Development of Low-cost IoT System for Monitoring and Enhancing Renewable Energy Feed-in Tariff at Household in Hong Kong

C. C. Lee[1][a] and George Chan[2][b]
[1]School of Science and Technology, The Open University of Hong Kong, Hong Kong, China
[2]Research and Development Department, ASM Pacific Technology Ltd., Hong Kong, China

Keywords: IoT, Feed-in Tariff, Smart Renewable Energy.

Abstract: Feed-in tariff schemes become more popular in many countries nowadays. In October 2018, the Hong Kong Government launched a new policy scheme which was comprised of feed-in tariff scheme and renewable energy certificates. The work mentioned in this paper aims at improving the efficiency of implementing the feed-in tariff scheme at household in Hong Kong by using an automatic intelligent and relatively low-cost IoT system. Besides improving the energy efficiency, the proposed system also includes a website and an App for monitoring the system performance. The experimental results showed that the energy generated by using the proposed system is three times more than the system without smart features. The payback period can be greatly reduced from 11 to 6 years by using the proposed system. It encourages the development of renewable energy sources in Hong Kong or other similar developed cities.

1 INTRODUCTION

Fossil fuel was used to be the most abundant energy resource when human discovered how electricity could be generated. For years, Hong Kong relied on the combustions of fossil fuels to generate electricity. The coal dominated the overall fuel mix with more than 50%. The data is shown that fossil fuels actually brought more harms than benefits to the environment (Ajlif, 2020). As planned, it should be reduced to around 20% in 2022, and it is expected to be completely eliminated in 2030. It is expected that Hong Kong's per capita annual carbon emissions of nearly 6 metric tons will be reduced to about 3.3 to 3.8 metric tons in 2030 (EcoSmart, 2019). Therefore, effort should be made to use more renewable energy.

It seems that Hong Kong is not a suitable place to invest renewable energy. But, Hong Kong has a subtropical climate where the sun shines usually from the south at noon. There could be a huge potential for Hong Kong to develop renewable energy sources like solar energy. According to the research of local officials, the daily average horizontal solar irradiation was 3.56 $kWhm^{-2}day^{-1}$ in 2017. Besides, the average global solar radiation in 2018 was 433.5 MJm^{-2}. In addition, the average wind speed of the particular site was about 7 ms^{-1} and the median wind speed was 6.6 ms^{-1}. These are the considerable conditions for Hong Kong to highly develop renewable energy sources including solar and wind.

As a result, the development of renewable energy sources would be inevitable. However, the contributions of renewable energy such as solar and wind energy have been less than 1% of the total energy resources of Hong Kong up to now. There are only a few people who installed solar or wind power facilities. The reason is obviously lack of policy incentives (Sauma, 2015).

Renewable Energy Feed-in tariff (FiT) could be an opportunity for residents and office owners to take part in by installing a renewable energy system on the buildings or houses. The user could charge the electricity suppliers by selling their electricity via the successfully connected grids. However, the long payback period hestiate the people to join the FiT scheme. In this work, it aimed to develop an IoT system for monitoring and enhancing renewable energy FiT at household or small office in Hong Kong or similar developed cities.

[a] https://orcid.org/0000-0001-9365-9397
[b] https://orcid.org/0000-0003-2821-7212

Lee, C. and Chan, G.
Development of Low-cost IoT System for Monitoring and Enhancing Renewable Energy Feed-in Tariff at Household in Hong Kong.
DOI: 10.5220/0010484403150322
In *Proceedings of the 6th International Conference on Internet of Things, Big Data and Security (IoTBDS 2021)*, pages 315-322
ISBN: 978-989-758-504-3

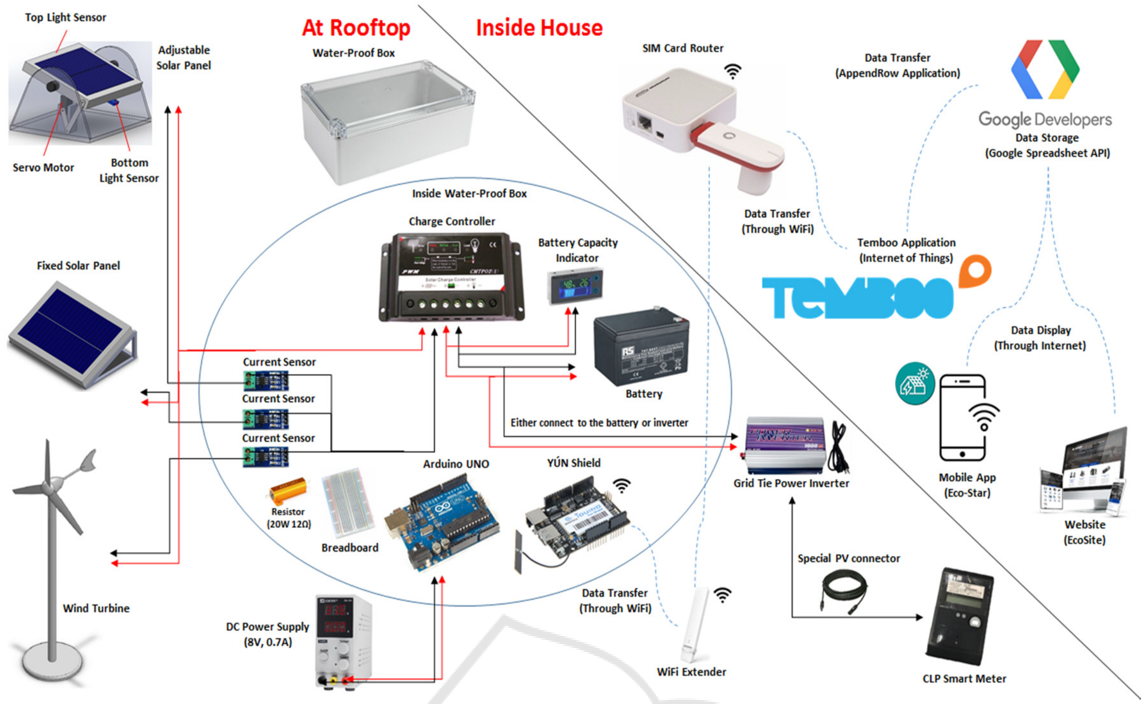

Figure 1: The schematic diagram of the smart IoT system for monitoring and enhancing renewable energy feed-in tariff at household or small office in Hong Kong or similar developed cities.

2 RELATED WORK & CURRENT TECHNOLOGY

Automatic intelligence IoT systems become more feasible and cost-effective in recent years due to the development of sensors and wireless communication technology (Mittal, 2019). One of the usage of such technology is to control and monitor the industrial production. It is expected that sensors and automation machine are also applicable in renewable energy system.

A few IoT-based monitoring systems periodically tracked the quality of power plants were proposed and demonstrated to endorse a better energy management from a single building to a wider context (Domova and Dagnino, 2017), (Carchiolo, 2019). There were also systems using modelling to manage and optimize the energy efficiency in various environment (Clarke, 2016), (Dao, 2017). However, there is a lack of IoT system which is comprised of both hardware and software to monitor and enhance the renewable energy in the household areas.

IoT system with sensors and feedback mechanism should be fully utilized. In the developed cities, like Hong Kong, most of the solar energy companies still using supporting stand for the solar panel. Although there are some adjustable solar panel. It could only be adjusted manually but not automatically. Solar tracking mount technology is also a developing technology which is similar to the proposed solar panel. Standalone trackers allow solar panels to maximize electricity production by following the sun as it moves across the sky. On the other hand, some companies have Apps to monitor the system and power generation (Atasoy, 2015). However, the technology is not stable yet until 2021 to replace ground mount solar panel. Most importantly, the cost of implementing the existing tracking solar panel is not efficient at household or small office. Also, there is no other sensors, like humidity sensor and wind sensors, and no other renewable energy source as a whole to implement the entire IoT system.

To the best of the authors' knowledge, the proposed work is the first low-cost IoT system for monitoring and enhancing feed-in tariff on various renewable energy sources at household and small office in the developed cities.

3 METHODOLOGY

As an IoT work, the implementation of this system required a large proportion of combination between hardware and software. In the aspect of hardware

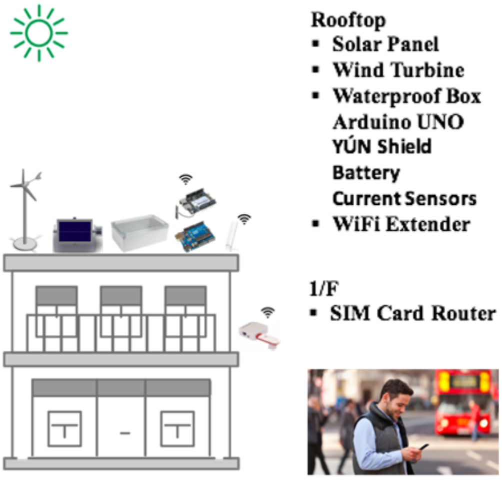

Figure 2: Proposed residential installation of the system.

development, selection of appropriate renewable energy devices, such as solar panels and wind turbine, is the most critical. It will directly influence the power output from the system. Besides, selection of development board is also crucial because it is the central processor of the system. Other selected components should be compatible to the selected development board. It can enhance the combination between hardware and software and reduce the time for troubleshoot in later stages.

In the aspect of software development, the system will be connected to the Internet through WiFi technology. By using Application Programming Interface (API), data will be uploaded automatically to the Google Cloud and stored in the Google Spreadsheet. The sketch of the development board and the procedure of proceeding the Authorization between Temboo platform and Google Developer are essential. Finally, the data will be displayed in the website (called EcoSite) and the Smart App (called EcoView). The EcoSite is a website for real time monitoring of the renewable energy system. It shows the chart in the page of Monitor that user can understand the amount of power generated, profit and paid back period of the renewable energy system. For the EcoView, it was developed to process, calculate and displace the raw data on the spreadsheet automatically and upload the results (total, average by hour, minimum and maximum of the income, energy, and power of EcoStar with the operative duration) to the Firebase project EcoStar thunkable 1 daily at midnight. More importantly, EcoView can display the charts and the data of the desired date. EcoView is applicable on both IOS and Android system. In the system, Google Sheets API is enabled in order to allow Temboo Application get access to the designated spreadsheet. Besides, AppendRow API is used to append rows of data to the spreadsheet. The Figure 1 shows the schematic diagram of the smart IoT system for monitoring and enhancing renewable energy feed-in tariff at household or small office, while the Figure 2 shows the proposed residential installation of the system in Hong Kogn or similar devleoped cities. Figure 3 shows the logical flow chart of the proposed system.

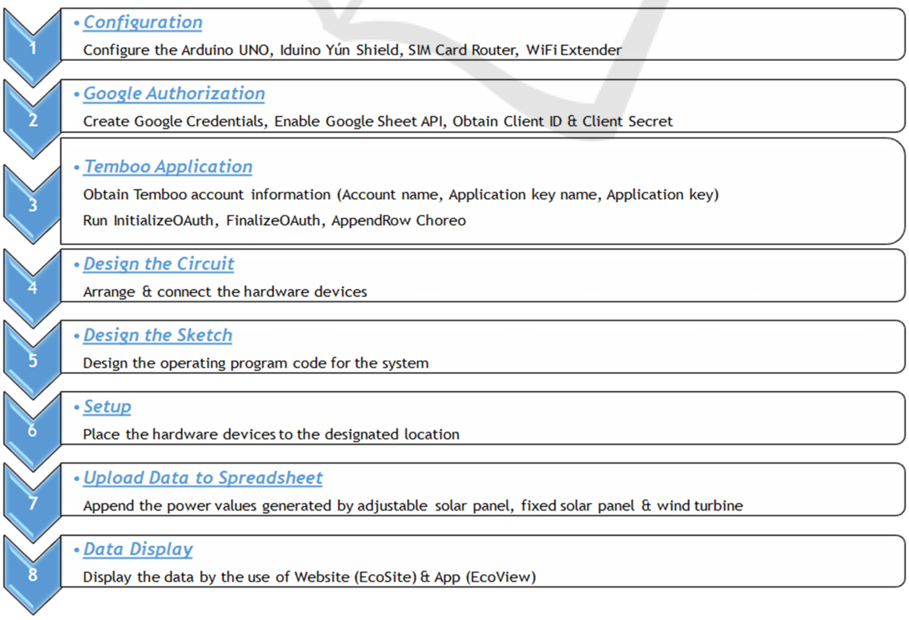

Figure 3: Logical flow chart of the proposed system.

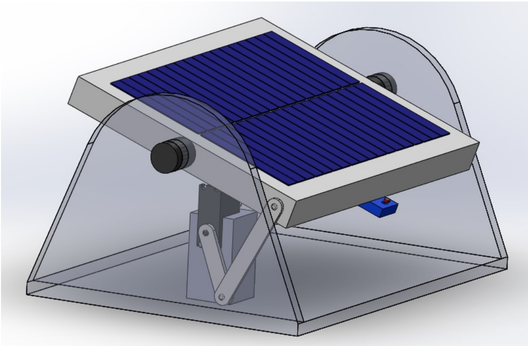

Figure 4: The base of adjustable solar panel.

3.1 Hardware Configuration

For the design of the system, all the renewable energy devices are connected to batteries through a charge controller. All the devices and components are DC (Direct Current). This setting is due to the budget and scale limitations of the project. However, if the system is applied to residential or commercial use, all the renewable energy devices will be connect to a meter by using special PV connector and Grid Tie Inverter (GTI). The meter will be provided by the Electric company. The meter used can only get the input of AC (Alternative Current) power. Therefore, it is recommended to use GTI for the conversion from DC power to AC power.

In the past, people used AC generator to convert DC power to AC power for providing back-up electricity. However, using AC generator will cause a high extent of power loss. During the conversion, the load current will flow through the armature of the AC generator. The resistance and inductive reactance of the armature will cause a voltage drop. Therefore, the voltage and power generated will be lost. For providing back-up electricity, the amount of power loss can be acceptable. However, for energy FiT schemes, the money earned depends on the amount of energy generated. It is unacceptable to have a high extent of power loss.

Using GTI can also convert DC power to AC power. However, a grid tie inverter can produce sine wave AC electricity that matches the voltage and frequency of the grid exactly. After matching the voltage and phase of the grid sine wave AC waveform, people can inject electrical power efficiently and safely into the grid. Therefore, the problem of power loss can be eliminated. As a result, if the smart system is applied to residential or commercial use, the charge terminals of the charge controller will be connected to a GTI through a special PV connector.

There would be three options of development boards for the Smart System, which would be Arduino UNO Rev 3, Raspberry Pi Model B 3+ and Micro:bit. Since the development board is the core in the system, therefore there is a need to be extremely careful when selecting the development board. Besides, there are other criteria for the selection of development board for the Smart System. For example, in order to monitor and control some hardware components, such as light sensor and servo motor, open source for hardware design is one of the requirements. Because of the connection to the hardware components, both digital and analogue I/O are required. Finally, since the connection of the Smart System is WiFi, therefore on-board WiFi chip is preferred. Therefore, Arduino UNO was chosen as the development board for the Smart System.

The phototransistors (light sensors) is placed on protective cases, which is produced by 3D printing that stuck on the edge of solar panel at the top and the bottom, in order to track solar orbit by comparing the light intensity. The smart system compares the light intensity and adjust the solar panel perpendicular to the sun by the movement of servo motor which was fixed on the 3D-printed stand on the base of adjustable solar panel as shown in Figure 4. Therefore, the solar panel is expected to enhance the efficiency by strengthening the light intensity collection.

Miroad KY55 5528 is selected as the light sensor in the system as it contains a MV358I chip that would make the control easier. In order to keep measuring the power generated by the solar panel and wind turbine, ACS712 current sensor as shown in Figure S12 was used. The ACS712 is a Hall effect based linear current sensor. The ACS712 Chip, as shown in Figure S13, works like a magnetic isolator since the current sensing element is electrically isolated from the measure device. The magnetic field surrounding the piece of wire when current flows through the current sensing metal and the Hall effect sensor detects that current through a little bit of integral electronics provides a signal on those pins that is between 0V and 5V.

After the selection of appropriate hardware devices and components, a circuit is designed to connect all these devices and components into a single system. For the operation of the system, Arduino UNO Rev 3 is the core development board. Iduino Yún Shield is a supplementary development board especially used for providing WiFi support. Two development boards can be connected by simply combining them together.

Generally, the positive terminal of all the renewable energy devices are connected to the positive input terminal of the charge controller. The negative input terminal of the charge controller are connected to IP+ (current in) terminal of all the current sensors. The IP- (current out) terminal of all the current sensors are connected back to the negative terminal of all renewable energy devices. Two batteries are connected in serial. The positive and negative terminal of the battery are connected to the positive and negative charge terminal of the charge controller respectively. The battery capacity indicator is connected to the batteries in parallel.

A servo motor and two light sensors are used. Together with the current sensors, all the sensors and the servo motor are powered by the 5V output pin of the Arduino UNO. All the above DC devices are connected in parallel. The negative terminal of these DC devices is connected to the ground provided by Arduino UNO.

For the arrangement of I/O pins, 5 analog pins and 1 digital pin are used. Top and bottom light sensors are connected to analog pin A1 and A2 respectively. Current sensors for adjustable solar panel, fixed solar panel and wind turbine are connected to analog pin A3, A4 and A5 respectively. Servo motor is connected to digital pin D9. The system is powered by the DC power supply, in order to mimic the stable power supply in residential house. However, if the system is directly connected to DC power supply, the current would be large enough to damage the development boards. Therefore, a resistor is connected to the development boards in parallel, in order to prevent large current flowing to the development boards. By using the Digital Multimeter (DMM), the resistance of the whole system is measured to be 11.4286Ω. After calculation, the suitable range of resistance of the selected resistor is between 10 and 12Ω. After some experiments, the suitable power rating of the resistor is 20W. Therefore, a resistor with 12Ω and 20W is connected to the system in parallel.

By using parallel resistance formula, the resistance of the system is reduced from 11.4286Ω to 5.8537Ω. The current flow of the system is increased from 0.7A to 1.3667A. However, the current flow to the development boards will be changed to 0.4481A, which is calculated by using the formula 1.3667A × [5.8537Ω / (5.8537Ω + 12Ω)]. The resistor used shares the rest of the current flow (1.3667A – 0.4481A = 0.9186A). The use of resistor is to reduce the current flow to the development boards, in order to protect it from damage.

By using the DC power supply, the optimum voltage and current for powering up the system is obtained to be 5V and 0.7A. The exact voltage of the 5V output pin from Arduino UNO is measured to be 4.1V, which is large enough to power up the servo motor and all the sensors.

3.2 Firmware Design

In the system, the software support takes an important part. For example, through the design of Arduino sketch, different hardware devices, such as solar panels and sensors, are optimum to monitor and enhance renewable energy FiT. By the use of WiFi technology, the system can be connected to the Internet. Data, such as renewable energy generated and the money earned by the users, will be uploaded to the Google Cloud automatically. The uploaded data will be further proceeded for analysis, and finally the results will be displayed in EcoSite and EcoView.

When particularly focusing to the software development of the system, it does not only required to design the sketch for the operation of the hardware devices such as motor and sensors, but also required to design the sketch for the connection between Arduino boards to the Internet. Before connecting to the Internet, it is critical to get the Google Authorization, which allows the Temboo application getting access to a designated Google Spreadsheets. After the operating sketch of the system has been designed and accomplished, it will be complied and uploaded to the Arduino boards. The uploading method is through WiFi. Therefore, no wired connection between the system and the personal computer is required.

For the use of comparing energy efficiency, both adjustable solar panel and fixed solar panel are connected to the system during simulation. One of the solar panels is installed to a fixed solar panel positioner. Another solar panel is installed to another solar panel positioner and controlled by a servo motor and two light sensors.

In the sketch used to control the solar panel by servo motor and light sensors, the light values are compared. If the light value from the top sensor is larger than that from the bottom sensor, the top sensor will take control of the servo motor. If the light value from the top sensor is less than or equal to that from the bottom sensor, the bottom sensor will take control. By executing the map() function, the servo motor, jointed with the solar panel, will rotate to the position that can obtain the highest light level.

For the simulation of generating renewable energy, the measurement of energy generated by the renewable energy device is required. In order to obtain the energy values, the power values are required to be measured. In the system, current sensors are used. The power generated by the adjustable solar panel, fixed solar panel and wind turbine are required to be measured. Therefore, three current sensors are used for the system. After that, the power values are obtained by multiplying those voltage values with the corresponding current values. Although the current sensors that we used are the same in module and rating, they can never be identical. Therefore, the above formula will be slightly tuned for measuring different devices.

After the sensors got the data, these data will be automatically uploaded to the Google Spreadsheet. In order to achieve it, the Google API and Temboo Platform is used. After creating the Temboo Header File and setting the profiles, the Arduino sketch was designed to upload data from Arduino to Google Spreadsheet by calling Temboo application through Arduino.

3.3 EcoSite Design

The Google-based application Google Site was selected for the collaboration and communication with the other users. It is because Google Site could help the inexperienced applicants who have no programming backgrounds to create and edit a website in an intuitive way. The methodology of the design and information sharing was simple and easy by dragging and dropping the functions provided in the toolbar. Moreover, the other Google-based applications such as Google Docs and YouTube can be included, integrated and organized in to one that it could be compatible with Google Sheets to which the raw data from EcoStar would be transferred.

3.4 EcoView Design

In order to allow the data, such as the units of energy generated, to be automatically updated and uploaded and the users of EcoStar to check for the data remotely, the App, called EcoView, was created. Supported by assistant online services including Firebase, Google Sheets, Google Script and Google Docs, the raw data of EcoStar from Google Sheets could be automatically updated and calculated. Next, the macro program written in Google Script would transfer and calculate the new raw data on a newly created sheet and upload the results to Firebase. Then, the prepared charts corresponding to the trends of data in Google Sheets would change along with the

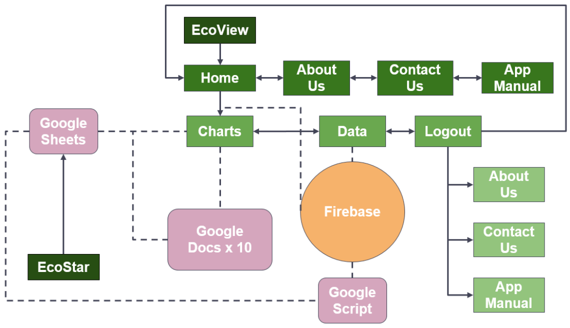

Figure 5: Structural Diagram of EcoView.

new data and be published for users to view by Google Docs. Simultaneously, as a real-time database supported by Google, Firebase would store the uploaded data in terms of links. The user may look for the data of certain days by tracking through the links. The process would be repeated daily with the support of the time-based trigger setting of Google Script.

To develop EcoView, the App developer Thunkable X was selected. There were three reasons for the decision. Firstly, Thunkable X was compatible with both IOS and Android systems so users of different systems could be supported. Secondly, it was designed with reference to another two well-accepted App developers, MIT App Inventor and Thunkable, which indicated that it was reliable and mature for App development. Thirdly, Thunkable X was built associated with the cooperative services with Firebase and WebViewer that it would be more convenient to upload data to or draw data from Firebase and the viewing of the charts would be allowed. The structural diagram of EcoView is as shown in Figure 5.

4 EXPERIMENTAL RESULTS

The prototype for the system was built as shown in Figure 6. All the hardware devices, including the solar panels, wind turbine and water-proof box, are set up at the rooftop. The SIM card router is set up in an in-house area at 10/F of the building in the campus. The WiFi extender is set up at the ladder between 10/F and 11/F of the same building.

The noncumulative power display on EcoSite with blue line and red line is as shown in Figure 7 to represent power (adjusted) and power (fixed) respectively. Meanwhile, the noncumulative power display on EcoView with blue line and red line is as shown in Figure 8 to represent power (adjusted) and power (fixed) respectively.

Figure 6: The first prototype of the proposed system.

The data obtained by the system is transmitted to the Google Sheet via the use of WiFi and Temboo platform. The data analysis on five different duration, time and date can be found in Table 1. The experimental results showed that the energy generated by using the proposed system is three times more than the system without smart features. In order to compare the payback period of system with and without the proposed system, a control experiment which do not have smart elements in it was also conducted. By analysing the cost of system and the gross profit earned. The payback period of smart system is 5.84 years while that of control experiment is 10.56 years.

5 CONCLUSIONS

A smart system, called EcoStar, was developed to enhance the renewable energy generated, through the well combination of hardware and software. As shown in the experimental results, it is proved that the development of this smart IoT system can increase

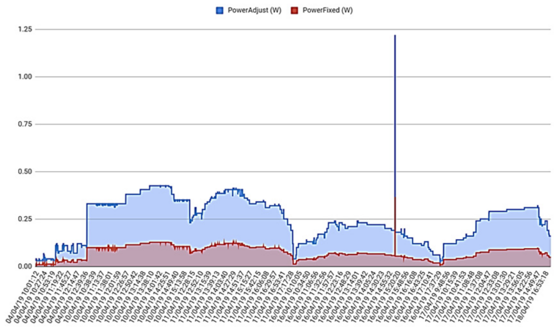

Figure 7: Noncumulative power display on EcoSite with blue line and red line representing power (adjusted) and power (fixed) respectively.

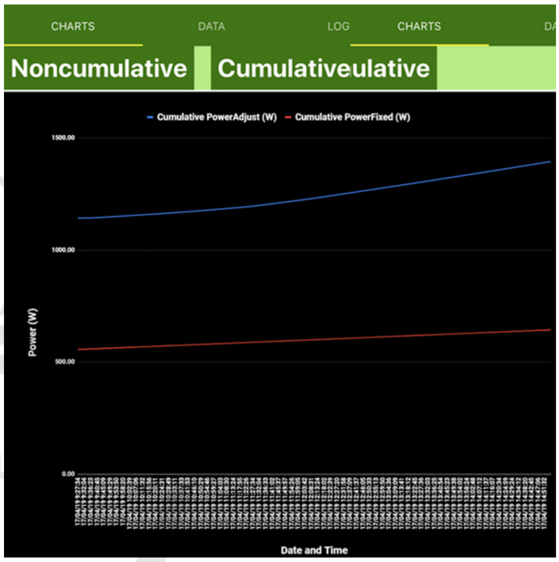

Figure 8: Noncumulative power display on EcoView with blue line and red line representing power (adjusted) and power (fixed) respectively.

Table 1: This caption has one line so it is centered.

Date and Time	Duration	Power of the Fixed Panel	Power of the Adjustable Panel
Day 1 (10:01:12 - 12:45:42)	02:44:30	0.18 W	0.54 W
Day 2 (10:20:54 - 15:32:02)	05:11:08	0.27 W	0.56 W
Day 3 (12:22:49 - 17:25:17)	03:02:28	0.28 W	0.69 W
Day 4 (09:53:24 - 17:42:53)	07:48:29	0.21 W	0.58 W
Day 5 (09:27:34 - 14:55:29)	05:27:55	0.29 W	0.57 W
Day 6 (15:12:00 - 17:40:14)	02:28:14	0.20 W	0.53 W

the energy efficiency of generating renewable energy. An automatic and wireless system has been developed, to not only increase the energy efficiency, but also provide a convenient way for users to monitor the results by the use of website and App. During the construction of this system, many opinions and feedback from different fields of stakeholders are received. Under the system EcoStar, a website called EcoSite and an App called EcoView are developed for monitoring the renewable energy feed-in-tariff. This smart system is a prototype, however, the application of this system can be well-projected as a cost-effective and intelligent system.

ACKNOWLEDGEMENTS

The work described in this paper was supported by The Open University of Hong Kong Research Grants (No. ROU/E08/19 and R5082).

REFERENCES

Ajlif, A. M., Joseph, S. C., Jayan, P. P., Raghavan, D. P., Joseph, A., & Chacko, R. V. (2020). Energy Efficient LVDC Architecture for House Boat Hotel Load System. 2020 IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy (PESGRE2020). doi:10.1109/pesgre45664.2020.9070720

Latest News. (n.d.). Retrieved January 25, 2021, from http://www.ecosmart.com.hk/en_US/%E6%9C%80%E6%96%B0%E6%B6%88%E6%81%AF/

Sauma E., Perez de Arce M. and Contreras J. (2015). Multiple Equilibria in Oligopolistic Power Markets with Feed-in Tariff Incentives for Renewable Energy Generation. 2015 48th Hawaii International Conference on System Sciences. doi: 10.1109/HICSS.2015.305.

Mittal, M., Tanwar, S., Agarwal, B., & Goyal, L. M. (2019). Energy Conservation for IoT Devices Concepts, Paradigms and Solutions. Singapore: Springer Singapore.

Domova V. and Dagnino, A., 2017. Towards intelligent alarm management in the Age of IIoT. In Global Internet of Things Summit (GIoTS), IEEE press.

Carchiolo V., Longheu A., Malgeri M., Sorbello S. and Torcetta A. (2019). Integration of Monitoring and Alarm Management in Power Plants.In Proceedings of the 21st International Conference on Enterprise Information Systems - Volume 2: ICEIS, ISBN 978-989-758-372-8, pages 658-665. doi: 10.5220/0007754706580665

Clarke, W. C., Manzie, C., and Brear, M. J. (2016). An Economic MPC Approach to Microgrid Control. In Control Conference (AuCC), 2016 Australian. Ferrarini, L.and Mantovani, G. (2013). Modeling and control of thermal energy of a large commercial building, IEEE International Workshop on Intelligent Energy Systems (IWIES).

Dao L., Ferrarini L. and Piroddi L. (2017). MPC-based Management of Energy Resources in Smart Microgrids.In Proceedings of the 14th International Conference on Informatics in Control, Automation and Robotics - Volume 1: ICINCO, ISBN 978-989-758-304-9, pages 246-253. doi: 10.5220/0006427902460253

Atasoy, T., Akinc, H. E., & Ercin, O. (2015). An analysis on smart grid applications and grid integration of renewable energy systems in smart cities. 2015 International Conference on Renewable Energy Research and Applications (ICRERA). doi:10.1109/icrera.2015.7418473