IoT-Based SCADA System Design and Generation Forecasting for Hydropower Station

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Abstract—**This paper points out controlling to the generator of power station, collecting the required information of the station, analyzing the communication metrics of the SCADA system and predicting the electricity production without hydrological events based on the historical data under the IoT-based SCADA system. SCADA system based on the IoT is the modernization of the SCADA system for hydropower station to get the required information and to conduct the power station for balancing with the national grid in a timely manner. This system supports the varieties of the information of the station such as alarm system, data monitoring and control system, data logging and generated capacity, and so on. Moreover, the performance of the IoT-based SCADA system such as communication metrics is analyzed by using the data packet analyzer and WiFi analyzer. In addition, historical data (generated electricity) is used to analyze and detect the circumstance of the production of hydropower stations and to predict the production for coming year by using the time series analysis. In this research, the actual historical data of the Yeywa hydropower station which is collected by on-ground recording is used for statistical analysis of generated capacity.**

Index Terms—**SCADA, IoT, data packet analyzer, WiFi analyzer, historical data analysis, time series analysis**

I. Introduction

SCADA is an abbreviation of "Supervisory Control and Data Acquisition" system. The SCADA system has been widely used for a variety of sectors such as water supply system, home automation system, industrial control system, electricity distribution system, power generation system, and so on [1]-[6]. Human Machine Interface (HMI) has already used as an industrial realistic monitoring system for power stations [7]. Nowadays, most of the industrial controls and automation systems use IoT (Internet of Things) devices to monitor and control system via the internet everywhere instead of HMI [8]-[11].

SCADA monitoring and control system was implemented based on the ZigBee wireless communication protocol and NI LabVIEW interface [12]. The automatic SCADA monitoring system was designed by using RS-485 serial communication interface and Labview VISA program and then it analyzed the power on the AC load line [13]. These SCADA systems carried out the monitoring and control system that can be applied to the operators at the same locations in the station. Thus, only the SCADA system is an impossible benchmark automatic control and monitoring system to inspect and collect the real-time information from a longer distance location. When the SCADA system combines with IoT technology, it will grow up as a modernized SCADA system.

In this research, IoT-based SCADA system design is proposed for hydropower stations to collect the acquired data and control the generator of the power station. The main objective of IoT-based SCADA systems is to design the user interface, to find out up-to-date station information and to conduct the power station on any location with the internet access [14].

The IoT-based SCADA system is composed of Master Terminal Unit (MTU) and Remote Terminal Unit (RTU) over the wireless network and its performance is a very important factor that is the data transmission and receiving process. Network traffic was analyzed and monitored by the users via the internet by using the packet sniffer method such as Wireshark tool [15]. SCADA system would go down because of the data traffic bottleneck that is due to malware threats and attacks. Therefore, data traffic is analyzed by using the Wireshark to test the SCADA network's situation [16]. The signal strength of the wireless network is appraised by network performance tools: InSSIDer, Acrylic Wi-Fi, Xirrus, Netspot [17].

In this research, the performance of the IoT-based SCADA system is measured and tested by using the Wireshark data packet analyzer and then the location of the RTU from Internet Service Provider (ISP) is regarded by using the Netspot WiFi analyzer [18].

The performance of the hydropower station can be analyzed over the historical data received from the SCADA system. The production of the hydropower station is predicted by using the time series model: ARIMA in Ecuador [19]. Most authors analyzed the electricity consumption and smart technology provided not only to get the load consumption profiles but also to conduct the electricity load demand, and smart meters were used to obtain electricity consumption profiles which are the main role to balance the power purchase and power sales portfolio of developers [20]-[23].

Estimated power consumption is a huge risk for the trader because the impact of its error is directly proportional to the gain and loss as well as the forecast of

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electricity production is also directly proportional to the industrial projects of the developing countries. Therefore, the state of the hydropower station is crucial to know the station information. In this research, IoT-based SCADA system assists to know the station's information, to control the generator of the power station, to analyze and check the performance of the power station and finally to predict the power station load optimization with least square line regression method of time series analysis.

The rest of the paper is organized as follows. Section II mentions the methodology of the proposed system. Section III presents the experimental results. Section IV highlights the statistical analysis of generated electricity results. Finally, the conclusion section is described in section V.

II. Methodology

The demonstration of hardware and software implementation of IoT-based SCADA system endeavors to find out the historical data and to control the hydropower station on any location via the mobile wireless network between the Remote Terminal Unit (RTU) and Master Terminal Unit (MTU) with the help of various electronic sensors. Fig. 1 gives an idea for the implementation of an IoT-based SCADA system to control and monitor for a hydropower station.

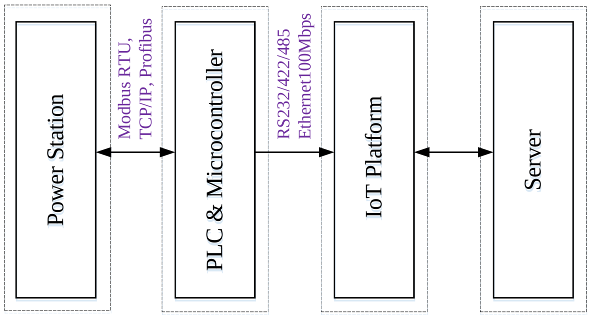


Fig. 1. SCADA system block diagram.

There are four levels in this system: lower level, middle level, communication equipment and upper level (see Fig. 1). The lower level is the power station which is composed of various measuring transducers, electro-mechanical devices such as generators, transformers and so on. The middle level is the controller devices such as programmable logic controller and microcontroller to control the various electronic devices for the operation process of hydropower station. The upper level is the client or server which is also a file server to store and manage the data files for operating computers on the same network. One of the main parts of the SCADA system is communication equipment. In this research, IoT device was used to be the modernized SCADA System called IoT-based SCADA systems [14].

A. Hardware Implementation

The design of hardware implementation for IoT-based SCADA system for hydropower station is composed of main electronic devices: ESP WiFi Module, AT Mega Arduino controller, programmable logic controller and varieties of sensors concerning the hydropower station as shown in Fig. 2. The MTU, RTU, and PLC stand for Master Terminal Unit, Remote Terminal Unit, and Programmable Logic Controller respectively. The real time clock (RTC) was utilized in microcontroller unit. ESP WiFi Module is an extremely cost-effective self-contained SoC with combined TCP/ IP protocol stack to get the WiFi network on any microcontroller.

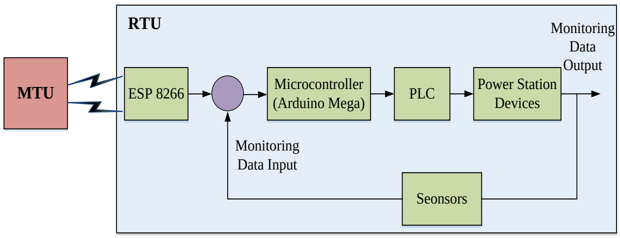


Fig. 2. IoT-based SCADA system design for hydropower station

A single-chip microcontroller, AT Mega 328 microcontroller is an Advance Virtual RISC (AVR) microcontroller. It is used in various projects and autonomous systems. Programmable Logic Controller (PLC) is an industrial digital computer that uses programmable memory to save the instructions and specific functions for on/ off statements to carry out the control system for various machines. In hydropower stations, PLC is mostly used for the control system of start/ stop generator, excitation system, synchronization system, water supply system, firefighting system and so on [24].

TABLE I: Main Information of Hydropower Station

No.	Collection Data	For objective items
1	Active power (W)	Power line, transformers and generators
2	Current (A)	
3	Voltage (V)	
4	Frequency (Hz)	
5	Power factor	
6	Temperature (°C)	Transformers, thrust bearing, upper guide bearing, lower guide bearing, turbine guide bearing, stator coil
7	Pressure (Pa)	Water Inlet (Penstock), water outlet (draft tube)
8	Water Level (m)	Upstream and downstream
9	Vibration (m/s^2)	Rotor
10	Flow of water (m/s^2)	Cooling water system for all bearing, shaft seal

PZEM 016 AC communication module and many sensors concerning the hydropower stations are used for collecting information on it. In this research, PZEM module is the main role to acquire the electricity data such as Active Power (W), Current (A), Voltage (V), Frequency (Hz), Power Factor. These data are primary for the transformer, generator and power distribution bus bar of the hydropower station. Temperature sensors will be used to know the heat state of transformers, all of the bearings (Thrust, Upper Guide, Lower Guide, and Turbine Guide), stator coil and generator of hydropower plant.

Pressure sensor is important for water inlet and outlet of hydropower (Penstock & Draft Tube).

Moreover, a water level sensor is used for getting information of head water (upstream) and tail water (downstream) situation. Vibration sensor is also needed to measure the condition of the rotor at a hydropower plant. Table I shows the essential data for hydropower plants with respect to the main parts.

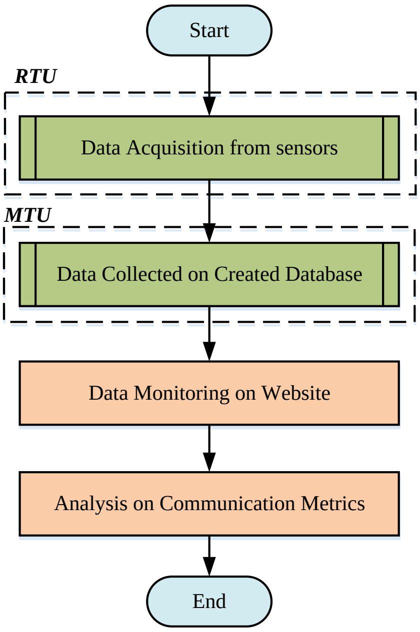


Fig. 3. Flowchart of performance analysis for IoT-based SCADA system.

B. Software Implementation

The management of control systems for hydropower plants is to be accomplished by replacing assured measuring equipment on behalf of human operators in network architecture. In this research, Industrial Internet of thing (IoT) devices are mainly used for SCADA systems on hydropower plants to communicate across the different electronic devices for data acquiring from sensors and controlling to electronic equipment by using the HTTP (Hypertext Transfer Protocol) protocols. ESP 8266 Node MCU WiFi module which is used as IoT device and microcontroller (Arduino Mega) device are used for SCADA system by uploading with the arduino language code. Programmable Logic Controllers (PLC) are used for controlling processes such as status of the generator, transformer, water supply system, gate opening and closing system, excitation system and synchronization system at the hydropower plants. Graphical programming language called ladder diagram logic software is developed on PLC devices for controlling process. SCADA system is a set of hardware and software combinations to collect the required data and control the process under the commands from and towards the process. The major purpose of the SCADA system is the automatic control system under the commands, the ensuring dialogue between the human (operator) and machine (investigation system), creating the database and network architecture for monitoring system and alarming system to the operator in up-to-date data losing process [25].

IoT-based SCADA system is composed of Remote Terminal Unit (RTU) and Master Terminal Unit (MTU). In this research, a microcontroller is used to find out the desired information and control the power station with the relevant sensors applied for the RTU system. For MTU systems, Mysql databases are constructed to accumulate the data in the back-end for hydropower stations. To review the back-end data, a website is created by employing a hypertext preprocessor (php) scripting language. Wireless network analyzer which is known as Wireshark software is used to analyze the performance of IoT-based SCADA System. Moreover, WiFi analyzer that is also known as Net spot software can be used to regard the location of RTU in a hydropower station. Fig. 3 shows the flowchart of communication metrics analysis for this system.

C. Network Architecture

SCADA System can also be known as a centralized control system and is implemented by two main systems: MTU and RTU which are composed of HMI, I/O devices, controllers, networking, software, and so on. In most industries, distributed network protocol (DNP) is used to acquire the data and it is contrived as an open, interoperable and simple protocol for IoT-based SCADA control systems. Master/ Slave polling methods are used to transmit and receive data, and RS-232, RS-422, RS-485 and optical fiber are designed as the physical layer. However, Distributed Network Protocol (DNP) is used as the universal de facto standard in SCADA factories for data acquisition and control systems. DNP only supports application layer, data link layer and physical layer and is based on the enchanted protocol architecture (EPA) for telecontrol applications to hold up the enhanced function such as message bigger than normal frame length of Remote Technical Unit (RTU).

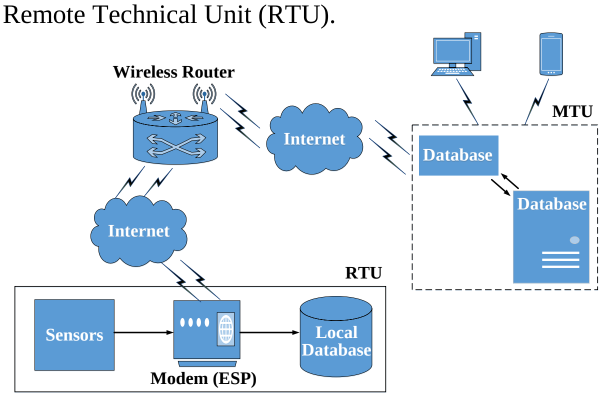


Fig. 4. Network topology of SCADA system.

In the IoT-based SCADA System, communication technology is indispensable to rapidly drive force in this system. For the Master Terminal Unit (MTU), LAN (Local Area Network) technology is a key component to support highly reliable and faster transfer speed for response time. The data transfer speed of LAN is about 10Mbps to 100Mbps. For Remote Terminal Unit (RTU), wireless networks such as spread spectrum satellite and fiber optics and meteor trial ionization technology have already been used as a non-vendor specific open standard interfacing to Master Terminal Unit [26].

In this research, to analyze the performance of IoT-based SCADA system and to implement the IoT-based SCADA System, wireless router is used as a communication interface and ESP 8266 Node (WiFi module) is used for data transfer devices to send and receive the required data between the users (operators) and Remote Terminal Unit (RTUs) of the station as shown in Fig. 4, [18].

III. Experimental Results

The IoT-based SCADA system is efficient and capable of monitoring and controlling power stations in real time operation mode. Industrial 4.0 standards IoT devices (ESP 8266 Node MCU WiFi Module) are used to transmit and receive data anywhere for monitoring systems of hydropower stations. Moreover, microcontrollers and PLC are used for control systems (on/ off state) of hydropower stations from IoT cloud to power station. Hardware implementation of IoT-based SCADA system is shown in Fig. 5 and the monitoring system on IoT cloud platform is shown in Fig. 6 that illustrates the system successfully controlled with the control panel on the monitoring window of SCADA system of hydropower station in real situation.

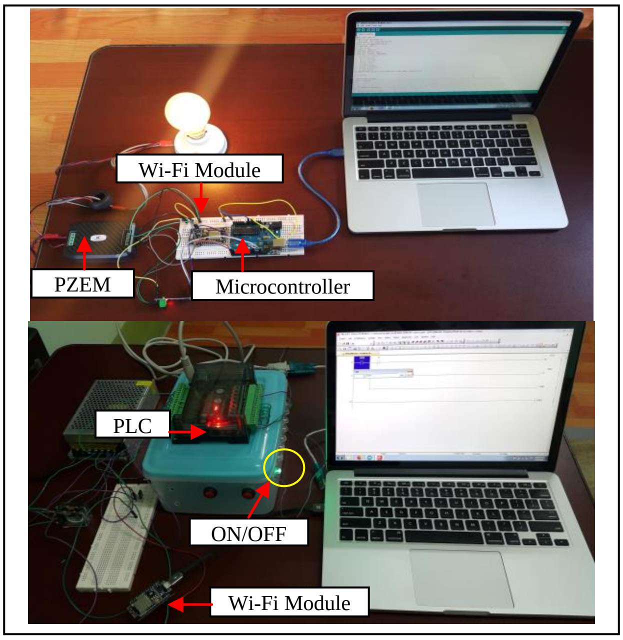


Fig. 5. Hardware implementation of SCADA system.

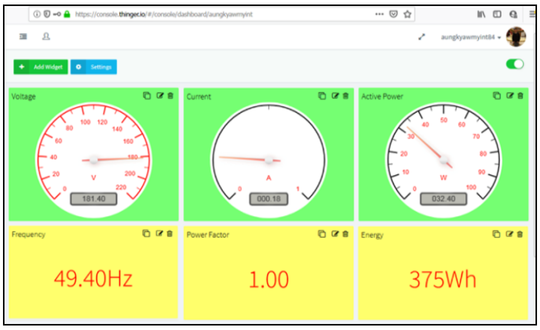


Fig. 6. Energy data for monitoring system using IoT platform.

And then, the performance of hardware implementation can be checked by the accuracy rate between experimental results and calculated results from power equation ($P=VI$). The tolerance between the value of real collected data from Modbus and calculated value is ±3% on this hardware implementation. The performance of the tolerance result is expressed in Table II and Fig. 7.

In this testimony, the tolerance is ±3%; hence, the accuracy rate is very good for hardware implementation of IoT-based SCADA systems [14].

TABLE II: CALCULATED DATA FOR POWER ACCURACY RATE

Time	Volt-age	Cur-ent	Power from Modbus	Calcu-lated Power	Power Ratio	Tole-rance
6:00:00	186.5	0.17	32.5	31.7	98%	2%
6:04:00	183.6	0.17	31.7	31.2	98%	2%
6:08:00	181.8	0.17	31.3	30.9	99%	1%
6:12:00	188.8	0.17	33.1	32.1	97%	3%
6:16:00	189.7	0.18	33.4	34.1	102%	-2%
6:20:00	191.2	0.18	33.8	34.4	102%	-2%
6:24:00	186.4	0.17	32.6	31.7	97%	3%
6:28:00	188.3	0.18	33.1	33.9	102%	-2%
6:32:00	189.7	0.18	33.5	34.1	102%	-2%
6:36:00	188.1	0.18	33.1	33.9	102%	-2%
6:40:00	193.9	0.18	34.6	34.9	101%	-1%
6:44:00	191.6	0.18	34.0	34.5	101%	-1%
6:48:00	194.9	0.18	35.0	35.1	100%	0%
6:52:00	202.6	0.18	37.0	36.5	99%	1%
6:56:00	200.3	0.18	36.4	36.1	99%	1%
7:00:00	200.2	0.18	36.4	36.0	99%	1%

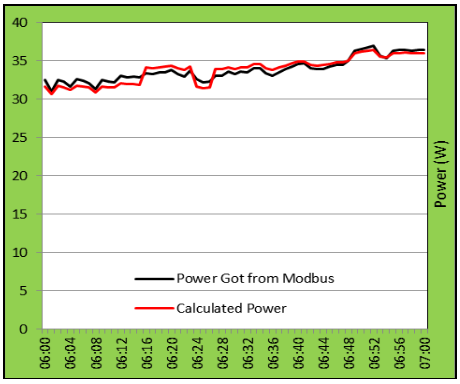
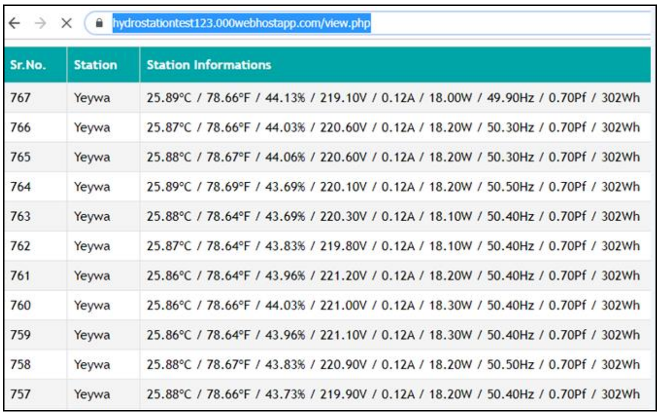


Fig. 7. Comparison between experimental results and calculated results.



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Sr.No.	Station	Station Informations
767	Yeywa	25.89°C / 78.66°F / 44.13% / 219.10V / 0.12A / 18.00W / 49.90Hz / 0.70Pf / 302Wh
766	Yeywa	25.87°C / 78.66°F / 44.03% / 220.60V / 0.12A / 18.20W / 50.30Hz / 0.70Pf / 302Wh
765	Yeywa	25.88°C / 78.67°F / 44.06% / 220.60V / 0.12A / 18.20W / 50.30Hz / 0.70Pf / 302Wh
764	Yeywa	25.89°C / 78.69°F / 43.69% / 220.10V / 0.12A / 18.20W / 50.50Hz / 0.70Pf / 302Wh
763	Yeywa	25.88°C / 78.64°F / 43.69% / 220.30V / 0.12A / 18.10W / 50.40Hz / 0.70Pf / 302Wh
762	Yeywa	25.87°C / 78.64°F / 43.83% / 219.80V / 0.12A / 18.10W / 50.40Hz / 0.70Pf / 302Wh
761	Yeywa	25.86°C / 78.64°F / 43.96% / 221.20V / 0.12A / 18.20W / 50.40Hz / 0.70Pf / 302Wh
760	Yeywa	25.86°C / 78.66°F / 44.03% / 221.00V / 0.12A / 18.30W / 50.40Hz / 0.70Pf / 302Wh
759	Yeywa	25.86°C / 78.64°F / 43.96% / 221.10V / 0.12A / 18.30W / 50.40Hz / 0.70Pf / 302Wh
758	Yeywa	25.88°C / 78.67°F / 43.83% / 220.90V / 0.12A / 18.20W / 50.50Hz / 0.70Pf / 302Wh
757	Yeywa	25.88°C / 78.66°F / 43.73% / 219.90V / 0.12A / 18.20W / 50.40Hz / 0.70Pf / 302Wh

Fig. 8. Data collection from website.

Low cost technology, SCADA system on the IoT cloud is convenient for industrial control systems but it is a less secure system than the control system from its own created website. Therefore, Mysql database and a website are created in the back-end to store and monitor the required data on Master Terminal Unit (MTU) by using the php scripting language. Fig. 8 expresses the monitoring system that collects the required data on the private created website.

After that, the best open source data packet analyzer: Wireshark software has also been used to analyze the performance of communications metrics for IoT-based SCADA systems such as throughput, Round Trip Time, Ack Round Trip Time. Delay time can also be measured by querying the IP address of source (ESP's IP address) and destination (website) such as RTU and MTU.

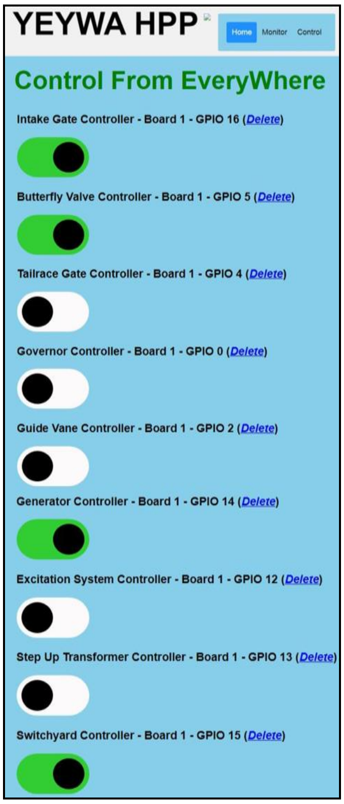


Fig. 9. SCADA control system from website.

In addition, Netspot software has also been applied to regard the RTUs location of the power station by measuring the signal strength over the wireless network. Pursuant to this research, signal strength (0 to – 60 dBm) and the distance (0 to 30 feet) are suitable for installation of the RTU from router (Internet Service Provider). As a result, throughput (6720 bit/s) and RTT (42.052ms) were measured in the research of communication metrics analysis for IoT-based SCADA system [18]. Finally, an IoT-based SCADA system assists the control system of the hydropower station. Fig. 9 illustrates an IoT-based SCADA system that controls and conducts the generation process of the hydropower station from the created website from anywhere via internet access.

IV. Statistical Analysis of Generated Electricity Results

Performance of the hydropower station has been checked by using the monthly generated load capacity (electricity) which can be predicated by analyzing the collected historical data and by checking factor changes. There are various methods to predict the electricity consumption [27], [28].

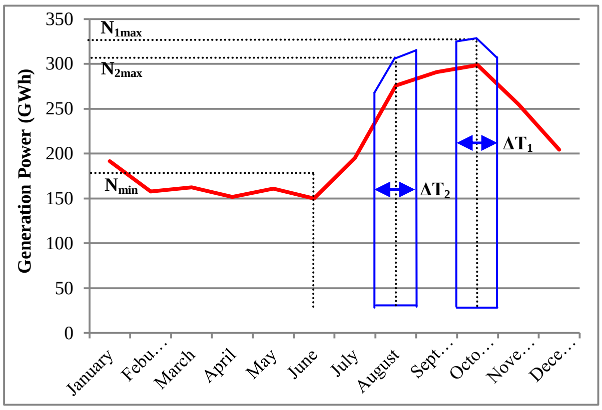


Fig. 10. Electricity load curve with representation parameters.

Integral and differential characteristics can be applied to execute the asymmetrical conditions of yearly load curves. Integral evaluation of yearly load curve can be calculated with monthly data for each year; however, differential evaluation of it can also be calculated with tremendous points for average yearly load curve [23]. Fig. 10 shows the yearly electricity load curve of Yeywa hydropower station and this figure is derived from the average value of annual generation (from 2011 to 2020).

To execute the integral evaluation for the generated capacity statement, the following parameters can be applied:

a) Load curve shape factor (k_f)
b) Root mean square deviation (σ_n) from average load value per year
c) Generated energy period for one year

A. *Load Curve Shape Factor*

Load curve shape factor will illustrate the variation in load demand over a specific time. That is why; for a power station's operator, it will be considered and scheduled how much power to generate in a given period of time by using (1). It is expressed as;

$$k_f = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n} N_i^2}}{\frac{1}{n}\sum_{i=1}^{n} N_i} = \frac{\sum N_{\mathrm{rm}}}{N_{\mathrm{avg}}} \tag{1}$$

where N_i is the monthly value of the ith point of yearly load curve (GWh), n is the number of points at yearly load curve, N_{rm} is the root mean square for load (GWh), and N_{avg} is the average yearly load (GWh).

B. *Root Mean Square Deviation from Average Load Per Year*

Root mean square deviation (σ_n) is the measurement of variation between the predicted values and the actual observed values. In this research, σ_n is used for the measurement of deviation from average load value per year by using below (2). σ_n is defined as follow;

$$\sigma_n = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(N_i - N_{\text{avg}})^2} \tag{2}$$

C. Generated Energy Period for One Year

The efficiency of a power station can be found out how much to generate the electricity and how long to operate the power plant. So, the generated energy period can be calculated in (3) as an integral evaluation. It is defined as;

$$\Delta t_{\max}^{\Sigma} = \sum_j \Delta t_j \tag{3}$$

where $\Delta t_{\max}^{\Sigma}$ is the cumulate time for one year and j is the value of time segment for the generated capacity for each month.

To carry out the differential evaluation, the following parameters can be used.

a) Yearly peak load (N_p)
b) Maximum load curve coefficients ($k_{\max}$)
c) Minimum load curve coefficients ($k_{\min}$)
d) Ratio of the $k_{\max}$ and $k_{\min}$ (λ)
e) Load fluctuations (k_d)
f) Peak load ratio for wet season and dry season (k_r)

D. Yearly Peak Load (N_p)

Peak load (GWh) is a maximum load demand for power consumption; however, maximum generated capacity is also peak load for hydropower plants. Therefore, peak load is the extreme highest point over the maximum and minimum points of the yearly load curve and it is described in (4) as follow;

$$N_p = \max\left\{N_{\max}^i\right\}, i = 1, 2, \cdots, n \tag{4}$$

E. Maximum Load Curve Coefficients (k_{max})

Maximum load curve coefficient is the ratio of peak load and average load as in below (5). Therefore, $k_{\max}$ value is always greater than 1 and it is described as;

$$k_{\max} = \frac{N_p}{N_{\text{avg}}} \tag{5}$$

F. Minimum Load Curve Coefficients (k_{min})

Minimum load curve coefficient is the ratio of minimum load and average load as in (6). So, the result of $k_{\min}$ is less than 1 forever and it is described as;

$$k_{\min} = \frac{N_{\min}}{N_{\text{avg}}} \tag{6}$$

G. Ratio of the k_{max} and k_{min}

Pursuant to get the ratio of $k_{\max}$ and $k_{\min}$, peak and off-peak condition well be known for generating of power station below (7). λ is described as;

$$\lambda = \frac{k_{\max}}{k_{\min}} \tag{7}$$

H. Load Fluctuation (k_d)

At the statement of peak internal, load fluctuation will appear due to the heavy current drawn and large voltage drop in the system. By reducing the load fluctuation, the operators prevent the equipment of the power station. k_d can be defined as;

$$k_d = k_{\max} - k_{\min} = \frac{N_p - N_{\min}}{N_{\text{avg}}} = \frac{\Delta N}{N_{\text{avg}}} \tag{8}$$

If the value of k_d is zero and λ is 1, load curve will develop completely smooth in horizontal.

I. Peak Load Ratio (k_r)

There are two peak loads every day: morning peak $N_{1\max}$ and evening peak $N_{2\max}$. In a load curve, $N_{1\max}$ and $N_{2\max}$ will be kowtow with the time slots: $T_{1\max}$ and $T_{2\max}$ and these peak load ratios can be calculated with (9). Although the following equation can be used for a daily load curve of 24 hours, it cannot be used for the yearly load curve of a hydropower station. k_r is also described as;

$$k_r = \frac{N_{1\max} - N_{2\max}}{N_{1\max}} \tag{9}$$

By using the above mentioned equations, the generated electricity from Yeywa Hydropower Plant in Myanmar was analyzed for wet season and dry season with the 10 years collected data (from 2011 to 2020), shown in Table III and Fig. 11. These data were collected on the mimic display board shown in Fig. 12.

TABLE III: GENERATED CAPACITY (GWH) OF YEYWA HYDROPOWER PLANT

Month	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
January	271.5	236.0	198.0	184.2	121.3	165.6	187.2	187.7	256.3	107.1
Febuary	204.1	230.7	154.6	149.9	98.1	154.0	137.9	166.2	163.6	118.4
March	190.9	176.3	165.9	186.8	173.1	137.0	126.5	127.9	191.1	148.0
April	155.3	95.7	160.8	174.7	220.6	161.0	121.9	147.3	184.1	93.8
May	155.5	90.0	103.9	198.0	137.4	201.7	199.4	214.6	134.5	174.9
June	173.6	90.9	127.7	136.6	108.7	120.7	208.8	273.3	106.1	153.4
July	225.1	153.2	155.2	153.0	181.6	199.2	245.6	337.8	106.4	192.9
August	281.2	310.2	326.1	268.9	298.9	284.3	283.8	327.5	162.0	215.1
September	155.3	314.2	324.5	324.5	301.2	275.3	322.1	349.1	149.6	393.3
October	309.1	298.3	344.2	312.4	289.8	217.5	315.1	369.7	186.2	342.0
November	279.5	232.7	316.0	272.1	274.3	210.0	238.0	332.6	174.5	217.5
December	331.6	198.0	232.4	168.3	202.2	217.4	194.9	238.0	120.5	140.5

Dry season | Wet season

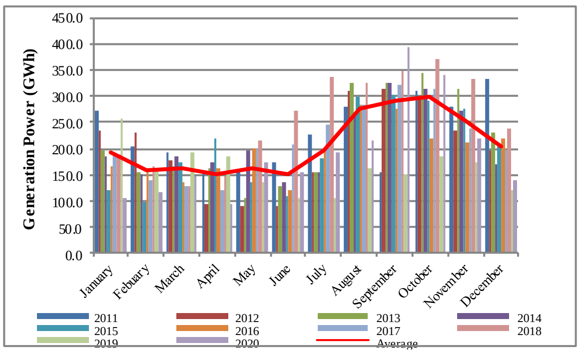


Fig. 11. Comparison of annual generated capacity of Yeywa hydropower plant from 2011 to 2020

Fig. 12. Mimic display board of Yeywa hydropower station.

TABLE IV: CALCULATED RESULT FOR STATISTICAL ANALYSIS OF GENERATED ELECTRICITY IN THE DRY SEASON

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
N_{max}	331.62	235.97	232.43	197.97	220.56	217.44	199.42	237.97	256.27	174.89
N_{min}	155.30	90.04	103.92	149.91	98.10	137.01	121.89	127.93	120.55	93.82
N_{avg}	218.15	171.12	169.28	176.98	158.79	172.78	161.31	180.28	175.02	130.45
N_{rm}	227.34	180.95	173.84	177.64	164.69	175.01	164.66	184.20	180.50	133.24
k_f	1.04	1.06	1.03	1.00	1.04	1.01	1.02	1.02	1.03	1.02
σ_n	63.96	58.84	39.55	15.29	43.70	27.86	33.08	37.83	44.13	27.14
k_{max}	1.52	1.38	1.37	1.12	1.39	1.26	1.24	1.32	1.46	1.34
k_{min}	0.71	0.53	0.61	0.85	0.62	0.79	0.76	0.71	0.69	0.72
λ	2.14	2.62	2.24	1.32	2.25	1.59	1.64	1.86	2.13	1.86
k_d	0.81	0.85	0.76	0.27	0.77	0.47	0.48	0.61	0.78	0.62

TABLE V: CALCULATED RESULT FOR STATISTICAL ANALYSIS OF GENERATED ELECTRICITY IN THE WET SEASON

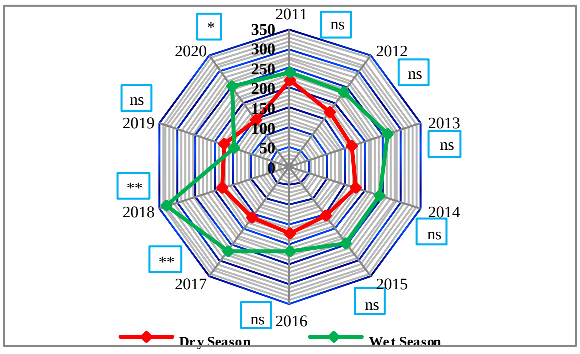
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
N_{max}	309.15	314.17	344.19	324.53	301.18	284.30	322.13	369.74	186.16	393.34
N_{min}	155.30	90.90	127.66	136.64	108.69	120.70	208.81	273.31	106.08	153.41
N_{avg}	237.32	233.25	265.62	244.58	242.44	217.84	268.92	331.69	147.45	252.38
N_{rm}	244.17	248.26	280.00	255.37	253.03	224.46	272.10	333.00	150.71	266.46
k_f	1.03	1.06	1.05	1.04	1.04	1.03	1.01	1.00	1.02	1.06
σ_n	57.44	85.03	88.57	73.46	72.45	54.11	41.43	29.48	31.21	85.48
k_{max}	1.30	1.35	1.30	1.33	1.24	1.31	1.20	1.11	1.26	1.56
k_{min}	0.65	0.39	0.48	0.56	0.45	0.55	0.78	0.82	0.72	0.61
λ_1	1.99	3.46	2.70	2.38	2.77	2.36	1.54	1.35	1.75	2.56
k_d	0.65	0.96	0.82	0.77	0.79	0.75	0.42	0.29	0.54	0.95

According to the calculated result of Table IV and Table V, each value for electricity load curve parameters is totally different each year because of analysis on wet and dry seasons. Yeywa hydropower station is the state own hydropower station, therefore, it generates the electricity dependent on the inflow of the reservoir and perfectly applies the inflow water to avoid the spill in wet season. Therefore, in the Republic of the Union of Myanmar, Yeywa hydropower station is generating more electricity as a state own station in wet season without purchasing the electricity from Independent Power Procedure (IPP) power station than the dry season as shown in Fig. 13. In this figure, all the data were analyzed by least square line regression method; time series analysis in Excel 2010.

The student's T-test technique is used for testing a hypothesis on the difference between two sample means such as dry season and wet season. Therefore, in order to compare the difference between annual wet season production and annual dry season production, the student's T-test is used and this value is shown in Table VI.

TABLE VI: STUDENT'S T-TEST VALUE FOR EACH YEAR (2011 TO 2020)

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Student's T-test value	0.629	0.209	0.051	0.072	0.052	0.129	0.001	0.000	0.280	0.012



{ns is non-significant difference at 5% level, * is significant difference at 5% level and ** is significant at 1% level by student's T test}

Fig. 13. Average annual load (GWh) for wet & dry season from 2011 to 2020 at Yeywa Hydropower Station.

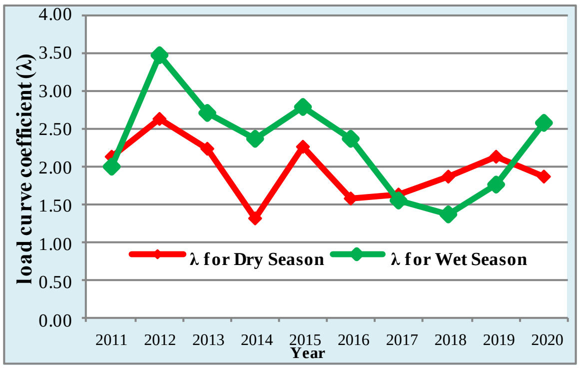


Fig. 14. Comparison of annual load curve coefficient between wet season and dry season.

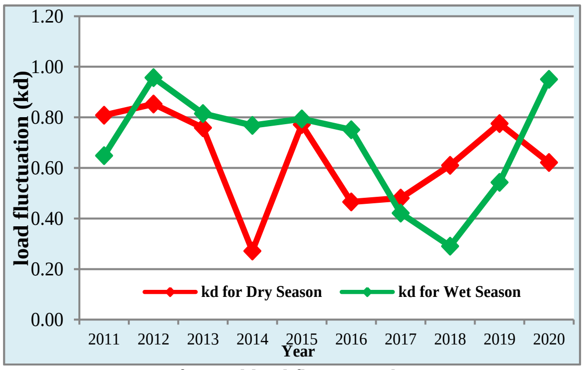


Fig. 15. Comparison of annual load fluctuation between wet season and dry season

Moreover, in the dry season with less reservoir water, Yeywa produced the electricity according to the load demand. So, the value of load curve coefficient ratio (λ) in dry season changes more significantly than in wet season shown in Fig. 14. According to these results, load fluctuation in the dry season also changes more than the wet season as shown in Fig. 15.

Pursuant to these results, the generated capacity of the Yeywa Hydropower Station produced the electricity in wet season more than dry season except in four-year drought (2011, 2017, 2018, and 2019) to avoid the spill and to effectively use the water in wet season. The production of dry season in these four years is more than that of wet season because the water is stored in reservoir to fulfillment in dry season.

TABLE VII: THE ESTIMATED PRODUCTION FOR YEYWA HYDRO- POWER STATION IN 2020

No	Month	Equation ($\hat{Y} = a + bX$)	Result (GWh) (Estimated Production for 2020)
1	January	$\hat{Y}$ = 200.8553+(-4.10163X)	180.3471
2	February	$\hat{Y}$ = 162.1310+(-6.41901X)	130.0359
3	March	$\hat{Y}$ = 163.9488+(-4.54528X)	141.2224
4	April	$\hat{Y}$ = 157.9266+(2.975776X)	172.8055
5	May	$\hat{Y}$ = 159.4515+(8.075520X)	199.8291
6	June	$\hat{Y}$ = 149.6051+(7.055744X)	184.8838
7	July	$\hat{Y}$ = 135.2339+(5.101280X)	220.7403
8	August	$\hat{Y}$ = 282.5491+(-8.23594X)	241.3694
9	September	$\hat{Y}$ = 279.5430+(0.467488X)	281.8805
10	October	$\hat{Y}$ = 293.6041+(-7.17728X)	257.7177
11	November	$\hat{Y}$ = 258.8646+(-5.63994X)	230.6650
12	December	$\hat{Y}$ = 211.4942+(-12.5058X)	148.9654
	Total		**2390.4621**

TABLE VIII: DEVIATION BETWEEN THE ESTIMATED PRODUCTION AND ACTUAL PRODUCTION FOR YEYWA HYDRO-POWER STATION IN 2020

No	Month	Estimated Value (GWh)	Actual Value (GWh)	Deviation
1	January	180.3471	107.07	68%
2	February	130.0359	118.35	10%
3	March	141.2224	148.03	-5%
4	April	172.8055	93.82	84%
5	May	199.8291	174.89	14%
6	June	184.8838	153.41	21%
7	July	220.7403	192.89	14%
8	August	241.3694	215.08	12%
9	September	281.8805	393.34	-28%
10	October	257.7177	342.01	-25%
11	November	230.6650	217.55	6%
12	December	148.9654	140.52	6%
	Total	**2390.4621**	**2296.97**	**4%**

Forecasting is a method or a technique for estimating future aspects of a business or the operation. It is a method for translating past data or experience into estimates of the future. It is a tool which helps management in its attempts to cope with the uncertain value of the future. Forecasts are important for short term and long term decisions. Therefore, the production of Yeywa hydropower station was forecasted by using the least square line regression method of time series analysis under only historical generation. The estimated equations of the linear regression line and the estimated production of the Yeywa hydropower station in 2020 for each month are illustrated in Table VII by using the historical data from 2011 to 2019. The performance of power station is regarded with the total annual generation and is not regarded with monthly generation because of the maintenance process in a power station. Accordingly, the result of estimated electricity is 2390.462GWh in 2020 and this estimated value is nearly the same compared with the actual value in 2020 (2296.97GWh) because the deviation of annual generation is 4% between them as illustrated in Table VIII and Fig. 16. In 2020, the actual value is lower than the estimated value because many industries don't use the electricity due to the COVID-19 pandemic. If this situation does not arise, the deviation is absolutely the same (less than 4%) between the value of real and prediction. Therefore, the production of Yeywa hydropower station for coming year (2021) can be predicted by using the mentioned method and the predicted value is 2328.1151 GWh as expressed in Table IX.

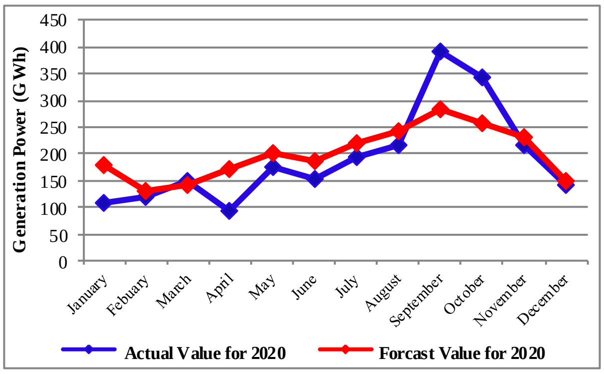


Fig. 16. Comparison of production between estimated value and actual vale for 2020 of Hydropower station.

TABLE IX: THE ESTIMATED PRODUCTION FOR YEYWA HYDRO- POWER STATION IN 2021

No	Month	Equation ($\hat{Y} = a + bX$)	Result (GWh) (Estimated Production for 2021)
1	January	$\hat{Y}$ = 191.4770+(-4.0492X)	146.9357
2	February	$\hat{Y}$ = 157.7532+(-3.5281X)	118.9436
3	March	$\hat{Y}$ = 162.3571+(-2.0869X)	139.4010
4	April	$\hat{Y}$ = 151.5158+(-0.6663X)	144.1866
5	May	$\hat{Y}$ = 160.9958+(3.3577X)	197.9309
6	June	$\hat{Y}$ = 149.9856+(2.6695X)	179.3500
7	July	$\hat{Y}$ = 195.0000+(1.7912X)	214.7034
8	August	$\hat{Y}$ = 275.8020+(-4.8350X)	222.6171
9	September	$\hat{Y}$ = 290.9230+(3.2736X)	326.9329
10	October	$\hat{Y}$ = 298.4442+(-1.2899X)	284.2556
11	November	$\hat{Y}$ = 254.7327+(-3.1778X)	219.7773
12	December	$\hat{Y}$ = 204.3967+(-6.4832X)	133.0811
	Total		**2328.1151**

Therefore, IoT-based SCADA system supports the operator to collect the information of the station as historical data from anywhere via the internet and these collected data are applied to analyze the condition of the station and forecast the capacity to produce in the following year as the above methods. So, the traditional (local) SCADA system which has been utilized on all of the power stations in Myanmar should be replaced with the modernized IoT-based SCADA system.

V. CONCLUSION

IoT-based SCADA system is a low-cost M2M industrial 4.0 technology and supports the operators to monitor the desired information and control the power station upon the generated capacity. The performance of IoT-based SCADA system is analyzed by using the data packet analyzer and the location of RTU is regarded by using the WiFi analyzer. The performance of the tolerance (±3%) is very well on hardware implementation and the result of throughput (6720 bps) and RTT (42.052ms) are very rapid to post the data from RTU to MTU under the communication metrics analysis for SCADA system. Statistical data analysis on this research assists the hydropower station how to control the condition of electricity generation in the dry season and wet season to justify the fulfillment of electrification for the country pursuant to the collected annual generated electricity. The deviation of annual generation between the actual value and predicted value for the year of 2020 is 4% which is calculated by using the lease square line regression method. For a hydropower station, this value is very small for generation forecasting. Moreover, the usage of electrification in 2020 is lower than another year because of COVID-19 pandemic in Myanmar. So, this method can be safety used to forecast the generation for all power stations in coming year. After upgrading and modifying this IoT-based SCADA system design, it is able to reduce human resources as an employee, to operate the power station with safety and to timely collect the station information.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Aung Kyaw Myint and Dr. Kyaw Zin Latt conducted the research; Dr. Tin Tin Hla and Dr. Nay Min Tun analyzed the data; Aung Kyaw Myint and Dr. Kyaw Zin Latt wrote the paper and all authors had approved the final version.

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