Intelligent Platform to Enable Diverse Demand Response and Energy Conservation Applications

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Summary
The growing demand for electricity and fuel shortage is a global challenge due to rapid growth in electricity demand, especially from air conditioning in residential and commercial buildings and huge difference in peak loads between summer and winter. This means, over time, the electricity authorities will have to raise the price for electricity during the summer when it costs more to generate electricity. One way to provide a sustained short to medium term (3 to 5 years) solution, is a combination of renewable energy, energy efficiency, and peak load reduction opportunities. But to make it practical and successful, appropriate algorithms and sensing/control hardware are needed to be developed. In today's grid, with the penetration of renewable energy sources, distributed energy resources and the expected introduction of plug-in electric vehicles (PEV), demand response applications can play a crucial role in balancing the load and generation. Targeting this issue, this paper proposes to develop an innovative platform, which consists of novel optimization-control algorithms and intelligent sensors and controller designs, to enable diverse demand response and energy conservation applications ranging from individual households to the electric power grid. Our proposed platform could offer to build a smart campus where they can propose to their campus buildings flexible choices of how much power to use and when to use it, all in real-time.
Key words:
Internet of Things, Smart cities, remote sensing, plug-in electric vehicles, load management.

1. Introduction

A city could be a smart city which uses smart sensors, remote sensing and Internet of Thing (IoTs). Now a days, as the cities faces numerous types of challenges like environmental, water, electricity etc., it is very serious matter to understand that how IoTs can play a vital role to solve these issues and make future cities more sustainable [1]. To build a smart city, the IoT is a key enabler in which the actuators, sensors, remote sensing devices, network devices and communication are major components [2]. The IoT enables to manage the devices in efficient, optimized and more precise way to take the decisions faster in real time [3], [4], [5], [6].

The growing demand for electricity and fuel shortage is a global challenge. The countries such as Saudi Arabia, which do not experience any power shortage now, will face challenges in the future due to rapid growth in electricity demand, especially from air conditioning in residential and commercial buildings [8]. According to Electricity and Cogeneration Regulatory Authority (ECRA), Annual Report 2015, peak electricity demand in Kingdom of Saudi Arabia is growing at a steady rate (i.e.51.9 GW in 2014 to 62.3 GW in 2015). Another unique challenge is the huge difference in peak loads between summer and winter. The winter peak is only about 60% of the summer peak. Same ECRA report is showing 34.58 GW in winter 2015 to 62.3 GW in summer 2015 [7]. This indicates a huge unused capacity in winter while the system struggles to meet the summer peak. As a consequence of that, the electricity authorities will have to raise the price for electricity during the summer when it costs more to generate electricity. This will be on top of recent increase of electricity price in the country. Currently the price structure of electricity in KSA is slab or ladder based having residential as largest which consume 49.8%. Industrial loads constitute 16.2% and government establishment constitute 13% of the total consumption. Same report indicates that forced reduction of loads is the method currently being used to maintain the balance between supply and demand for the industrial customers [7] [8]. The residential (which is the largest) and government offices should be the focus of any demand response initiative. The approach will be motivational as well as implementation of smart grid technologies. Effective DR program will reduce the peaking sources requirement and obviously trim down the carbon footprint. For the utilities such as Saudi Electricity Company (SEC) [11], DR will result the reduction of capital needs, reduction of service cost, improvement of operating efficiency and grid reliability, improvement of service quality and reduction of line losses. SEC already take some initiative to implement DR strategy in their network. As part of that initiative, the National Grid SA which is a subsidiary of

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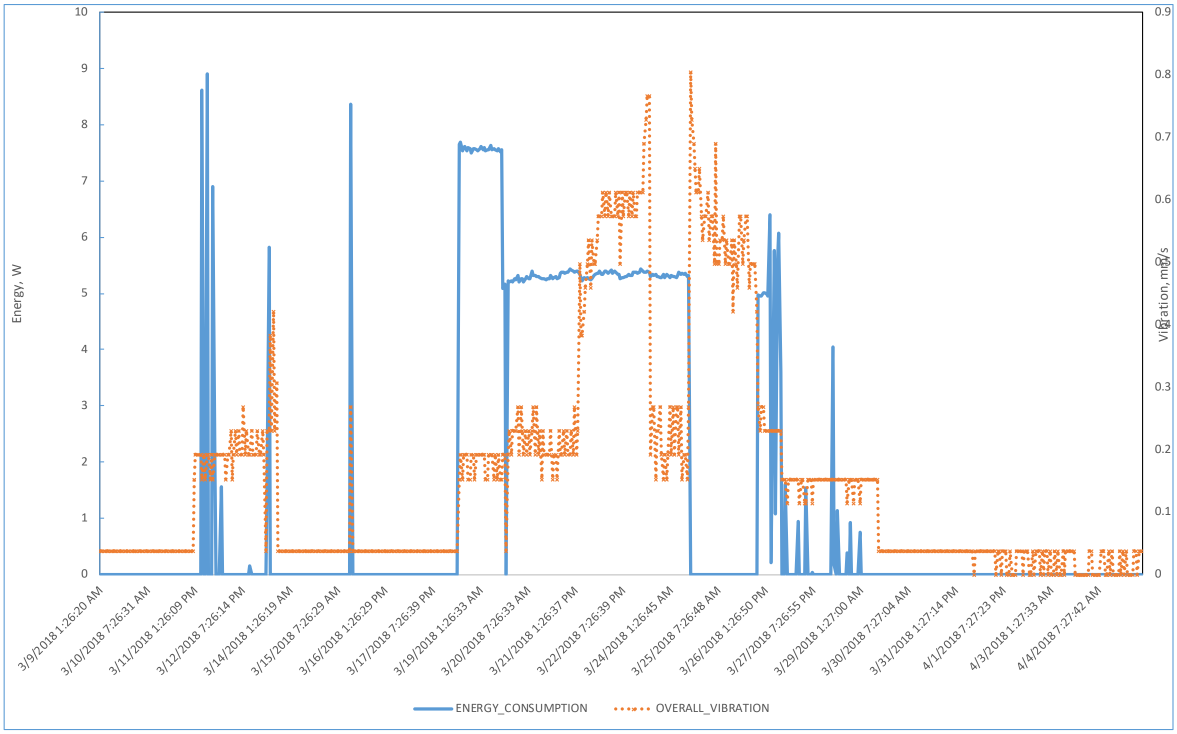

Fig. 1 IoT based demand monitoring in a campus MG

SEC has completed the installation of smart meters called Automatic Meter Reading (AMR) at all of its transmission and generation stations. The SEC intends to install 12.5 million smart meters in houses by 2025 [9-12].

Thermal energy storage (TES) can be used to shift air-conditioning (A/C) load and thus reduce peak electricity demand in Saudi grid [13]. Recent study shows that TES is effective in cooling office buildings in Saudi Arabia [14]. In this current study considering current demand scenario in KSA, we proposed a software platform to achieve the electric power system efficiency, reliability and effectiveness target, and along the way showcase how environmentally benign renewables can play a role in the country's power sector.

Academic campuses are one of the biggest users of electricity, and because of their awareness, they can develop plans and procedures to mitigate such price impacts on their cost of electricity. One way to provide a sustained short to medium term (3 to 5 years) solution, is a combination of renewable energy, energy efficiency, and peak load reduction opportunities. But to make it practical and effective, appropriate algorithms and sensing/control hardware are required to be developed. A successful deployment will show examples to entrepreneurs who can offer such services to other commercial and residential customers in the country who are the primary focus group of DR action plan. Our recent studies [14-17] show that establishing smart microgrid in a campus provide users tools to monitor the demand and deliver energy at an efficient manner. Figure 1 shows the energy consumption of a rotating load (motor) connected in the above-mentioned MG. Performance of this motor has been monitored by IoT based demand/condition monitoring technology from ABB Inc. By utilizing the platform technologies, a smart campus can be built where they can offer their campus buildings flexible choices of how much power to use and when to use it, all in real-time. These choices can be offered to the buildings at any time through the Premises Energy Management System (PEMS).

2. Methodology

One of the highlights of this research is the applicability of "demand response". The term "demand response" may have different meanings to different people. It has been used to mean "direct load control", "load management", "demand-side management by dynamic electricity pricing", "demand dispatch", etc. Here we provide a comprehensive definition:

"Demand response is a customer action to manage load to meet certain peak reduction and cost savings targets. The customer chooses what load to manage and for how long".

It is a set of programs implemented by the electric power industry to reduce or shift customer consumption to lower the peak demand and improve off-peak energy sales.

In today's grid, with the penetration of renewable energy sources, distributed energy resources (including storage), and the expected introduction of plug-in electric vehicles (PEV), demand response applications can play a crucial role in balancing the load and generation. Targeting this issue, this paper proposes to develop an innovative platform, which consists of novel optimization-control algorithms and intelligent sensor and controller designs, to enable diverse demand response and energy conservation applications ranging from individual households to the electric power grid. Another advantage is that the platform encourages the customer participation in energy conservation activities by enabling automatic end-use power management.

2.1 Platform Overview

An overview of the proposed platform is shown graphically in Figure-2. For development of the demand response protocol, the on campus electric power network is divided into two layers. They are called the substation layer and the end-use layer. The first layer involves the distribution circuit up to the smart meters at the customer premises. With automated metering infrastructure (AMI) implementation process most of the utilities will be providing these facilities in next few years [8-9]. AMI will be acting as an interface between utility's substation and end user layers. The end-use layer consists of an intelligent power management system called Premises Energy Management System (PEMS) and the controllable equipment/appliance in the building/under the platform, the demand control process is performed in a closed loop of two phases, as follows:

Phase 1 – Load allocation: When capacity shortage is anticipated due to high air conditioning demand, for example, the microgrid under study is notified of the amount and duration of the electricity shortage. The substation sends control messages to the smart meters of the target building. This message contains signals for the building PEMS to reduce or increase (for storage charging applications) its power consumption by a certain amount over a certain period of time. These activities happen at the substation layer.

Phase 2 – End-use equipment control and energy conservation: At the building level, the electric power usage is managed automatically with the use of the Premises Energy System (PEMS). Upon receiving the substation request, the PEMS decides whether to accept the offer and sends a response to the substation. If the offer is accepted, the PEMS controls the end-use appliances (loads, storage devices, etc.) so as to reduce or increase (for storage purposes) the building's power consumption as requested by the substation. Each customer can accept, decline, or partially accept any offer of load reduction. These activities are carried out at the end-use layer.

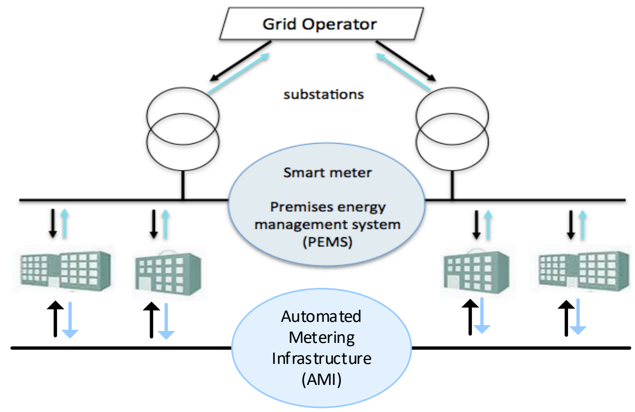

Fig. 2 Platform for smart demand response and energy conservation applications: two-layer protocol, two-way communications, and premises energy management system (PEMS)

At the microgrid level (involving one or more buildings) – within the end-use layer – the electric power usage is managed automatically with the use of the smart Premises Energy Management System (PEMS). This central control system calculates an optimal power-use plan for each building on a daily basis and controls the end-use equipment – including renewables and storage - according to the plan. The plan is devised and optimized based on various inputs, such as the daily power consumption profile, any load control signal from the electric utility, storage requirements/opportunities and user preferences.

To enable the smart energy management scheme, wireless sensor-control devices (SCD) can be embedded in the circuit breaker box of the equipment of the equipment to be controlled. In addition, intelligent control algorithms are developed for the PEMS. The PEMS and the SCD communicate wirelessly. With the aid of the SCD and two-way communication capability, the PEMS automates the end-use power management process, thereby helping the building manager achieve their own target for energy conservation and renewable use with minimal effort.

2.2 Design Overview

To facilitate load control and energy conservation activities at the customer premises by enabling automatic control of the end-use equipment. This phase belongs to the end-use layer, as defined earlier. The intelligent central control system is called Premises Energy Management System (PEMS). An overview of the end-use equipment control process is shown in Figure-3.

The PEMS monitors and manages appliances/equipment, namely HVAC (heating, ventilation, air conditioning), water heaters, PEVs (plug-in electric vehicle), along with the customers' renewable generators (solar panels and/or wind turbines) and backup energy storage devices. The PEMS controls the appliances with the aid of to-be-developed peripheral wireless sensors-control devices Figure-4. The PEMS may also control other internal electrical equipment at the building manager's discretion. The goal is to optimize the on-site renewable energy generation and manage critical loads to ensure the building occupants' comfort and safety.

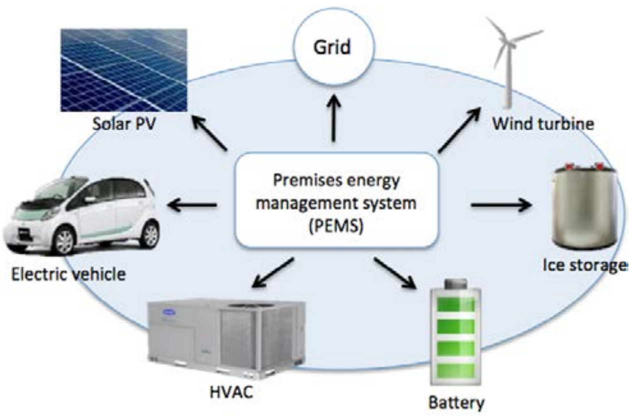

Fig. 3 End-use equipment control by Premises Energy Management System (PEMS)

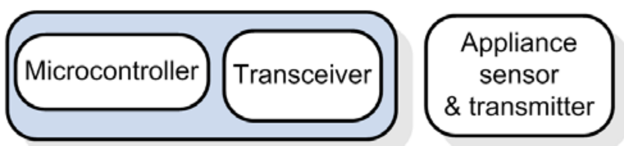

Fig. 4 Modules of the 240-Volt appliance wireless sensor-control devices (SCD)

2.2.1 Design of 240-Volt wireless sensor-control devices and HMS

The block diagrams for the design of the 240-Volt appliance wireless sensor-control devices (SCD) and the PEMS are shown in Figure-4 and Figure-5, respectively.

The general design of a 240-Volt wireless sensor-control device (SCD) includes a microcontroller, a radio frequency (RF) transceiver, and a sensor. The microcontrollers are installed in the equipment circuit breaker box to control power supply to the dedicated appliances and collect feedback data for control. The sensors are placed in appropriate locations to sense the appliance parameters needed for controlling them. To enable the intelligent power management scheme, the SCD is equipped with the capability to interrupt the power to the appliances operating at 240V and several current ratings (15–80A), as well as to report the current drawn by the appliance and sensed data to the PEMS. The SCD for HVAC would provide low-voltage and low-current switching options, which would replace its thermostat switching functions. For the PEV or the home backup storage, the SCD can provide feedback on the battery charge status. The sensors sense the appliance parameters such as indoor temperature for control of the HVAC, outlet water temperature for control the water heater, or exhaust air to monitor the clothes dryer operation. Then, the sensed data is sent to the HMS for optimizing the power use and control the appliances accordingly.

The Premises Energy Management System (PEMS, Figure-5) consists of 5 modules, namely, the Grid Interface, the User Interface, the Power Management module, the Communication module (the PEMS transceiver), and the Power Supply module. The Power Supply module is not shown for the figure's clarity. The User Interface unit is an input/output module where the user enters his/her preferences and views the power utilization of appliances. The Power Management module, equipped with a microprocessor, is the central processing and control unit of the PEMS. It acquires the user preferences from the User Interface, the electricity tariff from the grid via the Grid Interface, the sensor data (e.g. indoor temperature) to optimize the power consumption and control the appliances accordingly. The PEMS control signals are sent to the end-use appliances via the HMS transceiver. It outputs real-time information, such as current power consumption and daily saving, to the User Interface display to inform the owner of the energy conservation progress. The Grid Interface is to be designed to enable digital communications with the utility Smart Meter.

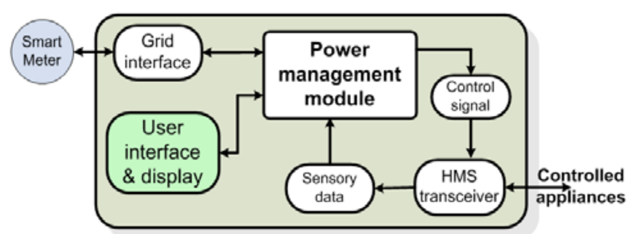

Fig. 5 Block diagram of Home Management System (HMS)

The Power Management module records and stores the building historical power consumption profiles for the owner's reference and for the power usage optimization purposes. To avoid duplicate measurement, it may simply copy the building time-series power consumption, measured by the Smart Meter. It can obtain additional power consumption data from the controlled appliances with the aid of the SCD. To optimize the customer power use, the Power Management module is equipped with an intelligent control algorithm.

2.2.2 Custom Development of Communication protocol

The wireless link of the SCD and PEMS uses protocols that operate in the unlicensed spectrum. The potential choice of the wireless protocols is Zigbee. Zigbee is a set of communication protocols for short-range, low-data-rate, and low-power digital wireless networking, which is developed by the ZigBee Alliance. It is compliant with the IEEE 802.15.4 standard for wireless home area network (WHAN). For this platform, customized versions of the ZigBee standard are to be developed to eliminate the overhead of unneeded functionality in order to provide improved power consumption, data capacity, and device costs. The wireless link includes an encryption layer to prevent unauthorized data access or appliance control. ZigBee supports the 128-bit AES (Advanced Encryption Standard) encryption. In addition, alternative protocols can be considered, such as Bluetooth and IEEE 1901 standard. The IEEE 1901 standard is the newest standard (approved in Oct 2010) for communication over power lines.

3. Conclusion

In today's grid, with the penetration of renewable energy sources, distributed energy resources (including storage), and the expected introduction of plug-in electric vehicles (PEV), demand response applications can play a crucial role in balancing the load and generation. On deployment of developed innovative platform, which will enable diverse demand response and energy conservation applications ranging from individual households to the electric power grid.

Another advantage is that the platform encourages the customer participation in energy conservation activities by enabling automatic end-use power management. By utilizing the platform technologies, anyone can build a smart campus where they can offer their campus buildings flexible choices of how much power to use and when to use it, all in real-time and communicating with utility's AMI facilities.

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