Distributed Data Acquisition and Monitoring System for an Integrated Energy Application

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Abstract - *This paper describes a distributed data acquisition and monitoring system using a multi-agent framework for a demonstration project for integrated energy application implemented in the National Research Council Canada, Institute for Fuel Cell Innovation. The physical energy system includes three major components: renewable energy source - a building integrated photovoltaic system; a hydrogen generator – an electrolyser and a hydrogen storage system. A distributed data acquisition and monitoring system based on our previously developed agent system framework is implemented for remotely acquiring real-time parameters from the individual devices and real-time monitoring the system running status. As the first step to approach the distributed cooperation and coordination among different technologies in an integrated energy application, this implementation of a distributed data acquisition and monitoring system paves the way for its further deployment in the distributed coordination and control for each individual device to further make the entire system more scalable and robust.*

Keywords: Agent, data acquisition, system monitoring, hydrogen, renewable energy.

1 Background

The increasing application of green energy resources plays a fundamental role in resolving environmental pollution and global warming problems. Diminishing conventional fuel sources also suggests us to consider renewable energy as an alternative energy source, such as solar and wind energy. However, as its inherent intermittent nature, renewable energy by itself cannot meet the practical requirements of most applications. Hydrogen, as an energy carrier, provides a good opportunity for effectively utilizing these energies in various applications, such as hydrogen fuel cell for automobile, residential and mobile applications. With the advancement of fuel cell technology, hydrogen and renewable energy will play an increasingly important role in the emerging hydrogen economy in a clean and efficient manner.

The integration of different energy devices in an energy system requires advanced control, communication and coordination which are essential for handling the tremendous traffic of information and power in an increasingly complicated interconnection energy system. The conventional monolithic, centrally control systems in charge of system coordination cannot scale economically to meet the demands imposed by such systems. The solution is to design and implement a robust system architecture matched to the distributed, multi-participant, and dynamic nature of a distributed resource management [1]. Multi-Agent System (MAS), as one of the important research topics in distributed intelligence, is promising to play an important role in the distributed energy system applications.

As one of the energy nodes on the BC hydrogen highway projects [2], an energy system prototype of building integrated photovoltaic (BIPV) integrated with a hydrogen production and storage system is installed at the National Research Council Canada, Institute for Fuel Cell Innovation (NRC-IFCI) at UBC campus. The integrated energy system and our research on the intelligent MAS techniques and its applications are described in this paper. As the first step to approach the final implementation of a distributed control and coordination system for this kind of application, a remote data acquisition and monitoring system based on our previously proposed IDEA framework (Integrated and Distributed Energy Applications) using MAS technology is presented and implemented. The implemented architecture technically paves the way for further upgrading the control and communication system in a distributed manner and makes it possible for further enhancing system's scalability and robustness. The future concluding remarks and perspective are discussed at the end of this paper.

2 Integrated Energy System

The objective of this integrated energy system is to create a prototype hydrogen generation system using photovoltaic renewable energy to reduce the amount of power drawn from the electrical grid. The complete system consists of a renewable energy - PV array, AC to DC power supply, hydrogen production- electrolyser, hydrogen compressor, hydrogen storage vessel and de-ionized (DI) water supply. In this section, the three major components namely renewable energy, hydrogen generation and hydrogen storage subsystems as well as their integration are briefly introduced.

2.1 Renewable Energy Source

The photovoltaic effect, i.e., directly convert sunlight into electricity was first observed almost two centuries ago. However, the development of quantum theory took a long time before this phenomenon was explained and practical devices were manufactured. In the past few decades, the decreasing manufacturing costs and increased efficiency achieved, opened a new market for photovoltaic technologies. Applications such as remote communication equipments, navigational aids, railroad switching systems, and irrigation are just a few of the areas where photovoltaic are being used. Solar electric system has also demonstrated its ability to provide power in urban settings for bus shelters, street lighting, safety lighting and warning signs. In residential applications, many remote homes have been using photovoltaic systems as an alternative to the high cost of extending power lines or running diesel engine generators, other utilities are experimenting with roof top photovoltaic systems for distributed generation of electricity.

The newest application of photovoltaic is called Building Integrated Photovoltaic (BIPV) and it offers the greatest hope for commercialisation of on-site power generation. BIPV incorporates photovoltaic modules directly into a building by replacing conventional building materials such as roof tiles, curtain walls and rain screens with photovoltaic.

In this integrated energy system, the glazing in the present building were replaced with BIPV modules, each solar PV module has a rated power output of approximately 70 watts. In order for the system to operate as planned, a coordination system is developed to determine when to operate the electrolyser from the DC power supply and when to operate it from the PV array. Paralleling the PV and the DC power supply creates a self -regulating system that will automatically switch between electrical sources as required.

2.2 Hydrogen Production & Storage

An electrolyser is a device that converts water (H_2O) to hydrogen (H_2) and oxygen (O_2). The reaction is driven by applying current to the electrodes of the electrolyser and is equivalent to recharging a battery. A PEM electrolyser, which is a comparatively new technology that produces very pure hydrogen, is applied in this application system. However, as the gases are produced at just above atmospheric pressure, a gas compressor is integrated with the electrolyser regardless of the designed gas-pressure storage. A one Nm^3 hydrogen per hour (nominal) manufactured by Hydrogenics is adopted in this project.

Hydrogen storage is one of the toughest technical challenges facing the hydrogen and fuel cell industry. Storing liquid hydrogen requires sophisticated cryogenic vessels and management of the inevitable gas boil-off. Metal hydride storage can achieve a good volume reduction with considerably less energy input but it is very heavy with the less percentage of hydrogen by weight. The current high cost and lack of availability of technology make it impossible for using it in some applications. Storing hydrogen as a pressurized gas is adopted by this project. In this demonstration, the hydrogen storage tank is required to deliver greater than 134 Nm^3 at 100 psig hydrogen (8 hours back-up, 20 kW fuel cell UPS @ 40% net electrical efficiency), after a review of cost and space requirements, the compressor output pressure and storage pressure requirement of 2000 psig is targeted. The hydrogen storage tank is designed to hold a 200 Nm^3 at 2000 psig.

2.3 System Integration

Figure 1 shows the integrated energy system, in which the electrolyser is powered by PV array and/or by grid power through an AC-DC power supply. The rated power input by the electrolyser is designed to be less than the rated PV system power output. A coordination and control system is implemented to switch withdrawing power either from PV array or from grid. The generated hydrogen is compressed by an internal integrated compressor and stored in the hydrogen storage cylinders for future use.

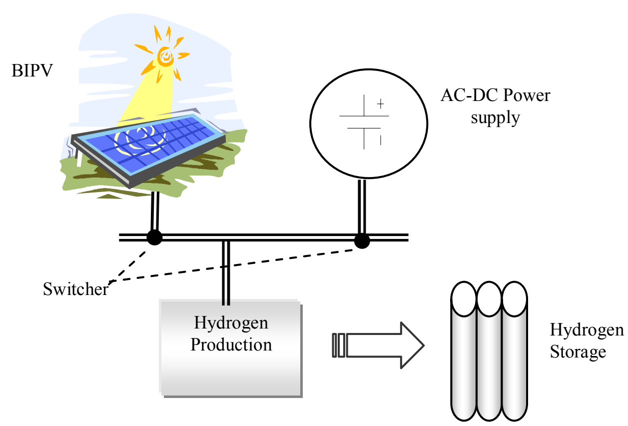

Figure 1. Integrated energy system

Currently, the control system is centrally implemented and connected to the building Ethernet network. A set of monitoring sensors located in various devices is connected to the electrolyser control system. Based on our previous research and development on agent technology [3], a data acquisition and monitoring system is implemented to remotely collecting real-time data and monitoring the system real-time status. This implementation built a solid basis for its further application in a distributed coordination and control system both in a virtual environment (a simulation tool to validate the designed operation logics) and in the physical system. An agent-based distributed control and coordination system will allow to plug-in any additional components, such as a fuel cell, to make the integrated system scalable and robust.

3 IDEA framework and MAS

A Multi-Agent System can be considered as embedding a "general software technology that was motivated by fundamental research questions" [4]. It is inspired by distributed artificial intelligence and characterized by a number of autonomous, generally heterogeneous, and potentially independent agents working together to resolve special problems. As described by Brennan [5], autonomous, cooperative, and open are the typical characteristics of an intelligent agent system. Agent technology provides an ideal optional solution for resolving the coordination and control problems in distributed energy systems.

Based upon our previous research and expertise on holonic design and operational environment [3][6] under the IMS-HMS project [7], we proposed and built a system framework for Integrated and Distributed Energy Applications - IDEA [8] based on intelligent agent and discrete simulation technologies to provide an effective, efficient and economical method in facilitating energy system design and engineering analysis. The developed IDEA framework has been previously applied in one of our industrial projects for hydrogen assisted renewable power applications [9].

As shown in Figure 2, there are five major components (i.e., physical energy system, simulation, database, coordination and control, and human system interface) in the IDEA architecture, whose application is scalable from energy devices, energy node to energy network [10]. The remote data acquisition and system monitoring subsystem presented in this paper is implemented using the IDEA framework in the demonstration project. According to the IDEA system framework, the next step's implementation of a coordination and control logic will be validated in the simulation environment first, which will provide a sound and solid basis for its further physical application in scaling up the system's capability (plug-in and play for a new component, e.g., add a Fuel Cell subsystem to the integrated system,) in the physical system environment.

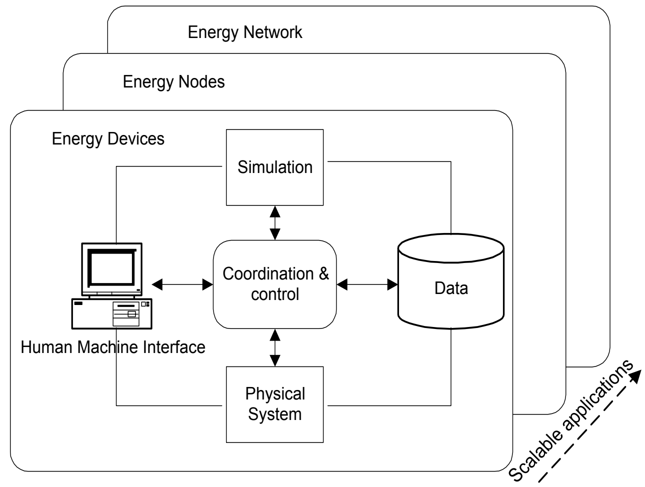

Figure 2: IDEA system architecture

4 System Implementation

As the first step of IDEA application in this project, part of these system components, i.e., physical system, database, and human system interface and the agent management and service system were developed and implemented at this stage (as seen in Figure 3). The virtual environment (in the dashed frame) is expected to be developed to simulate the physical system behaviors and to validate future distributed coordination and control logics before they are applied to the real physical system.

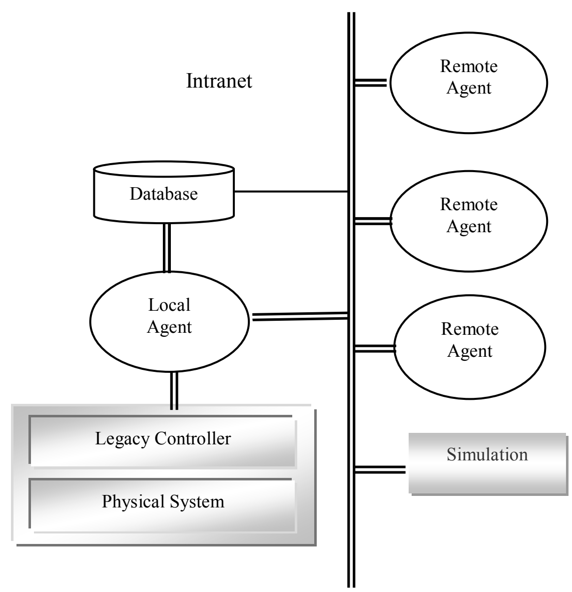

Figure 3. System implementation

4.1 Human Machine Interface

In the IDEA system architecture, the human machine interface (HMI) provides an efficient mechanism to support the human expert in the decision-making process, system configuration and operations. The role of the HMI in this project at this stage is twofold, the first is to launch the agent management system and its integration with the legacy controller; the second role is to initialize any number of remote agents within the system for remotely monitoring the system real-time running status. This mechanism provides an efficient way for staff to monitor the system's running status without physically be present on-site. The remote control of the system has yet been implemented with the HMI as the demonstration project is still at its earlier running stage. With further deployment of any new plug-in equipment, the capability of human intervention in the decision process will be added. Presently, the HMI is tightly integrated with its individual agent as stated in the following sessions

4.2 Data Acquisition

The physical integration for data acquisition in each device is through the input/output signal. All of the signals are classified into five categories: 28 analog inputs to hydrogen production system, such as PV voltage, PV current, PV array temperatures, etc; 34 discrete inputs to the hydrogen production system, such as water pressure, storage inlet pressure, coolant flow, etc.; 27 discrete out, such as oxygen purge value, PV contractors inhibit, heat trace contactor, etc; eight status bits, such as emergency stop, standby bit, recovery bit, etc.; and 63 alarm bits for each individual devices.

These signals from each device are captured by various sensors and then passed to the imbedded legacy functional module. The local agent wraps the legacy functional module and communicates with it through event passing. It is the local agent's responsibility to save these data into a local database. Figure 4 shows the HMI of a legacy agent and its integration with the legacy functional module.

4.3 Remote System Monitoring

In the current version, all of the agents are running within an intranet. Once the local agent starts, the agent management and service are also automatically started in the LAN. The user can feel free to start any number of monitoring agents within this LAN and it will automatically registered to agent management and service system. The communication among agents is implemented through FIPA Agent Communication Language (ACL) [11]. Presently, most of the tasks are completed through the "REQUEST" performative as in FIPA ACL standard sent by the remote agent to the local agent and "INFORM" performative sent by the local agent to remote agents.

Figure 5 gives an example of the HMI of a remote agent, in which the real time system running parameters are presented in the graphic interface.

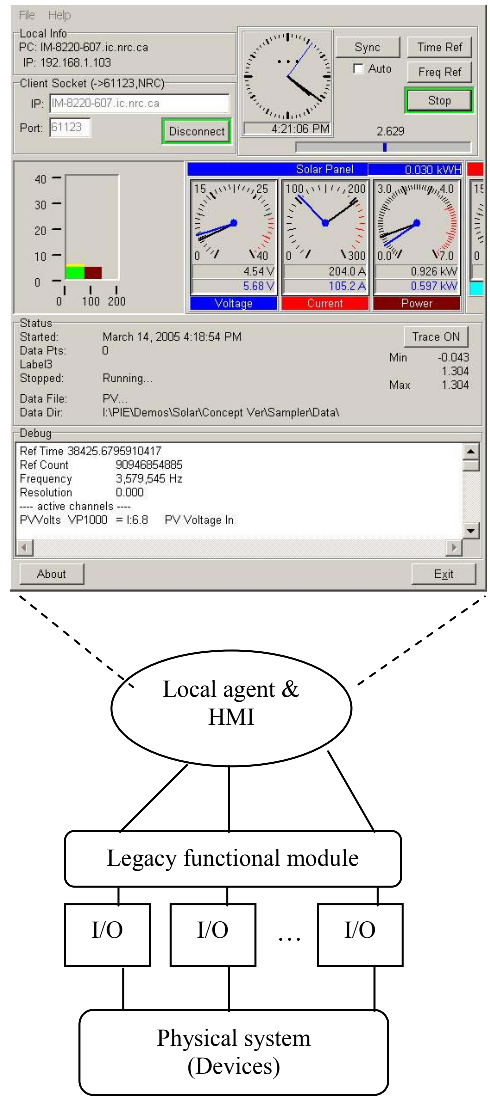

Figure 4: Local agent HMI and its integration with legacy system

4.4 Database

As indicated in Figure 3, a comprehensive database is directly integrated with the local agent. All of the real-time data is acquired through the local agent and saved to a centralized database, which can then be shared through the distributed agent system. The database also provides the (future developed) simulation model useful information about the energy system for various operational scenario analysis and what-if analysis. The load profile for hydrogen production, renewable energy profile of PV panel, and parameters of the any energy components in the system are also saved in the database.

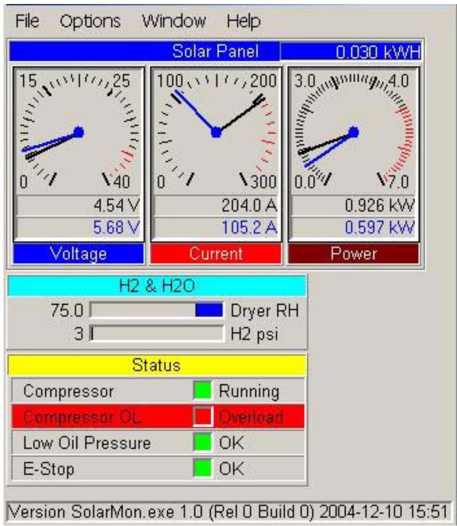

Figure 5: HMI of a remote agent

As the first step to approach a completed distributed cooperation and coordination using IDEA framework among different technologies in an integrated energy application, this demonstration of a distributed data acquisition and monitoring system for the energy application system is proved to be feasible and practical. This implementation paves the way for its further deployment in the distributed coordination and control for each individual device to further make the entire system more scalable and robust.

5 Conclusive Remarks

This paper presents the first step application of IDEA framework in an integrated BIPV and hydrogen production system. A brief description of the physical energy system followed by the development and implementation of a distributed data acquisition and monitoring system using this agent-based framework are introduced. As mentioned in this paper, the previous proposed IDEA architecture and integration technologies have been validated in both our prototype project and in our industrial application project. Based on the IDEA system architecture and technologies used in these applications, our ongoing development will focus on the development of a distributed coordination and control system and the virtual simulation environment, through which to enhance the physical system's increasing requirements on scalability and robustness.

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