Condition Monitoring and Automation of Building Loads Supplied by a Microgrid with IoT

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Summary

Energy delivery within a micro grid (MG) is expected to be monitored and controlled diligently. It is the integral part of a MG operation that brings intelligence to the grid, if done smartly. In this paper, smart condition monitoring and efficient control of a campus building connected to a MG have been illustrated. In the current set up, combined heat and power generator, along with other renewable energy sources, are supplying power to the building's rotatory and lighting loads. With automation and IoT enabled technologies, MG's generation, as well as, load dissipation can be monitored remotely to take proper control decision. Even though distributed control system (DCS) are executing control actions locally, the IoT-enabled building loads can be monitored or controlled remotely. Results show that the condition monitoring based control enhances the efficiency and reliability of electric power delivery.

Key words:
Micro-grid; internet of thing; sustainability, condition monitoring, automation.

1. Introduction

Large buildings, such as, offices, commercial buildings, or campus are some of the energy-hungry infrastructures. Inadequate planning and wasteful energy usage of building is a global problem which must be addressed for sustainability. Fortunately, these buildings are also creating opportunity to integrate renewable energy sources [1-4]. A MG can accommodate these renewable-source integration [1-2]. With proper monitoring and automation facilities, it also provides smart control of energy usage [3-5]. An automated MG is a well-equipped independent entity which can enable the smart grid phenomenon. It allows to produce optimal power according to the dynamic changes of the power demand [5-6]. Ensuring condition monitoring based remote control of loads provides another level of control that leads to optimization of power delivery [3-5].

Internet of Things (IoT) is a recently developed technology which is defined as the network of uniquely identifiable physical devices that can communicate with each other using the Internet [2-6]. They connect and exchange data using existing communication facilities. The available electrical power generation systems, along with power delivery, and optimized utilization can be ensured using the IoT [2-6]. This improvement could be achieved through the transition to distributed "smart micro-grids" that enable large buildings to utilize local sources of renewable energy and saving energy usage [3, 5]. IP based Sensors attached to individual physical components of the MG are connected to Internet using a cloud. Access control and authorization mechanism are used to ensure the acquired data is made available to the authenticated users and also used to send/receive control actions [3-6]. Both data monitoring and control can be either local or remote. Multiple technologies are available that can aid in energy saving. However, a coordinated effort is needed to achieve this goal.

In this paper, we have integrated multiple condition monitoring and communication technologies into a common control platform which is DCS. We have used MG as a testbed to proof the concept. With the implantation of IoT enable monitoring and distributed control we have observed energy saving while running either the generator or the load.

In this paper, the smart condition monitoring and control of the campus building connected to a MG have been illustrated. The rest of the paper is articulated as follows: section 2 discusses the related work in the field. Section 3 provides the details to the proposed system for the smart condition monitoring and control. Section 4 shows the results and observations; while section 5 concludes the paper.

2. Related Work

A good number of research works has been done in the field of energy saving; but IoT based load automation in a MG setting is still an area that needs further investigation. Authors in [7] proposed an energy management system based around ZigBee and Power Line Communication (PLC) devices. System proposed by Han et al. would place an energy measurement and communication unit in each outlet and light in consumers' home. In [8] the authors once

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again proposed sensors in all outlets and lights to measure the energy usage in homes. Collotta and Pau connect the Internet of things devices using Bluetooth rather than Wi-Fi, due to the lower power consumption. The system checks the current time and cross checks it with the peak time for energy consumption by the user's energy provider [8]. The authors in [9] proposed an Internet of Energy (IoE) network that combines IoT and smart grid technology using four key components: energy router, storage system, renewable sources, and plug-and-play appliances. In [10], the system heavily interfaces with the users' smartphones to monitor the building's occupants.
From the discussed literature, it is observed that, most of the research going on in the area of smart condition monitoring and control is to demonstrate individual technology, such as, communication, condition monitoring, IoT based automation, etc. However, a comprehensive approach to integrate multiple technologies for better efficiency is missing. This paper is intended to fill this gap by integrating multiple communication, IoT and automation technologies to achieve energy saving and intelligence to building operation.

3. The Proposed System

For integrating renewable generation and smart control, MGs provide a viable platform for energy harvesting and demand management at building loads. A commercially available DCS from ABB Inc. (800-XA system) has been deployed at the McNeese State University, as a central control module fed by wired or wirelessly connected intelligent electronic devices (IED). Control software along with the human machine interface (HMI) supplied by manufacturer has been customized to control building load as well as operation of energy sources of the MG locally [3-6, 14]. For remote monitoring and control of connected building loads, we have deployed another open source building automation software platform building energy management open source software (BEMOSS) developed in Virginia Tech [15].

3.1 System Architecture

Building energy system automation is a distributed architecture, where the Internet provides remote monitoring, access, and control. All building load are IoT enabled and fed by a MG. As an additional layer of control, local devices are employed to have the proper interfacing with the load.
A main command station has been considered to transmit the control commands via a TCP/IP network. A central node collects the commands from the TCP/IP network and execute control algorithms to the remote node using wireless communication link. Fig. 1 shows the high-level diagram of this common concept.

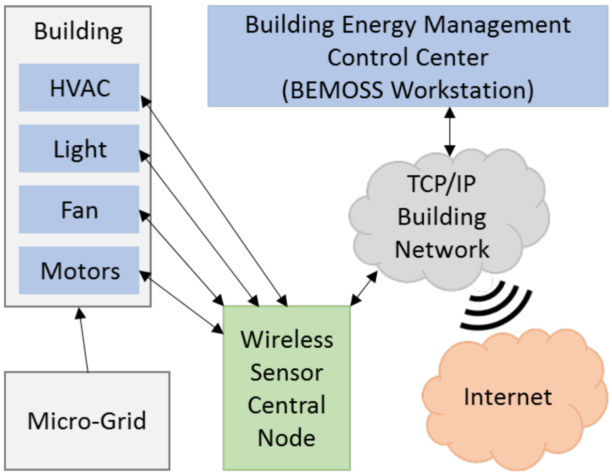


Fig. 1 High Level Diagram of System Architecture

Lighting and plug-in loads are connected to the building and remotely controlled using BEMOSS platform. Basically, we are reproducing the same operation done by the developer [15]. However, in our current study, rotating loads are controlled remotely by using IoT enabled sensors. We have used both proprietary smart sensors, as well as, customized the motor controller to be IoT enabled. For customized motor control, we have tested the system using local devices, such as, a Raspberry Pi. A conceptual diagram of motor control using Raspberry Pi has been shown in Fig 2. It is possible to employ multiple communication protocol to customize the device connection [1-2, 15]. It helps us in determining the amount of energy consumed.

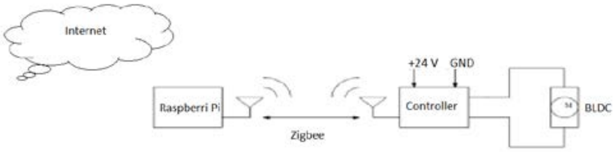


Fig. 2 Raspberry Pi- Motor Driver Communication

3.2 Micro-grid Setup as a Testbed

A MG, with generation from two 65 KW of combined heat and power (CHP) generators and 15 KW of photo voltaic (PV) sources has been established to supply a campus building [3-6, 14, 18]. The monitoring and control of the MG is performed by a DCS from ABB Inc. (800-XA system). For collecting the information ABB Inc. has provided a real-time web-based motor condition monitoring system, two of which are installed to collect monitoring data of the two motors [16, 17]. Proprietary smart sensors, as well as, the BEMOSS platform bring IoT based remote control capability to the loads connected to this MG. The primary goal of this research is to conduct a comparative study to investigate the effects of IoT based condition monitoring and intelligent control of rotating loads connected to an existing prototype MG platform. Following issues (also shown in Fig. 3) are considered in particular:

- Local or IoT based energy management of motors connecting to MG for cost saving
- Integrate multiple protocol for effective communication among MG elements (both load and generation)
- Preventive maintenance and safety assurance

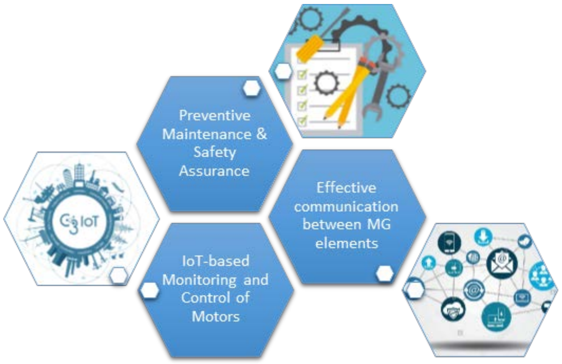


Fig. 3 The Objectives of the Research

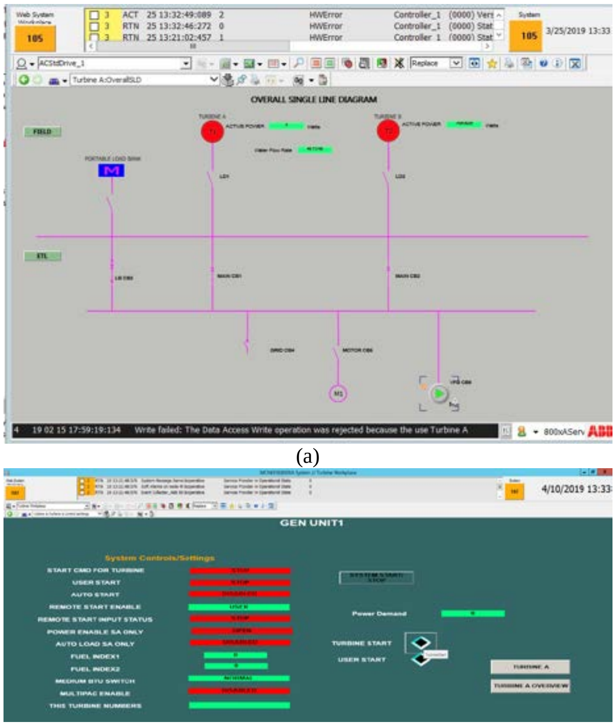
4. Results and Discussion

4.1 Implementing Distributed Control

DCS is an effective means to control energy delivery of a MG. We have customized the associated HMI for data gathering and control logic using a proprietary software from ABB Inc. called "graphicbuilder" [3-6, 14]. A set of sensors are used to collect the status information of different components of MG as input to the DCS. Subsequently, HMI visually displays information in more user-friendly manner. It uses Modbus for data transmission from the CHP generator and profibus from the PV inverter. This real-time data gathering capability enables user to perform smart monitoring and network planning for future. Fig. 4 shows the photograph of microturbines' communication with DCS and among themselves.

(a) (b)

Fig. 4 (a) Communication bay of Capstone microturbine including modbus translator and (b) DCS 800XA showing IO and communication module.



3 ACT 25 13:32:49:089 2 HWError Controller_1 (0000) Vers
3 RTN 25 13:32:46:272 0 HWError Controller_1 (0000) Stat
3 RTN 25 13:21:02:457 1 HWError Controller_1 (0000) Stat
3/25/2019 13:33
4 19 02 15 17:59:19:134 Write failed: The Data Access Write operation was rejected because the use Turbine A

(a)

4/10/2019 13:33

START CMD FOR TURBINE: STOP
USER START: STOP
AUTO START: DISABLED
REMOTE START ENABLE: USER
REMOTE START INPUT STATUS: STOP
POWER ENABLE SA ONLY: OPEN
AUTO LOAD SA ONLY: DISABLED
FUEL INDEX1: 0
FUEL INDEX2: 0
MEDIUM BTU SWITCH: NORMAL
MULTIPAC ENABLE: DISABLED
THIS TURBINE NUMBERS
Power Demand: 0

(b)

Fig. 5 (a) Single Line Diagram of the MG and (b) Generator status information displayed in HMI (graphic builder from ABB Inc.)

Fig. 5 display the single line diagram and generators operational status implemented in HMI. DCS provides automation facility by operating the switches. Fig. 6 shows the faceplate of start/stop operation of both generators as well as motor connected to the MG.

4.2 Automating the Switching Operation

For the DCS connections shown in Fig. 4, the outputs from the DCS needed to be connected to the isolation relay coils. The wiring diagram of connecting two circuit breakers for the two generators along with the PV inverter using isolating relay has been shown in Fig. 7. Currently, only three channels have been used and the remaining output channels will be used later for future automation, such as, to control relays for the full voltage non-reversing (FVNR) motor contactor and variable frequency drive (VFD) start/stop controls. The relays shown to the left were temporarily connected to prove the concept. A marshalling cabinet shown in Fig. 7(b) is hosting these connections for the sake of safety, convenience and future expansion.

Speed Actual 0 rpm
ManMode Speed Ref. 0 1200
PanMode Speed Ref. 0
AutoMode Speed Ref. 0 rpm
Motor Current 0.0 A
Motor Torque 0.0 %

(a) (b)

(c)

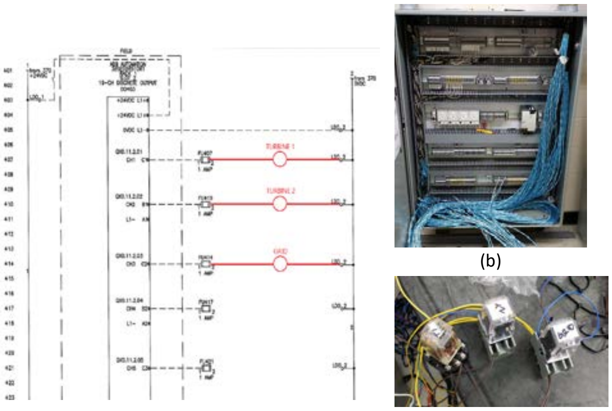
Fig. 6 Faceplate of machine operation (a) Generator (b) Motor and (c) Motor running information displayed in HMI (graphic builder from ABB Inc.)

4.3 Achieving High overall efficiency of CHP Generator by Thermal Recovery

The CHP generator is equipped with a heat recovery unit to increase overall efficiency. The circulating cold water recovers unused heat from the flue-gas. This water having recovered heat, is then circulated through the space heating system of the building providing a significant saving of heat energy during winter time. With the use of absorption Chiller this heat can be used to cool the building as well [3-6, 18]. DCS data acquisition ability helps us in determining the amount of thermal recovery and implement the control algorithm accordingly. The inlet water flow of the CHP generator can be considered as a control parameter. Following formulae has been used to calculate recovered heat [3-6]:

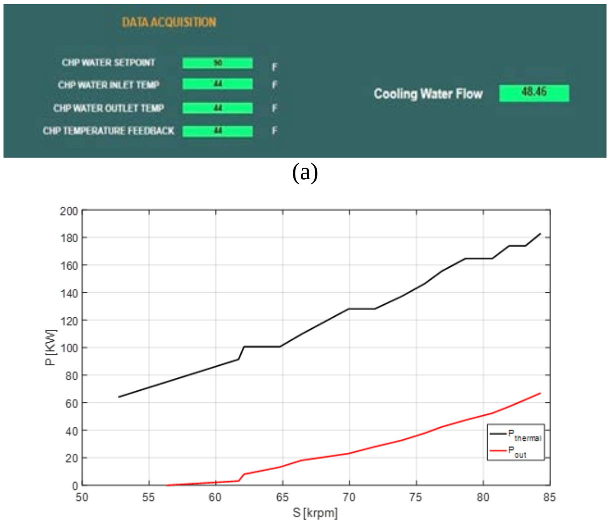
$$P_{thermal} = 0.063Q(T_2 - T_1)C_p \tag{1}$$

Where Cp is the heat capacity for water, which is 4184 J/kg-^{0}C, T_1 and T_2 are inlet and outlet water temperatures in ^{0}C, respectively and Q is the water flow rate in gpm.



(a) (b) (c)

Fig. 7 ABB Discrete Input / Output (a) Wiring Diagram (b) Photograph of Marshalling Cabinet and (c) Photograph of Isolation Relays



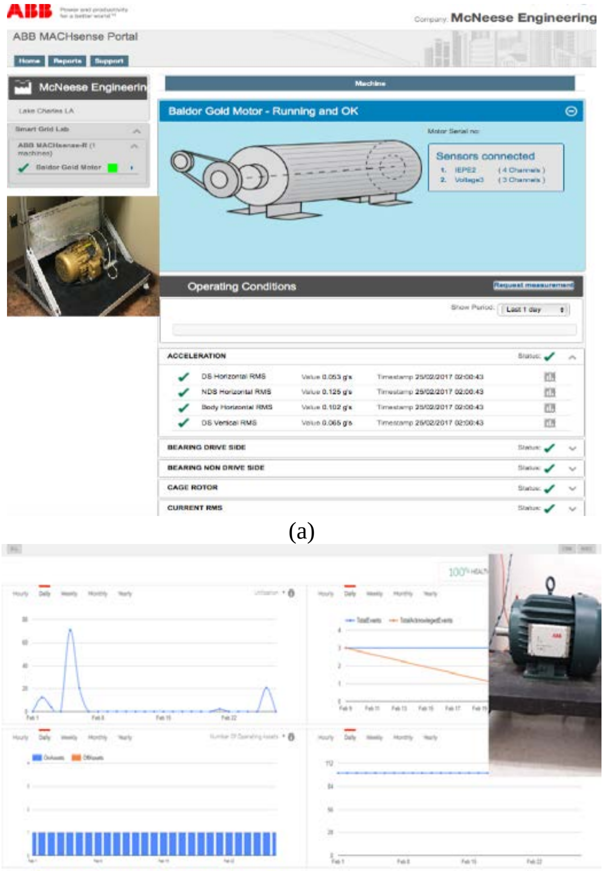
CHP WATER SETPOINT 50 F
CHP WATER INLET TEMP 44 F
CHP WATER OUTLET TEMP 44 F
CHP TEMPERATURE FEEDBACK 44 F
Cooling Water Flow 48.46

(a)

(b)

Fig. 8 Acquired temperature and water flow data shown in the HMI screen and (b) electrical output power and recovered thermal power variation with turbine speed

Fig. 8 (a) shows the value of the above-mentioned parameters displayed at HMI. Fig. 8 (b) shows the electrical output power as well as thermal power recovered by the cold water flowing through the heat recovery unit as a function of turbine speed. As observed from the figure the increased speed will generate more electrical power so does more thermal recovery. Thermal power is observed way more than the electrical output. It is expected because the electrical power conversion experience multiple types of losses whereas thermal power recovery is comparatively direct.



Baldor Gold Motor - Running and OK

Sensors connected
1. IEPE2 (4 Channels)
2. Voltage3 (3 Channels)

Operating Conditions

ACCELERATION Status: ✓
✓ DS Horizontal RMS Value 0.053 g's Timestamp 25/02/2017 02:00:43
✓ NDS Horizontal RMS Value 0.125 g's Timestamp 25/02/2017 02:00:43
✓ Body Horizontal RMS Value 0.102 g's Timestamp 25/02/2017 02:00:43
✓ DS Vertical RMS Value 0.065 g's Timestamp 25/02/2017 02:00:43

BEARING DRIVE SIDE Status: ✓
BEARING NON DRIVE SIDE Status: ✓
CAGE ROTOR Status: ✓
CURRENT RMS Status: ✓

(a)

(b)

Fig. 9 Sample web portal of motor condition monitoring systems: (a) McSense (b) Smart sensor (source: ABB Inc.)

4.3 Condition Monitoring of Building loads

For a large commercial building there are different outlets of energy consumption. Two major form of energy usages are electrical and thermal. It is critical to take integrated approach of energy management to achieve high efficiency that eventually reduces carbon footprint [11]. Monitoring both the thermal and electrical energy consumption as well as implementing energy saving control are keys to achieve the goal. Recent development of sensor equipped with embedded high signal processing power create opportunity to develop smart monitoring tool and eventually integrate in the system [16-17]. Some tools are already commercially available, and some more are under development [16-17]. Individual building energy system need customization and integration of these different technologies. Remote access to the monitoring tool along with the automation technology make the overall building energy management effort even more convenient. IoT based motor condition monitoring can bring any motor into the proper servicing before unwanted failure [3-6]. This is important for the motors carrying the critical load of the building such as motor driving elevators, heat or water pump etc.

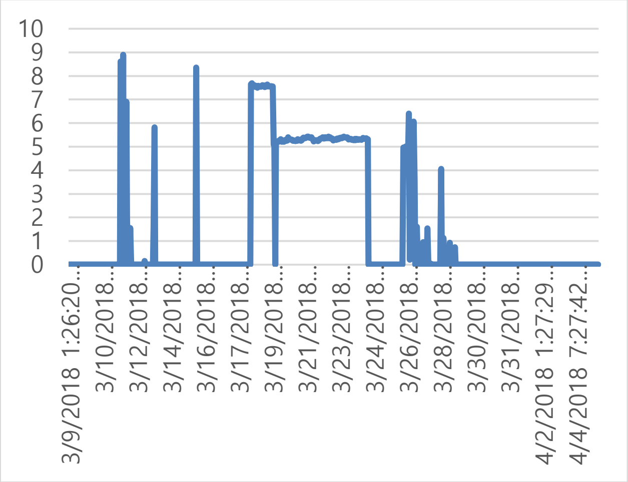
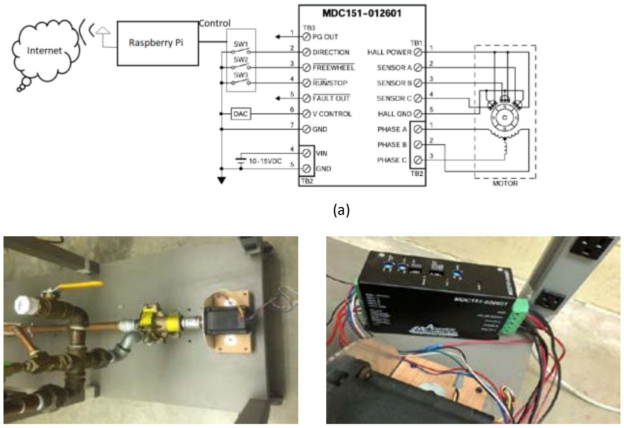


Fig. 10 Energy consumption data of motor monitored by Smart sensor

In the current study, we have integrated multiple sensors having different communication protocol in to our MG fed building power grid. We have used two proprietary smart sensors from ABB Inc. to monitor the operation as well as energy consumption of motors. Fig. 9 shows the web portals of the two sensors along with the pictures of the motors connected to them. The motor connected to the local sensor (McSense system) collects vibration and temperature data and transmit to the cloud using subscribed wireless data service. The proprietary computing algorithms processe data and present results in the web portals. Other sensor processes the time average data and buffers them in the local memory then transfers them to any smart phone using Bluetooth connection [16-17]. Using Bluetooth protocol ABB proprietary app loads this data into any smart phone and transmits to the cloud for further processing and presentation.

Fig. 10 shows the energy consumption of a connected motor monitored by ABB smart sensor. It indicates start/stop of the motor, energy consumption due to steady state, as well as, accelerated operation of the motor. By observing loading and vibration data, a user can identify the cause of energy consumption and initiate control action.

In an effort to integrate multiple technology into the MG, we have used another motor to drive pump used in the building. A prototype fluid pumping system driven by BLDC motor has been design and tested earlier. Controller (MDC151) from Anaheim Automation Inc. was driving the BLDC motor [19]. The input switch of the MDC151 controller has been modified to enable remote control using Raspberry Pi. This customization of the switch facilitates remote control of the controller using the Internet. The conceptual diagram of proposed modification of BLDC controller along with motor connection photograph has been elaborated in Fig. 11. Currently, only motor on/off and reversing operation has been implemented. However, in the future, IoT based speed control algorithm has been proposed and will be reported accordingly.



(a)

Fig. 11(a) Wiring diagram of MDC 151 with proposed modification to enable IoT based control, (b) photograph of BLDC motor driving prototype fluid pump, and (c) photograph of the controller connected to motor.

4.4 IoT based Monitoring & Control of Building loads

A testbed is created at the Islamic University of Madinah, which enables the IoT based solution for monitoring and controlling the loads at the campus. The testbed is shown in Fig. 12. The testbed is consisted of a plug controller and a light controller by WattStopper. The plug controller is provided with 220V AC input and it can monitor and control a universal plug (top-left of Fig. 12). The light controller is also provided with 220V AC input and it can monitor and control two light loads (one on the left and one of at the bottom of the cardboard). WattStopper devices uses a digital lighting management (DLM) network for communication. Therefore, a digital network module (venter-left small white device) is used to bridge the DLM network with the building automation and control network (BACnet) based BASrouter. The BASrouter (BACnet to Ethernet router, the black device in the Fig. 12) allows the BACnet and DLM to connect and communicate with the Ethernet based IP network, i.e. our Wired/wireless switch (shown on the top-right side of Fig. 12). A light sensor (top center-left) is attached with the light controller, which provides the value of the current luminescence in the room that could be used to device rules for turning on/off the lights.

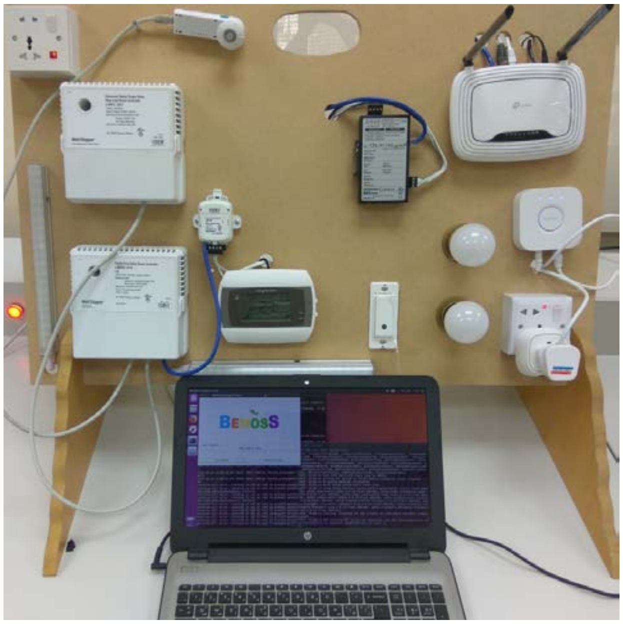
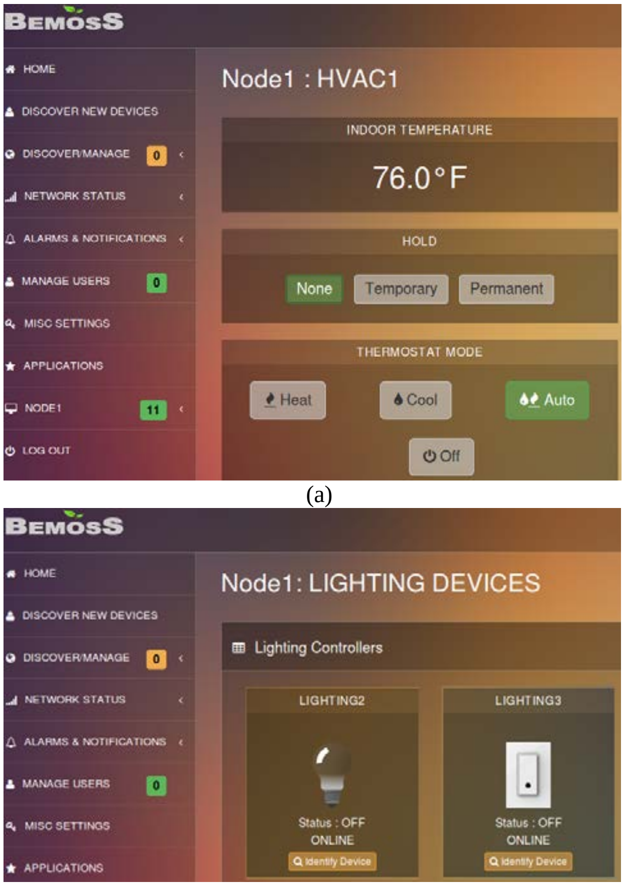


Fig. 12 A testbed for IoT based monitor and control of power-loads using BEMOSS software

A wireless enabled thermostat is connected to the wireless access point (WAP)/switch. The thermostat can be used to monitor and control the HVAC device. An IoT based switch is installed (small white device with a black dot, in bottom-center of the figure) which can monitor and control the bulb at the bottom. Similarly, an IoT-bases plug controller is installed (bottom-tight of the card-board) which can monitor and control the bulb at the top. Both the switch and plug are wirelessly connected to the wireless access point/switch. The bulbs are also IoT enabled manufactured by Phillips and are wirelessly connected to the Phillips bridge, which itself is connected to the switch by an Ethernet cable. Finally, the WAP/switch is connected to the laptop.

Using the network configuration on the testbed, the heterogeneous devices, although, from different vendors, can communicate with the laptop. For monitoring and controlling the devices, an open source software is running on the laptop, called Building Energy Management Open Source Software (BEMOSS™) [15]. BEMOSS is a software platform designed to improve the equipment detection and control capabilities of small to medium-sized commercial buildings, which is developed by our collaborators at Virginia Tech. Through BEMOSS, we are able to monitor the status of each load (light and plug), as shown in Fig. 13. BEMOSS also allows us to monitor the current power consumption (Fig. 14) and history of status and power consumption (Fig. 15). Similarly, data can be gathered from the attached sensors, such as, the luminescence sensor (Fig. 16) and weather sensor.



(a)

(b)

Fig. 13 BEMOSS snapshot for (a) HVAC and (b) light loads

Fig. 14 BEMOSS snapshot showing current consumption of a plug load

Based on the collected data rules can be created to turn on/off the HVAC, lights and plug loads or a schedule can be made. Using this approach, the power load of a building or a campus can be monitored and controlled efficiently from a centralized server.

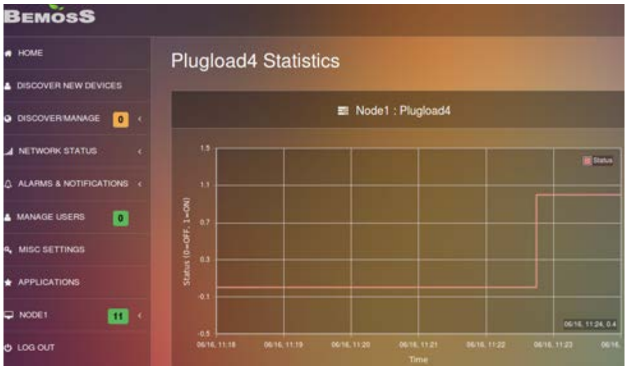


Fig. 15 BEMOSS snapshot showing the history of the plug load

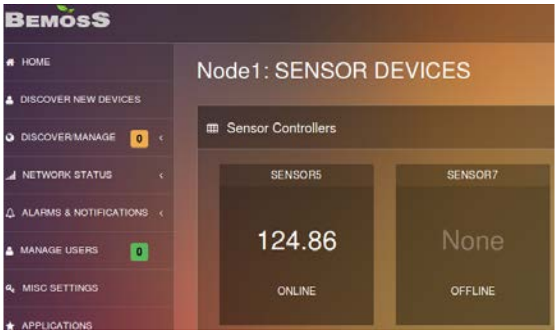


Fig. 16 BEMOSS snapshot showing the value received from the luminescence sensor

5. Conclusion

IoT enable condition monitoring and distributed control of building electrical load supplied by a MG is a building block for sustainable energy use. Information about energy consumption, automated control, energy saving, and integration of renewable energy can be achieved by properly designed MG. IoT enable monitoring and control bring intelligent to the building energy system. Results show that this technology improve energy savings as well as facilitate implementation of control algorithm for sustainability.

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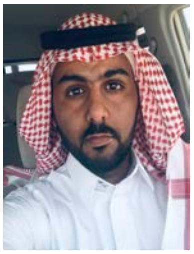

Fawaz S Aljahdali is an Electrical Engineer received his bachelor's degree from McNeese State University with a concentration in Electrical Engineering. He has two minors associated with his major; Power Engineering and Mathematics. During his studies, Fawaz has participated in National Engineers Week, where students are invited to tour McNeese's facilities and learn more about the engineering profession during a community open house. Also, Fawaz took part in DISTRIBUTECH Conference and Exhibition, where he presented his senior project about Microgrid.

M. S. Siddiqui received his BS from Department of Computer Sciences, University of Karachi in 2004. He received his MS and PhD in Computer Engineering from Kyung Hee University, South Korea, in 2008 and 2012, respectively. He is a member of IEEE and ACM. His research interests include routing, security, and management in Wireless Networks, IP traceback, and remote monitoring using IoT.

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