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Demand management through centralized control system using power line communication for existing buildings

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ABSTRACT

Managing peak demand efficiently is vital for maintaining uninterrupted supply of electrical power by utility providers. In this work, a pilot system was developed for managing and controlling the demand of major power consuming equipment in buildings from a central server, while relying mostly on existing infrastructure and maintaining consumer comfort. The system was successfully demonstrated on a selected group of buildings using the LonWorks networking platform. At the building level, the system utilized power line and twisted pair communication to control the thermostats of air-conditioning (A/C) units. The higher level communication was executed through extensible markup language (XML) and simple object access protocol (SOAP). The system provided control capabilities based on A/C unit priority, thermostat temperature, building type and geographic location. The development and execution of demand management strategies for selected buildings led to peak load reductions up to 74%, in addition to energy savings up to 25%. Implementing such a system at a national level in Kuwait is estimated to reduce peak demand by 3.44 GW, amounting to capital savings of $4.13 billion. The use of existing infrastructure reduced the cost and installation time of the system. Based on the successful testing of this pilot system, a larger-scale system is being developed.

1. Introduction

The demand for electrical power has increased every year in most countries worldwide due to the expansion in population and economy [1,2]. Managing peak demand is vital for most utilities to avoid blackouts [3,4]. A number of methods have been used to address the rise in peak demand. These methods include thermal energy storages, demand management and response applications, renewable energy resources and battery storages [5–13].

Kuwait has taken several measures to reduce both peak load demand and annual energy consumption including revision of Kuwait energy code of practice, as well as energy audits and enhanced building operation for government buildings and shopping malls [14–16]. With all these efforts, the national peak demand was almost doubled in 15 years from 5.36 GW in 1997 to 12.1 GW in 2012 as seen in Fig. 1 [17]. Similarly, the yearly energy consumption increased from 26.7 TW h in 1997 to 64.2 TW h in 2012 [17]. A recent study predicted that the national peak demand and the annual energy consumption in Kuwait are expected to reach 28.8 GW and 169 TW h, respectively, by the year 2030 as illustrated in Fig. 1 [18]. It is estimated that 70% of the peak load demand and 45% of the annual energy consumption are consumed by the A/C systems. Therefore, demand management efforts should focus on A/C systems. It should also be noted that electricity is highly subsidized in Kuwait, which makes energy efficiency programs harder to promote.

Demand management and response systems have been studied and implemented in many locations. Some programs focus on price response, where dynamic prices of electricity are used to encourage consumers to reduce peak demand [19]. However, it is difficult to implement price-based programs in highly subsidized energy markets, such as Kuwait. In these markets, price changes are not effective in changing consumer behavior. Other demand management programs focus on the power consuming equipment used by the consumers. During peak demand periods, power is disconnected from major appliances. The consumers' need for some appliances, such as washers or dryers, could be easily postponed to off peak hours. However, other systems such as air-conditioning units could be more needed during peak hours due to occupant comfort. A study in Norway focused on residential water heaters, as they represent a significant load in that region [20]. Another study demonstrated effective demand management for convenience stores by targeting air-conditioning, lighting, heating and refrigeration equipment [21].

Disconnecting power to appliances is effective in reducing peak demand. However, disconnecting air conditioning units in hot

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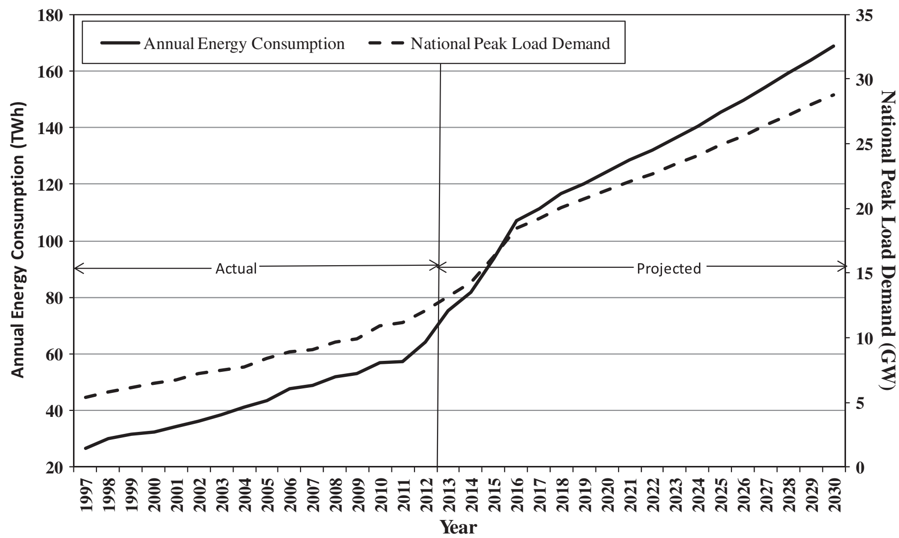

Fig. 1. Actual and projected annual energy consumption and national peak load demand from 1997 to 2030 [17,18].

climates could compromise occupant comfort. This work proposes an approach for demand management that demonstrates a balance between high demand reductions and consumer comfort. The demand response system incorporates consumer-defined priority of the A/C units and real-time space temperatures in the selection of equipment for load shedding. By raising the thermostat temperature, the system allows the A/C unit to resume operation if the space temperature rises significantly.

The aim of this work is to develop and demonstrate a pilot system for demand management (DM) utilizing the existing infrastructure in buildings, while maintaining consumer acceptance. The system provides centralized control over the major power consumers in buildings. For the hot climate considered in this work, the majority of building power was consumed by air conditioning units. Different types of buildings were selected in this study to investigate strategies for DM using the developed system. The buildings included a residential villa, an apartment, a school, a house of worship and two government buildings. The DM strategies were implemented and compared against the baseline performance for each building type. An analysis was carried out to illustrate the potential savings of implementing these strategies at a national level.

2. System architecture

The system architecture consisted of one central management system (CMS) and six distributed buildings as shown in Fig. 2. The operating platform for this pilot system was based on the LonWorks protocol. Within each distributed building, power line communication (PLC) and twisted pair were utilized as the transfer media. At the higher level, communication between the CMS and the distributed buildings was executed through extensible markup language (XML) and simple object access protocol (SOAP).

2.1. Hardware setup

The hardware requirements were based on the physical layout of each building. The number of smart servers and energy meters depended on the number of electrical supply feeders for each building, while controllers, digital thermostats and input/output (I/O) modules depended on the number of A/C units in each building. The components of the pilot system are explained in the next subsections.

2.1.1. Smart servers

A smart server utilizing the Lonworks protocol was selected for the pilot system. This server is capable of connecting various electrical devices to the internet, a local area network (LAN) or a wide area network (WAN). It enables controlling, monitoring and configuring any device within the network locally or globally. It could be used through a central server or as a standalone system. Its standard applications include web server, data logging, scheduling, email hosting and alarm functions and meter reading. These applications could be integrated together to perform specific activities based on built-in sequence of operations for the network. In the present system, the standalone features of the smart server are used to provide backup control and monitoring in case of temporary loss of communication with the CMS.

2.1.2. Power meters

Power meters were installed for each electrical supply feeder for the building. These meters were directly connected with the smart servers through twisted pair, as illustrated previously in Fig. 2. The power meters are used to measure the instantaneous values of voltage, current, power, apparent power, and other important electrical parameters.

2.1.3. Digital thermostats

Digital thermostats were exclusively designed for the pilot system with the capability to set the indoor air temperature locally by occupants or remotely through the central server. A special feature was also incorporated in these thermostats to allow an override protection by the CMS. This feature prevented any local changes to set temperatures by building occupants during the centralized control mode.

2.1.4. Controllers

A proportional-integral derivative (PID) controller was used for controlling the A/C units. It is featured with 12 I/O, multi-targeting, multi-controlling and supporting for user-interface. For this pilot system, the controller was installed to control the operations of the A/C units, but it could be used to control other equipment. The control was based on the logic discussed later for the sequence of operations.