores the data acquired from smart devices using interlinked servers, databases and software, in *cloud platforms*, which shares resources, provides access, and offers disk storage.

Research in the field of the Internet of Things IoT is continuously developing and reported in publications, from different disciplines, such as computer science, internet, communications, automated control, sensing, monitoring, and actuation, [1]. By creating access and interaction with devices, such as home appliances, surveillance cameras, monitoring systems, sensors, actuators, displays, and other, the concept of *smart cities* lead to the development of applications that use the big amount, and diversity of data generated by the above devices, and provides new services to citizens, companies and public administrations, [2].

Industrial applications with IoT in smart grids of energy systems, such as renewables wind and solar power stations, became parts of the *Industrial Internet of Things IIoT*. The role of *IIoT* in energy sector is monitoring, managing equipment, and installations, that mainly contain electric generators, and electric motors, and in renewable power generation units, such as wind, and solar, [3]- [4].

Bibliography introduces potentials of IoT integration with Wind Energy Conversion Systems WECS and examines the advances of technologies that enable WECS for *Internet of Energy IoE*. Challenges and new requirements of future WECS such as networking, control, safety, security, sustainability, and social parameters are reported in [5]-[6].

The price of electricity depends on energy load demand, fuel costs and equipment limitations, [7]-[8]. Smart grids contribute to decrease the peak demands, and minimizes energy costs. Specifically, in wind energy generating units, the role of IIoT refers to efficiency improvement, and real-time decision making by subsystems monitoring, prevention, and recovery of failures, thus improving the overall knowledge and performance, [9] - [12]:

- WECS transmit sensor data to control center and IIoT.
- Data are recorded and analyzed, for economic dispatch optimization, early discovery of maintenance needs, system warnings, and failures resolving.

- Using data, technicians perform efficiently the maintenance, or recovery from failure.
- Data are sent to IIoT, stored for future use, and made available to other smart grids, or other wind parks.

Globally, the interconnection of many wind and solar power plants with the *Internet of Renewable Energy IoRE* lowers maintenance and operating costs. Tasks of detecting failures of all kind of electrical machines were previously studied, [12]-[14].

2. Development of Energy Engineering Education with IoT

To face the challenges of the technologies discussed above, the existing infrastructure of educational laboratory must upgrade with a view to include new technologies in experiments, [15]-[17]. Sometimes, experience and knowledge of emerging technologies and in particular with Industry 4.0 and IoT is jointly developed by industries, and universities. Universities exploit their relationships with industry to extend the theoretical basis on which these technologies evolved and are applied in practice, [17]-[18].

IoT entered in the field of electrical machines and automation of drive systems. The control system of induction machine, if connected to IoT, avoids the wire-bound scheme and sends and receive commands using the internet. In such cases, sensors are required to generate feedback data for IoT-based control, [19].

We carried out extensive research in the area of educational programs of study, development of new curricula, and web-based education. We supervised many thesis in our Laboratory of Electric Drives, [20]-[22], with selected subjects from areas of control of electric drives, maglev fast speed trains, electrical transport, stepping motors, servomotors controls, programmable logic controllers, electrical generators for renewable energy wind and solar, ocean offshore for wind energy plants, smart electrical installations in buildings, autonomous buildings with solar energy for touristic or farming, fault analysis and diagnostics, double output induction machine in wind generation units, technical-economical evaluation, engineering education, etc. Recently, control systems with microcontrollers, such as PLCs, Arduino, Raspberry PI, with developed software, or with connection to IoT, [23]-[24]. We published many outstanding papers in scientific journals and conferences, [24]-[33].

This paper presents the development of our laboratory IoT based system for electrical machines and analyses two specific applications: control of electric drives motion, and control of wind energy generation system. Our aims are: a) to update and re-engineer the existing laboratory equipment and, b) to provide students with applied up-to-date knowledge on control systems with IoT.

3. Experimental Configurations Studied

In the following, we present the two experimental configurations of systems with IoT technology developed in our Laboratory of Electric Drives.

The dual operation, of induction machine as motor, or as generator, uses almost the same basic equipment, [25]-[26]. To obtain the two different operational states, the system must change the initial conditions, reverse the electromechanical energy conversion, and reverse the flow of electric energy between power networks, the drive system and loads, [27]-[28]. The motor-generator set can be of ac-dc type, or ac-ac type.

Based on our previous research and development, [24], [26], [32]-[33], the two experimental configurations are:

1. The control of one 3-phase induction motor over Internet, using one inverter, the microprocessors Arduino and Raspberry Pi, an SQL Database and web application on *Azure Cloud Platform*. The induction motor is connected to the mechanical load, which can be a dc generator, which supplies an electric load. Figure 1 shows the block diagram of the experimental configuration 1.
2. The 3-phase double output induction generator DOIG is driven by an external prime mover, such as one wind turbine, which is simulated by the 3-phase induction motor. The DOIG generates 3-phase ac voltage, that supplies a network. In Figure 2 is shown the diagram of the experimental configuration 2.

The design and implementation of experiments in laboratory need the following equipment, and operability:

A. The power generation & drive systems

- Electric Machine 1 – induction motor IM
- Electric Machine 2 – dc generator
- Electric Machine 3 – double output induction generator DOIG
- Rectifier-Inverter 1 - Three-phase rectifier-inverter with digital control, including keyboard, controller and programming.
- Rectifier 2 – ac-dc for the excitation of dc generator.
- Rectifier-Inverter 2 - Single-phase or three-phase rectifier, for the excitation of DOIG.
- Electric Loads.
- Three-phase transformer.

B. Networks

- A Wi-Fi internet connection
- An internet platform for hosting the web-application (Azure)
- One three-phase power network
- A second three-phase power network.

C. Data Acquisition, & Visualization

- Optical Encoder-Sensor for measuring the angular velocity of the shaft. Is connected to Arduino 1 Microcontroller.
- (between power & drive part, and digital & electronic & control part, for safety reasons) for voltage, current, power, and power factor measurements, which are connected to Arduino 2,
- Sensors, A/D and D/A converters
- Measuring Instruments for voltages, currents, speed.

D. The Control System

- A Raspberry Pi RPI small Single-Board Computer SBC, which is used as the local server. It is connected to the Inverter 1 controlling the IM, and, to inverter 2 for excitation of DOIG. Simultaneously, is collecting data sent from sensors through Arduinos.

- Software developed for the IoT control of the induction machines, IM and DOIG.
- Web application on Azure Cloud that communicates with local server for remote control of the system, while storing and processing data from sensors

E. User Interface

- Supervisory Computer, or laptop, or mobile devices, with access to Internet, and with the control's web page.

4. The IoT Control System

For the Experimental System 1, the control of IM is accomplished remotely over Internet through the supervisory computer (Raspberry Pi RPI microcomputer) by the link with Inverter 1. The Inverter 1 is equipped with the *Modbus serial communications protocol,* which is the way of connecting industrial electronic devices, [34]. The microprocessor RPI works as computer, and, by connecting it to a monitor, keyboard, and mouse, undertakes the role of *the server* for the control system. Using an USB to RS485 adapter, the Rectifier-Inverter 1 connects to the RPI. The connection is opened and controlled in *asp.net environment* by a *Mod-bus protocol* library. The code that controls the Inverter 1 (which drives the IM) is written in language C#.

The Rectifier-Inverter 1 is connected to the Network 1 of three-phase voltage 380V/50Hz, converts it to dc voltage, and then to ac variable-voltage-variable-frequency. Then, the Inverter 1 drives the IM and controls its speed by varying the frequency. The IM connects to the mechanical load, and drives a dc generator. Rectifier 2 supplies the excitation voltage to dc generator and the produced energy is supplied to an electric load.

The programmed functions are commands of the driving system: *Status, Start, Set Required Frequency, Send Frequency to system, Stop, Reverse, Emergency Stop, Reset Inverter, Read Real Frequency from the system*. Inverter 1 is driven from the Supervisory Computer, or from Laptop 1, or from any smart phones, with internet connection, using the *motor-control webpage*. The structure of the communication between the supervisory computer and Inverter 1 is *Master-Slave*, where the computer has the role of *Master,* which drives the Inverter 1 (*Slave*).

Transmitted messages are composed by an engine class that can be customized for any inverter. All engine classes implement a common engine interface with the prementioned predefined operations. The interface is accessed by an *asp.net web application controller, which* listens the requests from the *motor-control web page*. The motor-control web page can be accessed using the IP address of experiments.

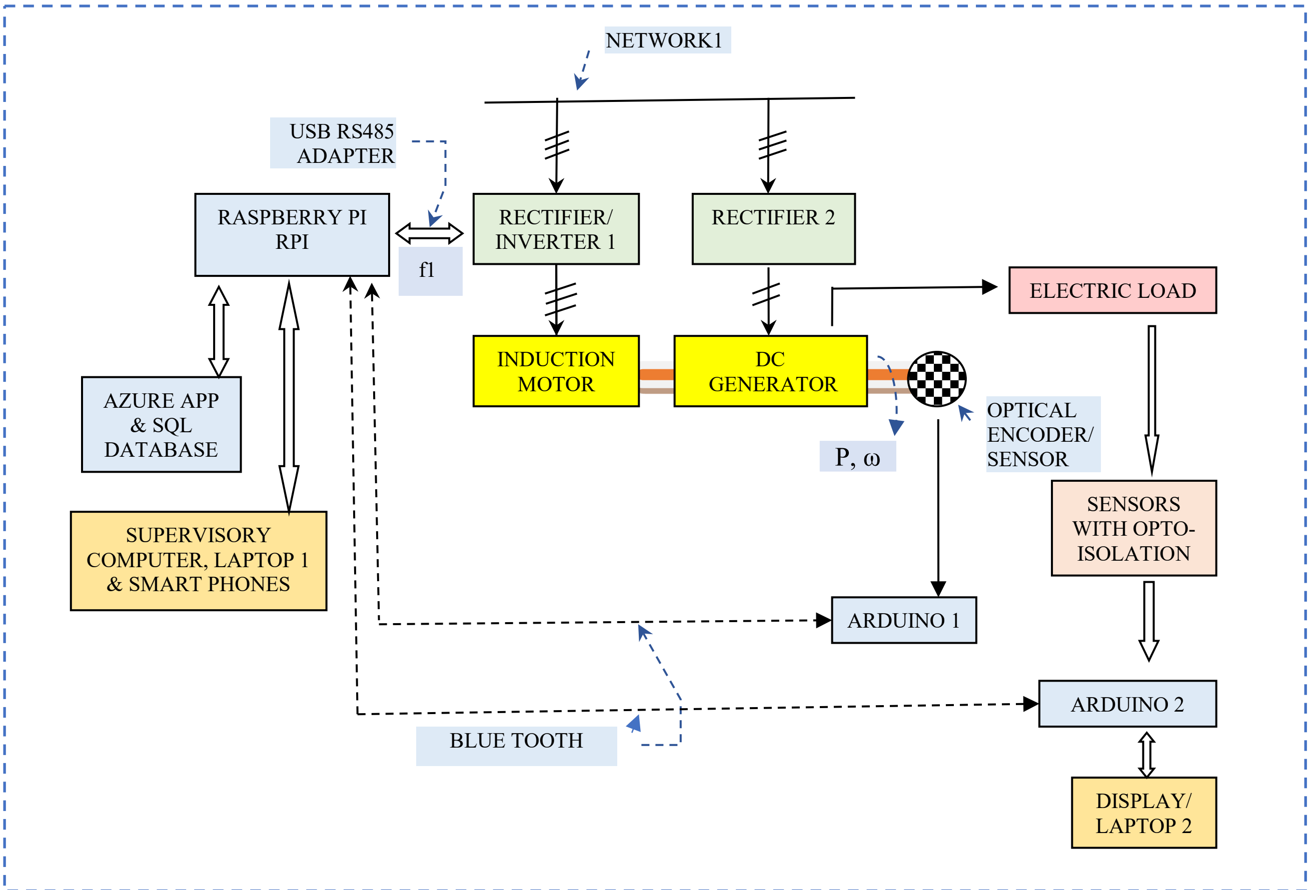

Fig.1. Experimental system for the control over Internet of 3-phase induction motor driving a dc motor.

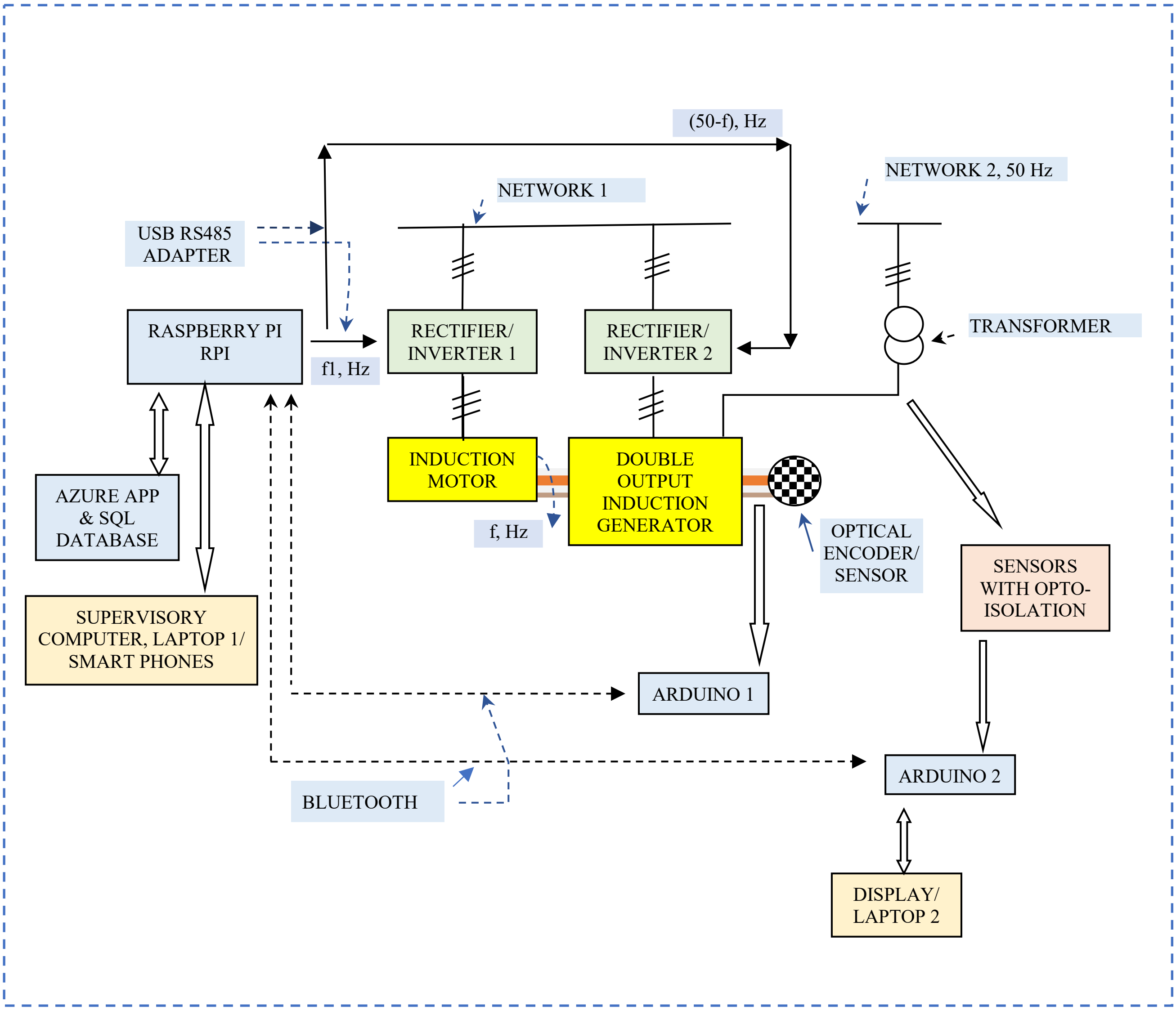

Fig.2. Experimental system for the control over Internet of 3-phase induction motor driving a double output induction generator

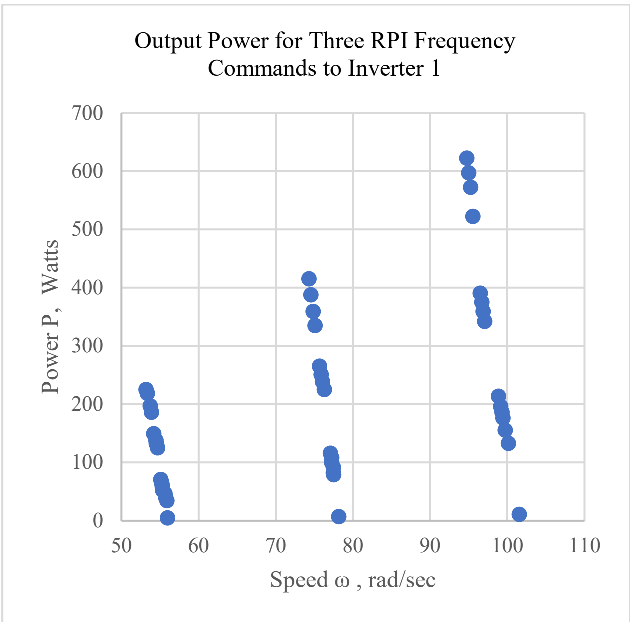

Fig. 3. Measured output power, for three frequency commands generated by RPI for Inverter 1: 35 Hz subsynchronous, 50 Hz synchronous, and 65 Hz supersynchronous,

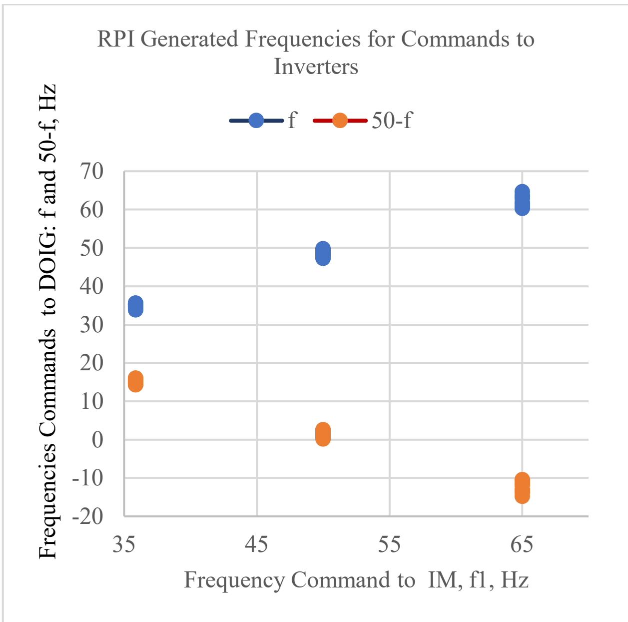

Fig. 4. The frequency commands generated by RPI for Inverter 1 and Inverter 2.

The connection and monitoring of the *optical encoder-sensor* to the remote system are implemented with Arduino 1 microcontroller. All measurements and data are acquired electronically and stored to the *SQL Database* located in *Azure Cloud Platform*. The *Optical Encoder,* or the *speed sensor*, is directly connected to Arduino 1 microcontroller, which transmits the measurement data through *Bluetooth connection* with the RPI, which in turn with a Java script calls an *Application Programming Interface API* of the web Application on *Azure* and uploads the data in the SQL database. Microcontroller Arduino 2 implements data acquisition from: True RMS Current Hall Sensor, and True RMS Voltage Measurement Sensors (optically isolated)~~,~~ electric load, and it displays data, and transmits data to RPI using blue-tooth connection, [21]. Fig. 3 presents the measured output power for three frequency commands generated by RPI for Inverter 1: 35 Hz subsynchronous, 50 Hz synchronous, and 65 Hz supersynchronous,

For the implementation of Experimental System 2, we replaced the dc generator by an induction generator of wound rotor type, and thus, introduced a double output induction generator DOIG. Inverter 2 supplies the slip frequency of the excitation voltage at the rotor windings of DOIG. From the stator side, the DOIG generates three-phase voltage, which supplies the *Network 2,* and can be connected to any electric loads. The Network 2 can be considered as autonomous grid, [29]-[31].

In this configuration, the RPI must generate commands for two frequencies of two inverters: $f1$ for Inverter 1 which drives the IM, and $(50\text{-}f)$ for Inverter 2 for DOIG. The necessary condition is that the frequency f corresponding to the rotational speed of the rotor, $f=(1\text{-}s)\cdot f1$, where s is the slip of IM, plus the frequency $(50\text{-}f)$ set to Inverter 2, equals to 50 Hz, which is the frequency of Network 2. In Fig. 4 the frequency commands generated by RPI for Inverter 1 and Inverter 2, are presented. In Figures 5.1-5.2 are shown some details of the experimental equipment.

5. Conclusions

We presented the design and implementation of two experimental configurations with IoT, for electric drive motion and for wind energy generating units. In our experimental systems, the IoT remotely connects the power generation and drive units, to the microprocessors and controls. The obtained added-value involves data acquisition from sensors, data analysis, device interconnectivity, and decisions for controlling and monitoring with microcomputers, hardware and software, all integrated in a remote-control system.

The laboratory upgraded with IoT connected devices, sensors, software, and intelligent algorithms, opens new research perspectives, with smart devices, computers, microcontrollers, power supplies and IoT in motion-controlled systems, and in wind generation of electric energy. Having developed the IoT infrastructure, the laboratory offers an environment for teaching and research, in design, implement and test smart industrial applications with IM and smart wind power systems with DOIG.

Taking into consideration the results obtained so far, there are significant benefits: new topics for programs of study, with new laboratory experiments, better educated electrical engineers for the jobs in modern technologies, needed by enterprises.

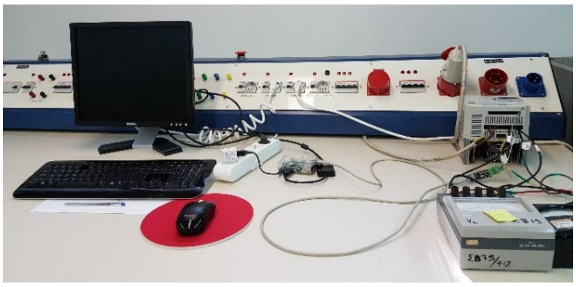

Fig 5.1. Experimental System: Microcomputer, inverter, measuring instrumentation, network.

Fig 5.2. Experimental System: Induction Motor, DC generator, Rectifier, optical encoder, speed sensor, and measuring instrumentation.

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References

[1] A.Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols and Applications", *IEEE Communications Surveys & Tutorials,* (2015), Vol. 17, pp. 2347–2376, doi: 10.1109/COMST.2015. 2444095

[2] S. A Papazis, and M. G Ioannides, "Emerging Smart Technologies for Sustainable Energy and Internet of Things", in Editors J. Gęsikowska, A. Mreła, "Technical Civilization. 21st Century Society Technology", (2019), KPSW Pub., Poland, pp. 75-84, ISBN 978-83-65744-06-7.

[3] K. Williams, and A. Qouneh, "Internet of Things: Solar array tracker", 2017 IEEE 60th International Midwest Symp. Circuits and Systems MWSCAS, (2017), Boston, MA, USA. doi: 10.1109/MWSCAS.2017. 8053109.

[4] M. Moness, and A. M. Moustafa, "A Survey of Cyber-Physical Advances and Challenges of Wind Energy Conversion Systems: Prospects for Internet of Energy", *IEEE Internet of Things Journal,* (2016), Vol. 3, pp 134–145, doi: 10.1109/JIOT. 2015. 2478381

[5] M. G. Ioannides, R. Tuduce, P.-D. Cristea, and S. A. Papazis, "Wind power generating systems based on double output induction machine: Considerations about control techniques", IWSSIP'2013 20th Int. Conf. on Systems, Signals and Image Processing, (2013), Bucharest, IEEE, doi: 10.1109/IWSSIP.2013.6623460, 2013, pp: 103–107.

[6] F. O. Igbinovia and J. Krupka, "The Prospect of the Internet of Renewable Energy (IoRE) in Electricity Networks," *2019 IEEE International Symposium on Technology and Society*

(ISTAS), Medford, MA, USA, (2019), pp. 1-6, doi: 10.1109/ISTAS48451.2019.8937918.

[7] S. A. Papazis and G. C. Bakos, "Generalized model of economic dispatch optimization as an educational tool for management of energy systems", Advances in Electrical and Computer Engineering, (2021), vol. 21, issue 2, pp. 1-10, ISSN: 1582-7445, e-ISSN: 1844-7600.

[8] S. A. Papazis, M. G. Ioannides, and P. N. Fotilas, "An information system for the multiple criteria assessment of renewable energy power plants", Wind Engineering Journal, SAGE Pub, (2000), vol.24, No.2, pp.81-99, https://doi.org/10.1260/0309524001495468.

[9] N. H. Motlagh, M. Mohammadrezaei, J. Hunt, and B. Zakeri, "Internet of Things (IoT) and the Energy Sector", Energies, (2020), Vol. 13, 494, pp. 1-27, doi: 10.3390/en13020494

[10] L. Faria, A. Silva, Z. Vale, and A. Marques, "Training Control Centers' Operators in Incident Diagnosis and Power Restoration Using Intelligent Tutoring Systems", IEEE Transactions on Learning Technologies, (2009), Vol. 2, pp. 135–147, doi 10.1109/ TLT.2009.16.

[11] A. Lopez-Martin, J. M. Algueta, and I. R. Matías, **"**Energy harvesting approaches in IoT scenarios with very low ambient energy**"**, Renewable Energy and Power Quality Journal RE&PQJ, (2019), Vol. 17, pp. 183-187, https://doi.org/10.24084/repqj17.257.

[12] O. A. Syggeridou, and M. G. Ioannides, "Induction motors' faults detection and diagnosis by using Dedicated Software", Journal of Materials Processing Technology, (2007), Vol. 181, Issues 1–3, pp. 313-317, doi.org/10.1016/j.jmatprotec.2006.03.041 .

[13] J. L. F. Victor, S. C. S. Jucá, R. I. S. Pereira, P. C. M. Carvalho, and L. M. Fernández-Ramírez, "IoT Monitoring systems applied to photovoltaic generation: The relevance for increasing decentralized plants", Renewable Energy and Power Quality J. RE&PQJ, (2019), Vol. 17, pp. 536-545, https://doi.org/10.24084/ repqj17.368.

[14] M. G. Ioannides, and S. A. Papazis, "Potentials of Utilization of Renewable Energy Sources in Remote Areas: Cases of Rivers' Deltas", The 22nd Scientific Symposium Deltas and Wetlands, (2013), A33, pp. 226, ISBN 978-973-88117-5-1.

[15] R. Klaassen, P. de Vries, M. G. Ioannides, and S. A. Papazis, "Tipping your toe in the 'Emerging Technologies' pond from an educational point of view", Proc. 45th SEFI Conf. Education Excellence for Sustainability, Azores, Portugal, (2017), pp. 1190-1198, ISBN 978-989-98875-7-2.

[16] P. J. Papadopoulos, and S. A. Papazis, "An Assessment of Modern Web-Based Education Tools and Technologies", Proc. 2nd Int. Conf. on Interdisciplinarity in Education ICIE 2006, (2006), Athens, Greece, pp.170-171, ISBN 960-89028-2-7, ISSN 1790-661X.

[17] M. G. Ioannides, and S. A. Papazis, "Teaching and research in emerging electrical energy engineering education", Int. Conf. on Applied and Theoretical Electricity ICATE 2021, (2021), IEEE Conf. Pub., pp. 1-5.

[18] M. G. Ioannides, and S. A. Papazis, "Development of New Curricula in Vocational Education for the Needs of Enterprises and Employability of Graduates", Proc 15th Int. Conf. Information Technology Based Higher Education and Training ITHET 2016, (2016), Istanbul, Turkey, IEEE Conf. Pub., Pp: 1–5, doi: 10.1109/ITHET.2016.7760753.

[19] A. P. Stamelos, A. Papoutsidakis, V. Vikentios, S. A. Papazis, and M. G. Ioannides, "Experimental Educational System of AC Electric Drives with Internet of Things", XXIII International Conference on Electrical Machines ICEM 2018, Alexandroupoli, Greece, (2018), pp. 1497-1502, doi: 10.1109/ ICELMACH.2018.8506991.

[20] M. G. Ioannides, "Thesis supervised", retrieved (2018) http://artemis.cslab.ece.ntua.gr:8080/jspui/handle/123456789/9119

[21] V. Vikentios, "Design and implementation of a scheme for remote measurement with IoT technology with microcomputers Arduino and Raspberry Pi", (2018), Diploma Thesis, NTUA.

[22] M. Zavou, "Remote control of induction motor via internet using microprocessors Arduino & RPI", (2017), Diploma Thesis, NTUA, http://artemis.cslab.ece.ntua.gr:8080/jspui/handle/ 123456789/13627/.

[23] A. P. Stamelos "Development of software application for multiple database connections", (2015), Diploma Thesis, NTUA, doi:10.13140/RG.2.1.3136.*7520,* http://artemis-new.cslab.ece.ntua.gr:8080/jspui/handle/123456789/12714

[24] M. G. Ioannides, S. A. Papazis, and F. G. Ioannidou, "Implementation of scalar control scheme for variable frequency induction motor actuator system", Sensors and Actuators A: Physical, (2003), Vol. 106, Issues 1–3, pp. 306-309, doi.org/10.1016/S0924-4247(03)00191-2.

[25] M. G. Ioannides, "Doubly fed induction machine state variables model and dynamic response," IEEE Transactions on Energy Conversion, (1991), vol. 6, no. 1, pp. 55-61, doi: 10.1109/60.73789.

[26] M. G. Ioannides, "Design and implementation of PLC-based monitoring control system for induction motor", IEEE Transactions on Energy Conversion, (2004), Vol. 19, No 3, pp. 469-476, doi: 10.1109/TEC.2003.822303.

[27] S. A. Papazis, M. G. Ioannides, and M. Cernat, "Investigation of wind turbines in power generation system based on double output induction generator", Proc. 4th Int. Conf. on Interdisciplinarity in Education ICIE'09: New Emerging Disciplines: Renewable Energy**,** Environment, Life Sciences, (2009), Vilnius, Lithuania, pp. 284-290, ISBN 978-960-89028-8-6.

[28] M. G. Ioannides: "State space formulation and transient stability of the double output asynchronous generator", IEEE Transactions on Energy Conversion, (1993), Vol. 8, No. 4, pp. 732-738, doi:10.1109/60.260988.

[29] M. G. Ioannides, "A new approach for the prediction and identification of generated harmonics by induction generators in transient state," IEEE Transactions on Energy Conversion, (1995), vol. 10, no. 1, pp. 118-125, doi: 10.1109/60.372576.

[30] P. D. Ladakakos, M. G. Ioannides, and M. I. Koulouvari, "Assessment of wind turbines impact on the power quality of autonomous weak grids", Proc. 8th Int. Conf. Harmonics and Quality of Power ICHQP, (1998), Athens, Vol. 2, pp. 900-905, doi: 10.1109/ICHQP.1998.760162.

[31] P. D. Ladakakos, and M. G. Ioannides, "Estimation of wind parameter variation effect on the power quality of hybrid weak grids", Wind Engineering, SAGE Pub., (1999), Vol. 23, No. 6, pp. 353-364

[32] P. G. Vernados, I. M. Katiniotis, M. G. Ioannides, "Development of an experimental investigation procedure on double fed electric machine-based actuator for wind power systems," Sensors and Actuators A: Physical, (2003), Vol. 106, Issue 1-3, pp. 302-305, doi:10.1016/S0924-4247(03)00190-0.

[33] I. M. Katiniotis, M. G. Ioannides, and P. G. Vernados, "Operation of induction generator in the magnetic saturation region as a self-excited and as a double output system", Journal Materials Processing Technology, (2005), vol 161, iss 1-2, pp. 263-268, doi: 10.1016/j.jmatprotec.2004.07.034.

[34] O. Hersent, D. Boswarthick, and O. Elloumi, "ModBus," in "The Internet of Things: Key Applications and Protocols", Wiley, (2012), pp. 79-82, doi 10.1002/9781119958352.ch5.