Application of Power Plant 4.0: Process Digitalization and Challenges

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Abstract

Most power plant process control concern on optimizing the power generation, reduce unplanned shutdown and reduce inventory cost. These challenges can be solved by implementing newly technology called Industry 4.0, which integrates the industrial internet of things (IIoT) and the cyber physical systems (CPS) as well as cloud computing. This paper presents a prototype system loop as an example of the power generation network to measure the rotating speed, number of turn and the frequency of vibration for the rotating device, humidity & temperature of the physical cooler or heater device within the plant in order to explain the interoperability principle of Industry 4.0 through the implementation of Power Plant 4.0. Base on the test results then used as a basis for identifying the challenges that will arise and the solution to implement Power Plant 4.0 with effectively and efficiently.

Keywords: Power Plant 4.0, industrial internet of things, SCADA, Industry 4.0

Abstrak

Fokus utama dalam proses kontrol yang ada di pembangkit listrik adalah bagaimana mengoptimasi proses pembangkitan listrik, mengurangi pemadaman yang tidak direncanakan, dan mengurangi biaya inventori. Tantangan-tantangan tersebut dapat diatasi dengan menerapkan teknologi baru yang disebut Industri 4.0, yaitu teknologi yang mengintegrasikan *industrial internet of thing* (IIoT), *cyber physical systems* dan *cloud computing*. Makalah ini menyajikan sebuah prototipe contoh sistem *close-loop* untuk mengukur kecepatan putar, jumlah putaran dan frekuensi getaran untuk *rotating equipments* pembangkit serta mengukur kelembaban dan suhu pada mesin *heat exchanger* dalam rangka untuk menjelaskan prinsip interoperabilitas Industri 4.0 melalui penerapan *Power Plant 4.0*. Dari hasil pengujian kemudian dijadikan dasar untuk mengidentifikasi tantangan-tantangan yang akan muncul dan solusinya untuk mengimplementaskan *Power Plant 4.0* secara efektif dan efisien.

Kata kunci: *Power Plant 4.0, industrial internet of things, SCADA, Industry 4.0*

1. Introduction

The initiative of digitalization integrates the internet of things (IoT) and the internet of peoples (IoP) as well as the cyber-enhanced systems and cloud computing. This integration has originated in Germany to advocate the full automation of manufacturing processes to make the quick accessibility of the system control and enhance the system to be faster [1-2]. Industry 4.0 new revolution in the industrial process, globalize and integrated the digital technology features and provide the design principles to facilitate the mutation of smart system to the high level of information technology operation through CPS, IIoT, machine-to-machine (M2M) communication, cloud computing and big data analytics. The design principle such as interoperability, virtualization, decentralization, real-time capability, service orientation and modularity [3] allow the supervisor control unit of power generator to investigate the potential transformation of Power Plant 4.0 technologies.

The interoperability has been selected to be discussed in this paper for designing the prototype of power generation network and theoretical review of challenges and principles to sustain the design simulation. Meanwhile, the interoperability is a key success for smart process and a factor of power network communication between CPS resources (workpiece carriers, assembly station, pumps and machine) of various installed station as well as the components, machines and people to be able to communicate through IIoT within the power plant.

Industry 4.0 present the execution systems within the connected blocks which are embedded systems with advanced connectivity and decentralized control. The system resources are mounted in which it provides the easy access of collecting and exchanging real-time data for identifying, locating, monitoring, tracking and optimizing the processes at any workstation [4]. Furthermore, the connected system still needs the protocol depending on the specific operation of the physical resource in order to achieve the optimization and operational purpose of the system. Different operational technologies resource has been established such as Supervisory Control and Data Acquisition (SCADA), Manufacturing Execution Systems (MES), PLCs, meters, valves, sensors, actuators motors and machines etc.

The implementation of Industry 4.0 principles into the process presents the different faults revealed to be committed into the business models and process models as long as the industrial digitalization reacting the needs required to implement the design principles of Industry 4.0 and its strategies to adopt the whole plant process. The traditional and previous models are forgotten instead of being considered for integration [6]. The various requirement features have been discussed for Industry 4.0 to face those challenges presented during this paradigm shift as an example of “interoperability”, which reveal the barriers between human and smart power plant communication. The digitalization based on interoperability lessen to more networked workstation inside the plant and the outside connection system, i.e. the grid and customers associates, standardize the system platforms, protocols to make it to the fundamental requirement [7] of the process within a closed loop system. This paper uses the interoperability principle of Industry 4.0 to adopt the SCADA for process automation while dealing with the feasibility of Power Plant 4.0.

2. Methodology

2.1 System Network with SCADA

The digitalization of Power Plant 4.0 process in this paper is the SCADA to encompass the network automation which needs robust for certain application process within a plant and at long range network without requiring high speed of computing. The paper is also discussing the other two types of automation in the digitalized network which are:

- Distributed control system (DCS): An automation process to assist SCADA for high computing power divided into two classes a) *Essential automation* which will be used for prototyping a closed loop system presented in this paper. The essential automation helps by providing the small and medium-sized operation process in a looped system which is scalable. b) *Extended automation* is the second class of DCS which may help for modularity principle requirement i.e. the communication outside the loop and integrate the supervisory control via camera control, telecommunication control, and power supply controls in and outside the plant [2].
- Programmable Logic Controls (PLC): The type of automation which used for measurement devices installed in the plant. This research identify the PLC used for prototyping a closed loop system as shown in Table 1, which are Arduino Uno R3 Kit, wires and Firebase Database a cloud-hosted NoSQL database that lets the prototyped system store and sync data between Supervisory Terminal Control (STC) with other remaining terminal (Figure 2) in real-time process [2].

Table 1: Prototype assembly list with its function.

No	Device label	Type	Properties functions/specification
1	MOTOR1	28BYJ-48 Stepper Motor	Solenoid motor
2	Part1	Arduino Uno (Rev3)	Type Arduino UNO (Rev3)
3	R1	Rotary potentiometer	Track Linear; type Rotary Shaft Potentiometer; maximum resistance 100kΩ; size Rotary - 9mm; package THT
4	R2	Photocell (LDR)	Resistance @ dark 300 kOhms @ 10 seconds; package THT, resistance @ luminance 16 kOhms @ 10 lux
5	R3	220Ω Resistor	Bands 4; tolerance ±5%; pin spacing 400 mil
6	RHT1	Humidity and temperature sensor	Power supply 3.3-5.5V DC; Polymer humidity capacitor
7	Login	NodeMCU V3.0	The chip ESP8266 chip with 4MB of flash memory
8	ULN2003A	ULN2003A - Stepper Driver Board	Pins 11; chip label ULN2003A - Stepper Driver Board; spacing 300mil; variant 2; package breakout board
9	LM393, e-radionica.com	LM393 vibration sensor breakout	Detect the vibrations, using the built-in comparator [13]

The paper uses the DCS and PLC to adopt the SCADA requirement for process automation and IIoT within the plant. The SCADA monitor the Android App which developed using the Android studio Interface Development

Environment (IDE), and Android Software Development Kit (SDK). This App has a user interface (UI) easy for reliable attributes for the STC to handle data input and output display within the system. The Arduino Uno R3 is programmed using the Arduino Software IDE, a microcontroller of the potentiometer sensors to calculate the rotation speed of solenoid and its revolution per minute (RPM). The Fritzing software is used for breadboard circuit diagram design, circuit schematic and Printed Circuit Boards (PCB) layout design of the prototype.

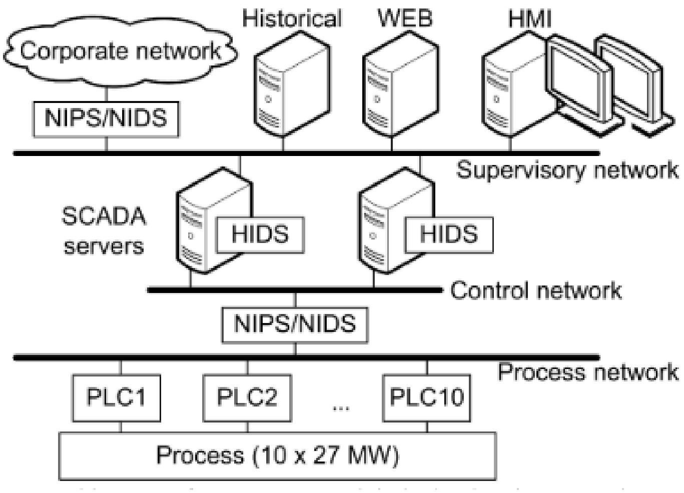

Figure 2: A SCADA network example in a hydroelectric power plant [8]

2.2 Example Design of Prototype System Network

The prototype design method includes the data transfer cycle within the SCADA loop from the physical resources to the supervisory control terminal Figure 3, where the parameters inside the system constitute four elements within the power plant. These parameters include a) temperature and b) humidity for Turbine, Boiler and for the other warming/heating devices, c) rotation motion for the rotating device, and d) frequency in the form of analogue data from the travelling devices. Figure.4 explain the IIoT in power plant communication network while implementing the smart power generation for SCADA. The networked system includes all the requirement and the needs of the service at the workstation for data transfer within the power plant. The cycle loop shows the interaction network from the DCS to the PLC within a vice versa. The DCS explain the supervisory control unit for smart matters and measurement, smart control workstation which integrate the requirement of CPS and the principles of interoperability for Power Plant 4.0.

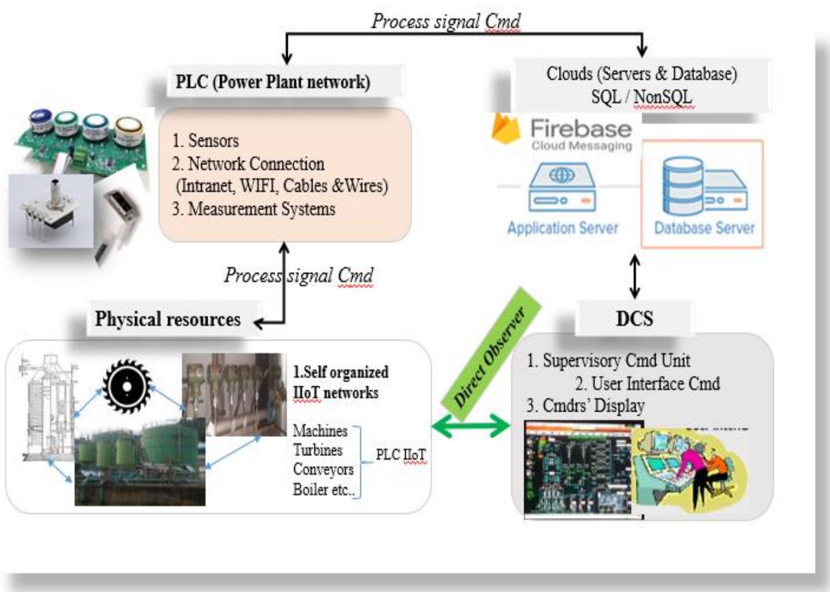

Figure 3: Framework of the smart power generation network.

The DCS may be extended for the smart consumers' needs while deliberating the modularity of real-time capability of the process signal input and output as the feedback response command from the physical resources such as turbines, boilers, valves, actuators etc. The physical resources act as the self-organized IIoT within the network in order to respond to the Command signal of the power plant network. These physical resources are optimized when it is used based upon the specification and required function from the PLC and at the workstation.

Furthermore, the PLC devices used in the Power Plant 4.0 may act as the ears or eyes of the signal measurement control signal upon on the actuation physical devices such as motors, drives and/ or other programmable device for control systems which act as the brain and the nervous system of the whole plant [2]. The direct observers is required for this simulation outside the PLC and clouds resources for quick evaluation of the framework metrics include big data analytics measures, Inter Message Time (IMT), Time To Failure (TTF), Inter Reconnection Time (IRT), Number of Reconnections (NR), Number of Lost Messages (NLM), Number of Congestions (NC), Mean Inter Message Time (MIMT) and Percentage of Lost Messages (PLM) as it has recommended for the direct observation function [9].

The neural network on a distributed network present different characteristic based on the designer of the network, the capability efficient to conduct within the system and the function of the system [10]. The Power Plant 4.0 is a projected trend for smart power generation where the plant elements have to communicate each other with a neural servo or neural network and corporate the human behavior in an online fashion through the use of IIoT protocols.

The network loop system designed includes different device sensors (Table 2) with various functions. The loop presents the following characters features to ease the interoperability principle within the Power Plant 4.0 or the smart power generation.

- Data transfer and analytics
- Minimal loss in data connection
- Resources capability and performance
- Extensibilities and scalability
- Data security and authentication

The network installation and design require high MM level where the management has to state the functionality of the physical resources and role at the workstation.

The network should be designed to ease the sophistication of the network from the data collection of the power generation control to the store station i.e. server/database. The previous research recommends that the network has to be designed to allow the expansion of the service delivery at the workstation means interoperability features and the growth of the safety and the effective comparative including reliable analytic and system capabilities of the physical data resources M2M. Moreover, the network should incorporate additional data types and sources with the inclusion of specific software standards [10] for data analytics. As an example, the prototyped system designed require the Arduino IDE sources for writing the code and upload it to the system board while the Fritzing software provides the simulation of the PCB and ease the testing of the electronics material composed the system.

3. Result and Discussion

3.1 The Digitalization of Power Plant

The digitalization of the power plant pre-requires the condition-based monitoring which gives the functionality of the prototype designed network. The elements assembled has the ability to control the data include temperature and humidity of the physical resource (Table 1) through the DHT22 sensor, the frequency of vibration with a vibration sensor module and rotational velocity for the rotating physical device (Figure 4). The designed system shows the management behaviors in the digital transformation of utilities by detailing the function and role of the machine at the workstation. The digital transformation helps the power plant companies to improve the efficiency of power generation and distribution of electricity to the customers and in the distributed grid [1]. Although this principle may present the modularity features of Industry 4.0 where the interaction between the plant and the consumers is facilitated by providing more capabilities to the service benchmarking of the plant and choices around their energy use within the Power Plant 4.0.

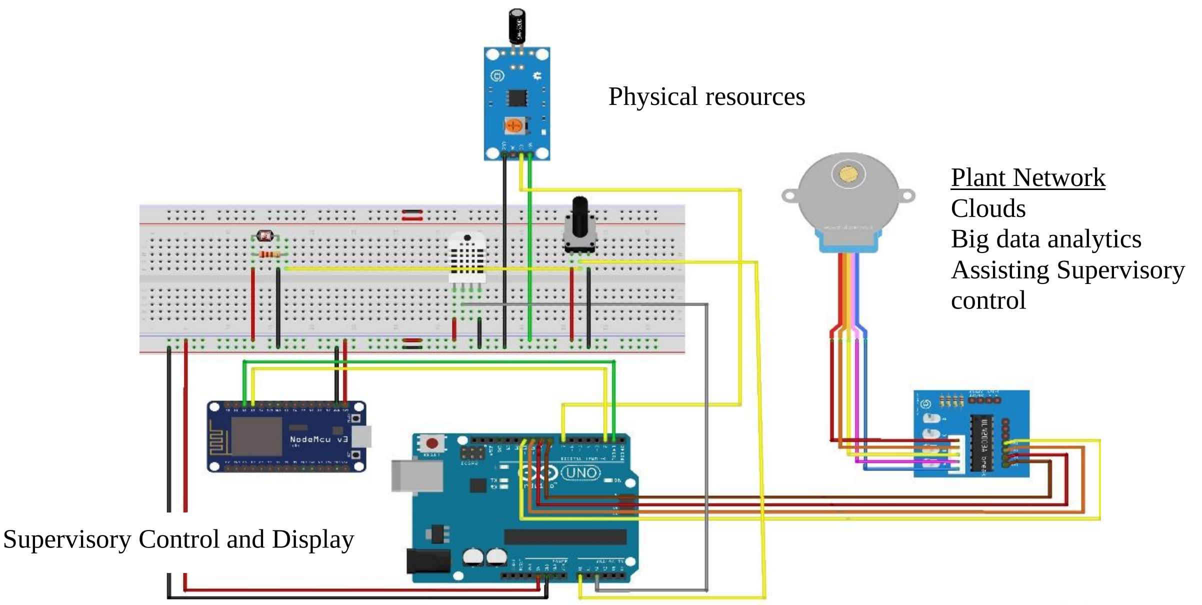

Figure 4: Schematic network graph of the prototype.

Figure 4 summarize any example of the data transfer across the multi-agent system control from different resources and shifting supervisory control. However, as a framework of the Agent-based Intelligent Distributed Control System (AIDCS) [14-15] the prototype incorporates the Android platform, (Figure 5) and cloud platform with firebase database for data analytics, transfer and share with different terminals in a closed loop system. Previous few researchers found that the use of the mobile devices, especially Personal Digital Assistants (PDAs) and/or with the embedded technology or the Web technology [15-16] may improve the modularity feature of Industry 4.0.

An example was presented for condition-based maintenance which requires the specification of Computerized Maintenance Management Systems to control the intake system of power plant maintenance but it does not provide prognostics or diagnosis of high data analytics accuracy, i.e. the analytics of the data interact with the remote sensing and the clouds terminals [12]. As the result, the system should present the capability to interact through the application of advanced Artificial Intelligence (AI) approaches [11] and the required data monitoring sensors with high level control to protect the deadlocks in the power generation network [12].

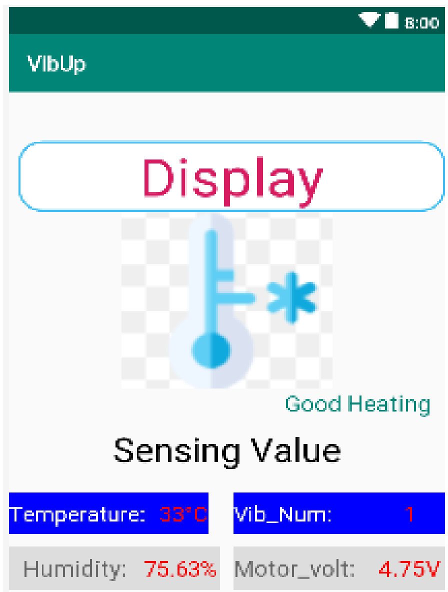

Figure 5: User interface displace of sensed data.

3.2 Challenges

Industry 4.0 digitalization faces various challenges which should be overcome while implementing the digitalization of the Power Plant 4.0 for smart power generation. The evaluation of framework metrics for big data analytics, said PLC devices are the major area providing a different kind of failure. Throughout the design of the prototype, the similar following challenges have been faced as it has been shown in the previous researches.

- The lack of situational awareness of the abnormal events for data acquisition in order to ensure the continued access of the operators in real time [5].
- Network sophistication to the upstage of supervisory knowledge which requires enough access to the high level within maturity model (Industry 4.0-MM). The challenge obliges the management to set period training of the users and the programmer to ensure the feasible update of the features to the closed-loop system of SCADA.
- The continuously collected data and the unattended data to identify the leaks and the bottlenecks of the operation, it is attacked by deadlocks in the neural networks which steadily overlook M2M communication conditions and it gives the guarantee of the process regularity [14].
- Data security and authentication are one of the biggest challenges for industries while implementing CPS of Industry 4.0 and it is also faced during modularity principles in order to keep the response time competitive in the horizontal value chain and at the market with customers' needs and while moving to the good-quality of services delivery.
- The industry 4.0 still faces the lack of implementation in the Small Medium Enterprises (SMEs) as their processes are not well-organized and the cyber-physical system devices require high connectivity between all the processes within the system [15].

The digitalization of Power Plant 4.0 should not only be stopped on the SCADA challenges through the power generation control; it should also optimize other areas inside and outside the plant such as logistics, customer service, management, human resources by using the specific standard software (3S) and data analysis through the shifting to the Power Plant 4.0.

4. Conclusion

The digitalization of the system is optimized with the implementation of multi-sensor systems for data collection and data analytics to achieve the decision taking within the SCADA. The system design ensures the traceability of the components along the entire horizontal value chain composed the closed loop system. The data transfer from the CPS and the server/database has the minimum response time ≈10ms while the prototyped system capable to collect the humidity between ≈ 0 % to 100 %, the temperature between ≈ - 40°C to 125 °C with a resolution of 0.10 °C and the potential value through the recording pin from the potentiometer analogue read from 0 up to 1023 proportional to the amount of voltage ≈ 5V being applied to the pin connected for reading.

References

[1] Owens B. The digital energy transformation. GE Power. 2018.
[2] ABB. How Digitalization addresses sugar production challenges. Vol. 1, 2018.
[3] Hermann M, Pentek T, and Otto B.: Design principles for industrie 4.0 scenarios: A literature review. Working Paper No. 01/2015.
[4] Rojko A.: Industry 4.0 concept: Background and overview. Int J Interact Mob Technol. 11 (5): 77-90. 2017.
[5] Modelec. Make Your OT, IT, IIoT protocol interoperability easier for Industry 4.0. 2018 [cited 2019 Apr 2].
[6] Lang M.: From Industry 4.0 to energy 4.0: Future business, models and legal relations.2016.
[7] Ibarra D, Ganzarain J, and Igartua JI.: Business model innovation through Industry 4.0: A review. Procedia Manuf. 22, 4–10, 2018.
[8] Markovic-Petrovic JD, and Stojanovic MD.: An improved risk assessment method for SCADA information security. Elektron ir Elektrotechnika. 20 (7):69–72. 2014.
[9] Dondossola G, Garrone F, and Szanto J.: Cyber risk assessment of power control systems - A metrics weighed by attack experiments. IEEE Power Energy Soc Gen Meet.: 1-9. 2011.
[10] Brown J, Holmes J, Maro J, et al.: Design specifications for network prototype and cooperative to conductive population-based studies and safety surveillance. Eff Heal Care Res Rep. 13:1–62. 2009.
[11] Efthymiou K, Papakostas N, Mourtzis D, et al.: On a predictive maintenance platform for production systems. Procedia CIRP 3: 221–226. 2012.
[12] Munyensanga P, Widyanto SA, Aziz MNA, et al.: Information management to improve the effectiveness of preventive maintenance activities with the computerized maintenance management system at the intake system of the circulating water pump. Procedia CIRP 78:289-94. 2018.

[13] e-radionica.com. Vibration sensor with LM393. 2019 [cited 2019 May 2].
[14] Viek T. LSTM neural network for industry 4.0 condition-based monitoring. Towards Data Science. 2018 [cited 2019 May 2].
[15] CLR Global. Main challenges of industry 4.0 today. CLR Global website. 2018 [cited 2019 May 2].