Smart Monitoring of Microgrid Critical Assets using Smart Sensors

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Abstract: Smart monitoring of critical components of Microgrids is required to ensure their economic and reliable operation. We implement a working MG as a test bed which is controlled by an advance distributed control system (DCS). We integrate a smart sensors network supporting internet of things (IoT) into the DCS for real-time as well as time lapsed condition monitoring of valuable assets. Cyber and physical securities are provided by proper authentication and access control to the condition monitoring and remote automation platform.

Keywords: condition monitoring, distributed generation, microgrid, remote control.

1. Introduction

The Energy demand in modern power systems dynamically changes due to more nonlinear switching loads being connected to the power grid [1-2]. Power system are getting more and more distributed generation (DGs) such as micro generators and renewable sources. Globally, power systems are striving to adopt cheaper resources. Particularly in industrially developed countries, growing environmental concern is the driving force to integrate DGs in the network. Microgrid (MG) provides one of the most viable infrastructure for the integration DGs. It can be worked either in islanded mode or in grid connected mode if wanted [1-2]. Key physical components of a MG are: sensors, switches, power electronics, energy storage devices, generators, protection equipment, control systems and smart metering [2] Geographical location, available energy resources, existing grid infrastructure, socio-economic status of the country/region play a vital role in building MG infrastructure [1-6]. As an independent entity, a well-equipped and automated MG can be considered as a building block of the smart grid approach where generation is optimized by responding to the dynamic changes of the demand [1-4]. To ensure economic and reliable operation of the network, smart monitoring and automated control of network elements are some of the key technologies to be implemented [1-6]. There are recent report showing growing interest among researchers to control and monitor MG operation using available technologies [7-9]. Here in this paper we are presenting the remote control and condition monitoring of critical components of a campus MG.

Communication mechanism between physical devices is a very critical step toward smart grid that is capable of properly responding to dynamic changes of demand [10-12]. Traditionally the wired communication technology is playing a vital role in monitoring and controlling the grid critical elements. However, there is a realistic limitation of this technology due to the physical distance, external hazard, amount of conductor wiring [2], [5]. To overcome this limitation, modern wireless technology is gaining a huge momentum. It implements the smart network of sensors that gather status information of intelligent devices using industry standard protocols [3-4]. It exists both in demand as well as in generation side to facilitate demand response (DR) in a smart grid. In [13], Tsoukalas and Gaoan show that “smart grids are an energy Internet where energy flows

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from suppliers to customers like data packets do in the Internet." Both wired and wireless communication was used to control and monitor devices connected to this campus MG.

Traditionally supervisory control and data acquisition (SCADA) is generally employed to control electric grid substations where central and multiple remote data units work in master-slave configuration. At a micro level a distributed control system (DCS) is a viable solution to control and monitor multiple components of MG which are distributed in nature. In our campus MG, we used DCS from ABB Inc. (800-XA system) and customize it for several critical components [2-4]. It also supports human machine interface (HMI) using its proprietary software and customized HMI was built data acquisition and remote control [3-4], [14]. IoT is defined as the network of physical devices to connect and exchange data. Each thing is uniquely identifiable but is able to inter-operate within the existing Internet infrastructure [11]. In our MG, condition monitoring devices are connected to internet through an IP cloud or through DCS. With proper authentication the acquired data are made available to the user. However, for supervisory control we employed access control at DCS to allow certain operation remotely.

2. Microgrid Design and Commissioning

A model campus MG has been designed and implemented at McNeese State University in Lake Charles, Louisiana to be used as a test bed for teaching and research. [3-4]. In the MG, there are two 65 KW of combined heat and power (CHP) generators from Capston Inc., 15 KW of photo voltaic (PV) simulator with battery storage unites from Chroma Inc. USA, a smart inverter (Trio from ABB Inc.) resistive and rotating loads are available. We integrate several variable speed derives into the MG which has probable application in petro chemical processes [3-4, 8-10]. Two real-time web-based condition monitoring systems are deployed for motor health monitoring. We are monitoring the performance of MG at different loading conditions and available generation so we can make proper computer-based control actions. Figure 1 (a) shows the ETAP simulation view of the MG single line diagram. Here we consider MG as both islanded and grid connected mode and run simulation later on compare the results with the actual measurement. Figure 1 (b) shows the HMI screen first developed by using proprietary control builder software from ABB Inc. and later use that for MG control. All circuit breakers are enable to operate both manually by pressing the local switch and remotely by using this HMI. The motors are operated by using variable frequency drive which are also enabled locally, as well as remotely.

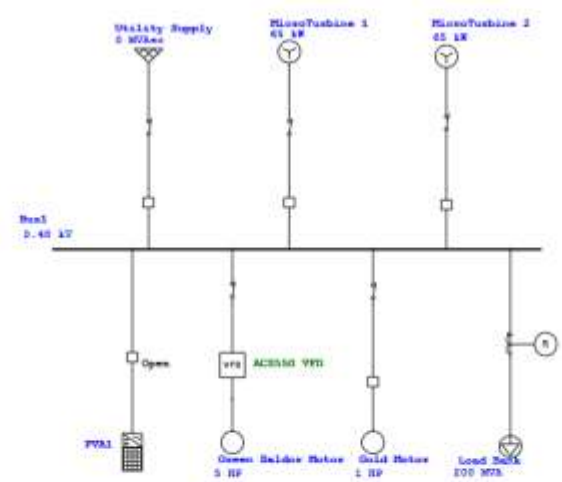

Figure 1(a). MG single line diagram used for ETAP simulation

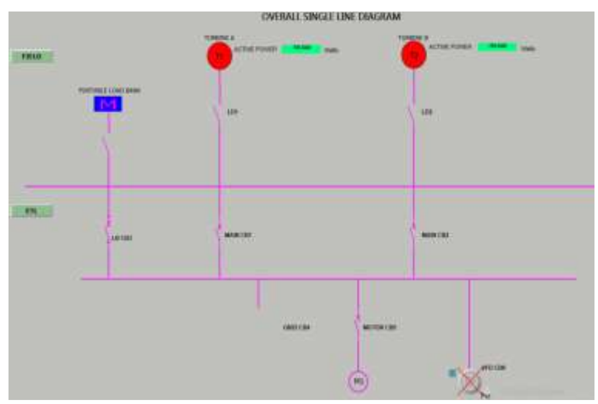

Figure 1 (b) MG single line diagram developed in HMI screen used for remote control

All these critical assets such as DGs, bus, load feeder and motors are protected by microprocessor based protective relay system. CHP generator has multiple relays for overvoltage, overcurrent, and over heating protection. The feeder and motors were

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protected by using REF/REM 615 relays from ABB Inc. Unlike traditional electromechanical relays these are intelligent. They work with sets of digital data and are capable of communication with other intelligent devices using appropriate protocol. Figure 2 shows MGG control center with attached generator and load.

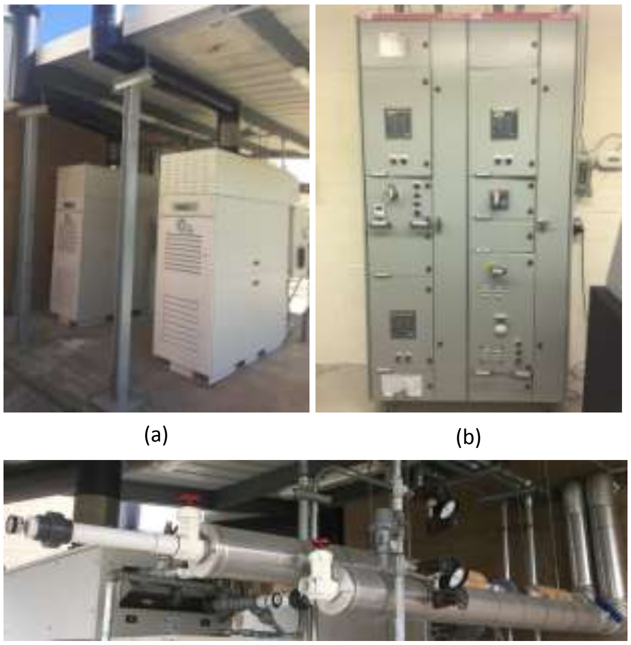

Figure 2. Photograph of Microgrid Equipment (a) two Capstone micro turbines (b) Machine Control Center (MCC) from ABB Inc. and (c) water inlet-outlet piping to recapture unused heat

3. Distributed Control and Condition Monitoring

DCS plays the central role to control and monitoring the status of different components connected to the MG. Control operation of MG is performed remotely by using 800-XA, consisting of a personal computer along with OLE for process control (OPC) server. It supports different intelligent devices (IED) using different communication protocol: for example, communication module of micro turbine can communicate using Modbus protocol, REF/REM 615 relays using 61850 protocol etc. Figure 3 shows the way the micro turbine communicates with DCS and LAN using Modbus protocol. Through a LAN switch/router and a Modbus translator located at the back of the turbine. User can gain access to the internet provided that proper authentication has been done prior to the access [9]. We built HMI for data acquisition and control action using proprietary software from ABB Inc. named “control builder.” Figure 4 shows the HMI screen for turbine automatic operation and data acquisition from a remote terminal. For example, starting and stopping of the turbine, adding/removing the load, controlling the load value such as using VFD operation can be done automatically using our current setting. However, these can be upgraded in software as more and more new hardware will be added in the future.

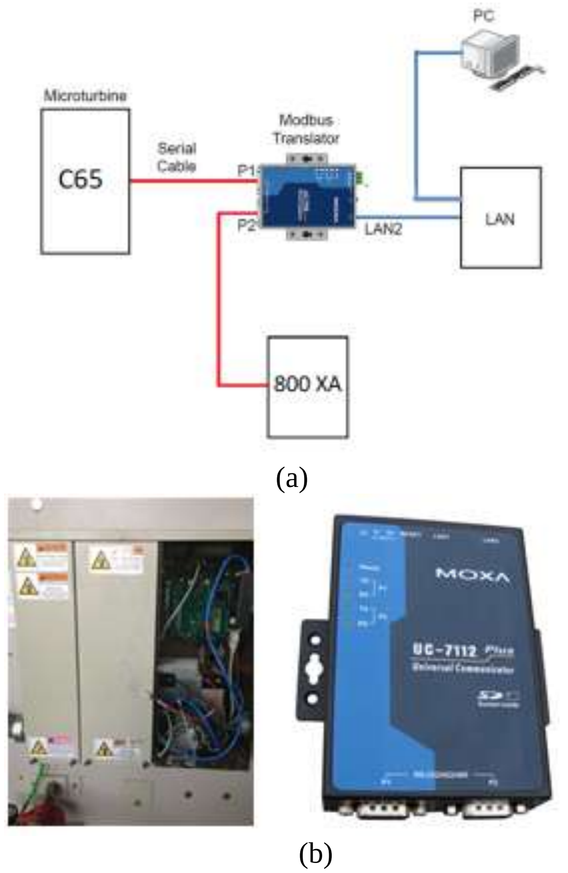

Figure 3 Micro turbine of the MG communicating with DCS using Modbus protocol (a) typical connection diagram and (b) Modbus translator located at the back of Capston micro turbine [5], [9]

All sensors indicate the status of different components, such as battery charge level, temperature, and output from each turbine in a multi-pack arrangement etc. The register

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receives this status information update these value and HMI can visually display that information. The following figure 5 shows some selected status of MT when it is running. Operator can monitor and if necessary, make supervisory action on the turbine operation based on this information. Most importantly, the information facilitates real time decision making process by using smart algorithm. Best part of this effort is that the utility can customize the algorithm based on individual circumstances: socio economic environment, availability of energy resources, reliability and power quality requirement etc. Based on the sensed and acquired data individual alarm, protocol for supervisory action, energy delivery strategy has to be be determined to maintain quality with economic generation. In our MG, we have CHP generators, so thermal gain is important to achieve higher efficiency of the overall system and energy savings [2], [5], [15].

Figure 4 (a) ABB 800 XA with interfacing of devices that support multiple protocol

We decide the control operation of turbines such as opening or closing of circuit breakers or keep the turbine in standby mode, based on acquired data such as inlet and outlet water temperature etc. The software algorithm can be set to automate the control operation. In our case we control the inlet water flow of the CHP generator based on the load. Based on the seasonal weather data, we can run the turbine at higher efficiency and does peak shaving. This algorithm implemented in the software can be an interesting future study. It is observed that by knowing thermal gain we make control operation and save energy. At our MG we are currently doing the control by using remote HMI intervention. However, in the future, water temperature will be set to an upper and lower bound make turbine operation command.

The CHP generators display the sensor output both in local display also in remote terminal through DCS with HMI capability. We monitor the inlet and outlet water temperature as T1 and T2 respectively in 0C. Also, either local reading or with data input to the analog input of the DCS from water flow meter we monitor the water flow, Q in GPM. Recovered Heat calculated as

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

Cp is the heat capacity for water it is 4184 J/kg-0C

Figure 4 (b) HMI showing MG automation and data acquisition function

Figure 5 HMI display screen of turbine condition monitoring data

Figure 6 show the thermal power absorbed by the cold water flowing through the heat recovery unit of micro turbine at different loading condition. As observed the thermal power gain increases substantially as the electrical output increases, demonstrating higher overall efficiency at higher loading condition. In brief, more load means more generation and eventually more heat recovery. However, the

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best thermal recovery was possible at a water flow rate of 52.3 gallon per minute (gpm). DCS allow remote recording and archiving of these sort of data.

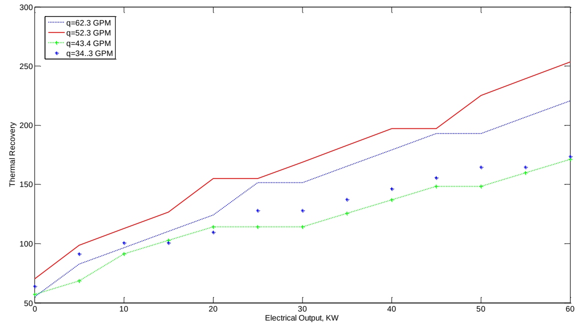

Figure 6. Thermal recovery of CHP generator at different loading and water flow condition

We also use the remote monitoring system of the CHP manufacturer Capston Inc. The proprietary software Capston Remote Monitoring (CRM) system allows users to control the micro turbine and acquire necessary status data from the sensor placed at different locations at the generator. It uses serial data port for data transmission. Figure 7 shows the control panel with listed parameters. A list of about 100 sensor data has been displayed and made available for the user. This real-time data acquisition with achieving facility provide us the smart tools for monitoring, control and future network planning.

4. Condition Monitoring MG Loads Using Smart Wireless Technology and IoT

To achieve smart operation of MG it is necessary to operate and control connected loads by constantly monitor them and able to operate remotely when required. Smart wireless technology with easier high-speed internet accessibility provided that opportunity. The traditional rotating loads are monitored by using smart sensors and lighting and another residential load can be controlled by using internet. Recent development of smart wired and wireless communication technology even makes this activity possible from remote location. Motor condition monitoring by utilizing the IoT can bring any motor into the proper servicing before unwanted failure and makes it very economical for large operation [16-17].

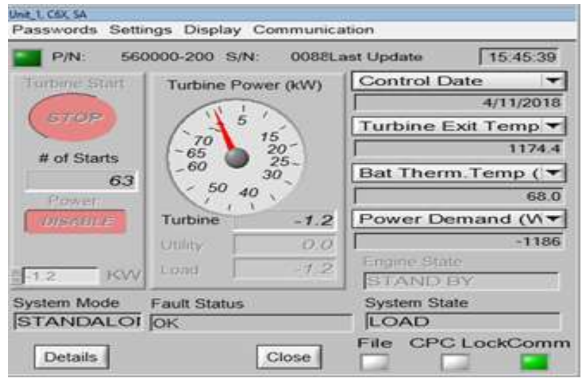

Figure 7 CRM Control window for Generator control and selected acquired data display

We used two different types of motor condition monitoring system. In the first system, an induction motor equipped with sensors to collect line current, speed, vibration and other data. These data transmit to ABB MECHsense server through dedicated wireless channel which was subscribed earlier [16]. The ABB proprietary algorithm then process the data and presented the report in the portal. Figure 8 shows the acceleration and displacement value of an induction motor collected from the MECHsense portal.

In the second system we use smart sensor from ABB to record data at an hourly interval and store them in the sensor. Bluetooth activated Mobil phone-based application allow the user to download data and send those to the cloud for later use. Similar as the first type of sensor it also records speed, vibration, energy use, etc. We manipulate these measured data to evaluate our desired quantity and generate report. The sensor also provides number of start, health trend, alert etc. User has the option to observe the data in online portal, set alarm, email notification, etc. It allows operator planner necessary tools to make schedule maintenance decisions based on the recommendation provided by the proprietary software algorithm or customize their own algorithm based on the raw data available online. Figure 9 shows the recorded motor data at different times and customize it by comparing the relation between one parameter to another.

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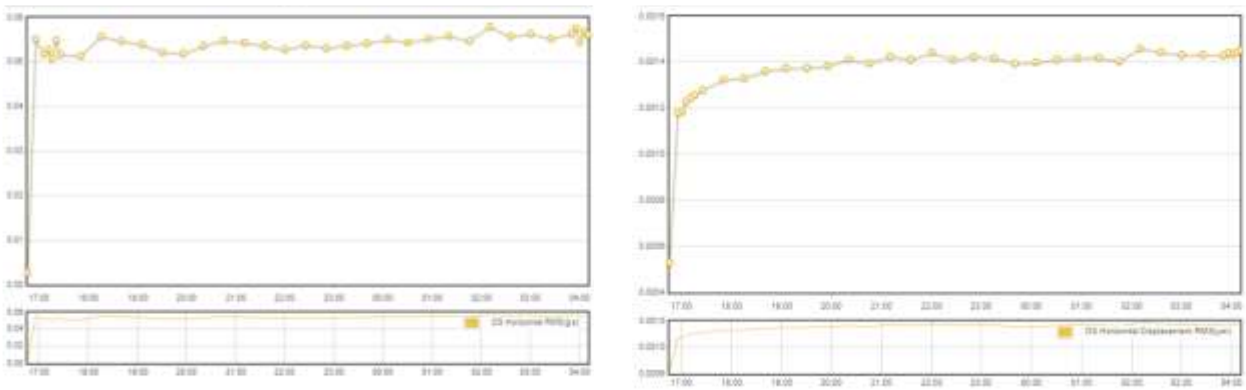

(a) (b)

Figure 8. Machsense (a) wireless transmitting unit and (b) web portal showing processed data for the induction motor connected to MG

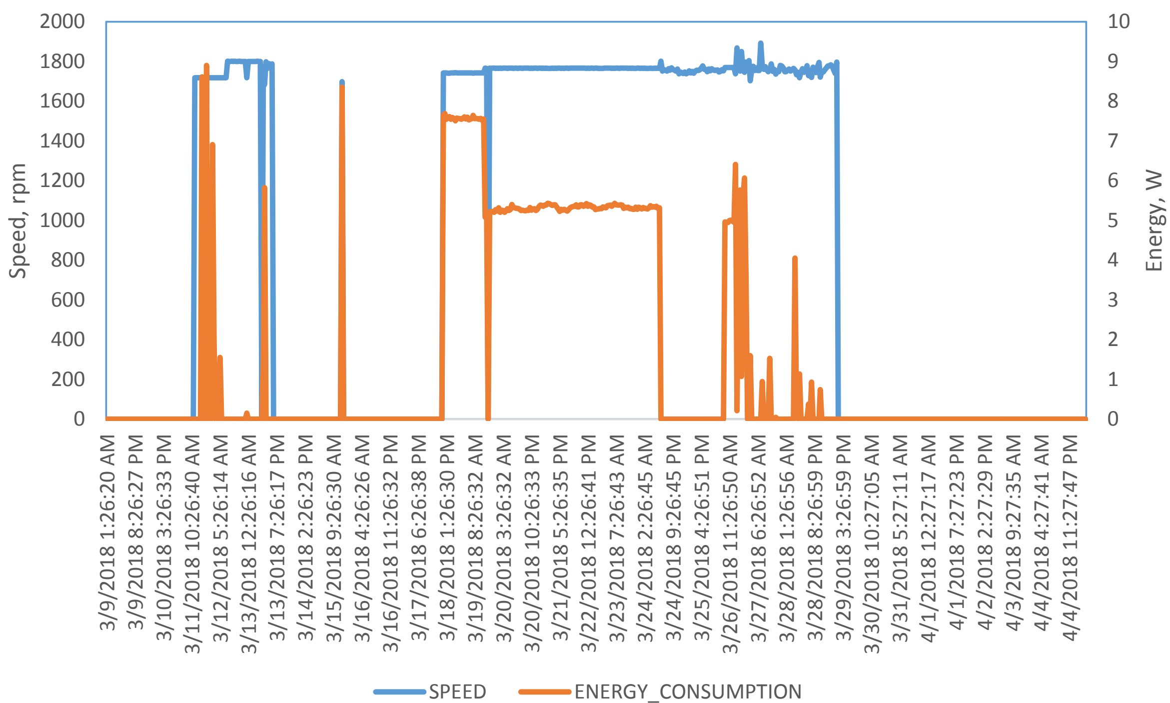

Figure 9 Condition of a running induction motor: relation between speed and energy consumption

In our microgrid we deployed IP cameras to visualize the operation of the MG and condition monitoring of critical resources. Figure 9 shows several snapshots of rotating load and MG control center from video obtained by the IP camera. We access the camera using proper authentication and with administrative privilege we can control the movement of the camera remotely.

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5. Conclusion

Critical assets of MG can be controlled by using a remote automation. IoT enable monitoring and distributed control make MG operation more viable and control decision are more accurate by integrating high efficiency generation and smart demand management. It also facilitates preventive maintenance of critical assets. Results shows that monitoring based control decision enable high efficiency operation of CHP generators by more heat recovery.

Figure 10 (a). Snapshot of deployed IP camera images (a) running MG with night vision on

Figure 10. (b) Snapshot of deployed IP camera images running motor with Machsense with wireless transmitter

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