ENGINEERING JOURNAL

Review

Iterative Learning Control of Energy Management System: Survey on Multi-Agent System Framework

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Abstract. This paper presents a brief survey of recent works on Iterative Learning Control (ILC) of Energy Management System (EMS) based on a framework of Multi-Agent System (MAS). ILC is a control methodology which is especially suitable for dynamical systems whose control tasks are executed in a finite time interval and are repeated over and over. The key idea of ILC is to take available system information in the past and current runs, to generate the control input for the next run. EMS is a computer-based system to monitor energy consumption, control operation, and optimize energy supplies and demands. EMS can be naturally modeled as MAS since each power-generated or power-consumed component of EMS can be cast as agent. Each agent of MAS is a dynamical system itself and has its own target such as tracking desired trajectory and minimizing energy. Moreover, there are common objectives of EMS which aim to attain its energy efficiency, reliability and optimality. Then one agent can cooperate with other agents to achieve some global objectives, in addition to their own local goals, by exchanging information with other agents. Lastly, we will explore some open research problems and their potential applications.

Keywords: Iterative learning control (ILC), energy management system (EMS), multi-agent system (MAS), building temperature control (BTC).

ENGINEERING JOURNAL Volume 20 Issue 5
Received 26 August 2016
Accepted 26 August 2016
Published 25 November 2016
Online at http://www.engj.org/
DOI:10.4186/ej.2016.20.5.1

1. Description of Energy Management System and Multi-Agent System

Energy Management System (EMS), in a broad sense, refers to a system to monitor and control various aspects such as measurement, operation, scheduling, and optimization of energy-related systems. Prominent applications of EMS includes electric power grid EMS and Building Energy Management System (BEMS). For power networks, especially for the next-generation or the so-called smart grid with a strong information and communication technology (ICT) infrastructure and intermittent renewable energy penetration, EMS becomes a crucial component for efficiency, reliability, and flexibility of power grids. At a smaller scale, BEMS is much less complex but still very important since the energy consumed in residential and commercial buildings takes a major portion of the total energy consumption. For example, in the U.S. the residential and commercial buildings consume up to 40% of total electricity [1] whereas in Thailand the share by residential and commercial sectors is up to 42% of total electricity [2]. Thus, researchers have been paying much attention to EMS and its applications in power grids and BEMSs to increase their efficiency, reliability, and optimality. One way to achieve that is to replace the traditional centralized EMS by distributed EMS, i.e., to allow the local measurement, control, and optimization, and the information exchange among local sensors and local controllers to achieve the global targets of highest efficiency and lowest energy consumption while increasing the system reliability by eliminating the central coordinator which receives, processes, and broadcasts a large amount of information to local components.

Multi-Agent System (MAS) is a graphical concept to describe a set of subsystems or so-called agents which may or may not have physical interconnections but certainly have communication links among agents. The key advantage of MAS is its capability of simultaneously achieving global objectives for the whole MAS and local goals of each agent by performing local measurements and controls at each agent and collaborating among agents using that local information. Therefore, MAS and its cooperative control problems have been extensively studied and applied to many practical systems due to their attraction in both theory and applications, including power grids, wireless sensor networks, transportation networks, systems biology, etc. [3, 4].

MAS is a natural representation of EMS since each power-consumed or power-generated component in EMS can be cast as an agent and each agent has its own target such as minimizing energy or fuel consumption while the common objective for the whole EMS is to attain its energy efficiency, reliability and optimality. Furthermore, MAS fully support distributed controller design which is the aim of recent control issues in EMS. Figure 1 displays a demonstration of a building temperature control system represented by MAS framework.

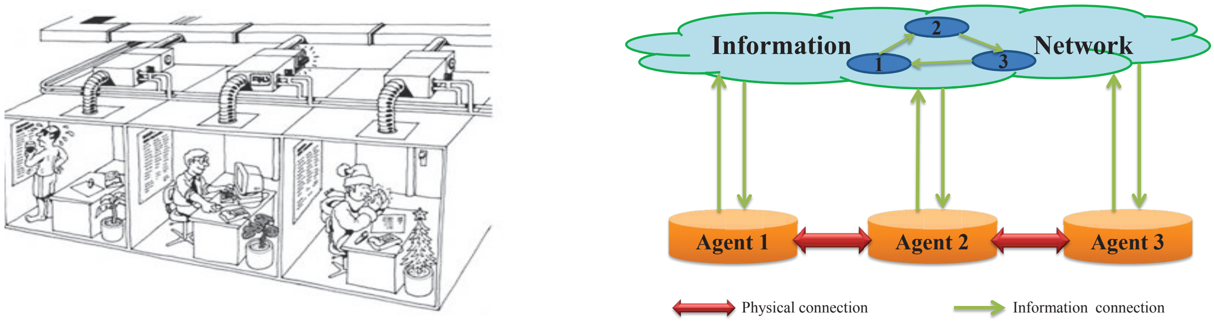

Fig. 1. Demonstration of a building temperature control system: (left) a three-room model and (right) MAS representation.

2. Iterative Learning Control and Applications to EMS

Iterative Learning Control (ILC) is a control approach specifically developed for certain systems which operate periodically and whose control tasks are repetitively executed [5]. The key point of ILC is the utilization of system information including the control input and the tracking error between the system output and the desired reference of the past and current iterations to generate the control input for the next iteration so that the system performance is improved trial-by-trial. As a result, ILC outperforms conventional controllers when dealing with repetitive control systems [6, 7]. In particular, conventional controllers attempt to asymptotically regulate the system output to the desired trajectory. Typically, it takes infinite time for system output to converge to the target trajectory. However, ILC operates for a finite time interval and drives the system output to the desired trajectory at all samples over the time interval as the number of trials increases. Moreover, for the systems in the presence of inexact model or repeated disturbance, ILC can give perfect tracking whereas conventional controllers cannot always achieve a desired performance. Hence, ILC has been an important research topic in the field of control systems as well as has been employed to a large number of engineering applications.

Recently, several researches has utilized ILC as control algorithms for specific EMS with or without employing MAS framework. In what follows, we briefly summarize recent results [8, 9, 10, 11, 12, 13] and introduce some research directions on designing ILC law for EMS described as MAS.

In [8], ILC is combined with the Internal Model Control (IMC) principle to design a control algorithm for a nonlinear solar thermal plant where the variant solar radiation is approximated with a periodic disturbance. The control objective aims to keep the outlet fluid temperature from the system at a given optimal value by manipulating the fluid flow rate while taking into account the time delay induced by the fluid flow. Next, research in [9] focuses on on a small-scale refrigeration system and the control target is to keep the temperature within a certain range in presence of a large and repetitive disturbance caused by load variation. It is showed that ILC is a really effective control method when combining with the classical PI controller to increase the tracking performance.

Building Temperature Control (BTC) is a sub-problem of BEMS. There are several interesting studies including [10] and [12] which have great potential of ILC application to EMS. While [10] only considers an office building with a single zone represented by an electric-analogous 3R2C model, [12] investigates multi-room buildings whose models are described by RC model. Both researches employ learning controllers together with feedback controllers to improve the tracking performance under repetitive disturbances. Furthermore, [12] also considers the input constraints in ILC design. At the largest scale of power grids, [11] and [13] propose ILC for the Economic Dispatch (ED) problem and the load scheduling problem which aim to optimize certain cost function of generation and consumers, respectively. The work in [11] employs ILC and consensus algorithm for MAS to derive the same incremental cost for generators which is the solution for the ED problem. On the other hand, [13] utilizes ILC for parameter adjustment of the load scheduling as an optimization problem.

Overall, ILC has been employed as an effective control method for various problems in EMS, especially for improving tracking performance and eliminating the effects of periodic disturbances. When applying ILC together with classical control methods such as PID control, it gives a much better control performance. In addition, the combination of ILC method and MAS framework results in a powerful approach to deal with large-scale problems in EMS and to derive fully distributed control algorithms. The structure of ILC for MAS is illustrated in Figure 2.

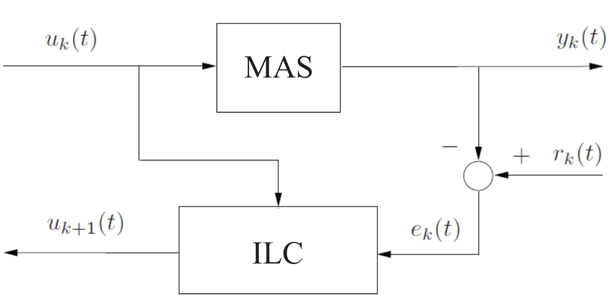

Fig. 2. Structure of ILC for MAS.

3. Future Research

Although there have been several studies on ILC and MAS for EMS, there is a great potential for future researches on this topic. First, the results in [8, 9] may be extended to a larger scale, i.e., solar thermal networks and refrigeration networks instead of considering individual plants. Second, BEMS, especially BTC problem, is a very suitable system for MAS-based ILC researches. BTC problem can be naturally treated as an MAS with the tracking control problem formulated as a nonlinear optimization problem and solved by ILC method. Finally, there are many problems in smart grid which can be considered under ILC and MAS framework. For instance, extensions of design problems considered in [11] and [13] with additional physical constraints, or their combinations, or the Environmental Economic Dispatch problem [14], or the load control problem, just to name a few. All of aforementioned researches would lead to interesting results and great impact to both industrial automation control systems as well as power and energy systems.

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