ID-Based Power Flow Coloring for Power Fluctuation Management: Concept and Classification

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Abstract-- This paper implements the unique concept of the power flow coloring, by allocating a unique ID to each power flow between a specific power source and a specific power load. It allows us to design versatile power flow patterns between distributed power sources and power loads by taking into consideration energy cost, accessibility and gas emissions. This paper first explains the concept of the power flow coloring and then compares existing implementation methods of the power flow coloring with our proposed cooperative distributed control implementation method. The realization of our proposed control method is also discussed in this paper.

I. Introduction

Internet of Energy (IoE) is stated as a combined dynamic network infrastructure based on communication protocols that connect the energy network with the Internet allowing units of energy (locally generated, forwarded, and stored) to be dispatched on demand. IoE proposes novel solutions for combining or interfacing the Internet with the power systems with functions for electric transport more sustainable, efficient, clean, secure and seamless. Like internet networks, the aim of the IoE is to provide a robust system for exchange of energy between distributed power sources, storage batteries, and power loads.

To achieve this will require extensive intelligent monitoring and control of distributed and alternating energy production, storage, and consumption. Moreover, the dynamic power consumption behaviors of power loads with distinct characteristics and power usage patterns of storage battery has attracted an increasing amount of attention from government and energy companies all over the world such as Feed in Tariff (FiT) and grid parity. These dynamic changing power supply and consumption patterns yield in development of sophisticated power control systems with varied components

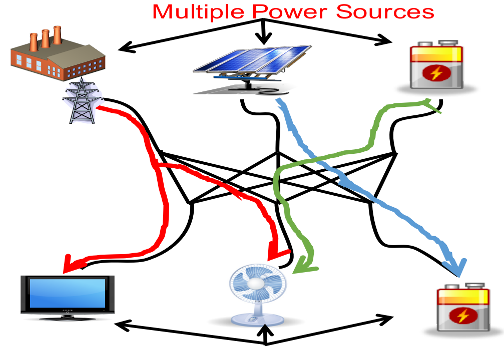

Fig. 1. Concept of The Power Flow Coloring.

and versatile functions relying heavily on reliable high-speed communication networks for monitoring and control.

In order to develop such sophisticated system, it is a crucial and fundamental requirement to give a unique ID to each object/entity such as IP addresses in the Internet, social security numbers in welfare and health care systems etc. In [1], [2], the concept of the Power Flow Coloring is proposed, which assigns the unique identification to each power flow between a pair of power source and a load. Fig. 1 illustrates the power flow coloring concept. It allows us to design adaptable power flow patterns between distributed power sources and loads. Note that as shown in Fig. 1, a power source can supply power to multiple power loads and a power load can be supplied power from multiple power sources. For example, watch a TV with the utility supplying power, mix utility power and power from storage battery to operate a fan, and charge battery with PV generated power.

There have been proposed several implementation methods for the power flow coloring, which can be classified as power switching, power routing, cooperative distributed control method, and consignment of electricity. (See Table. 1).

II. The Power Flow Coloring for Power Fluctuation Management

Our proposed cooperative distributed control (CDC) method for the power flow coloring can be categorized as power source and load control method. It can be used not only inside a house domain but also over the existing grid without mass reserves. Our method focuses on power sources and loads control and manages power fluctuations (both noisy power fluctuations and large power variations) by controlling power sources and loads in real-time.

A CDC system consists of multiple power sources and loads connected with a common electric power line. A power agent (i.e., power source agent, or power load agent) is attached to each power source and load. The power agent is responsible for measuring and controlling suppling/consuming power of the attached power device (source/load). All power agents communicate with each other for the cooperative work to realize the power flow coloring (see Fig. 2).

A user can specify nominal power levels (in Watt) for each power flow from a specific power source to a specific load. If the physical power levels are constant, then there is no problem with the existing methods. But in real physical world, power supply and consumption by a power source and a power load fluctuates and sometime varies a lot due to the automatic changes of the operation modes (e.g., automatic power control in an air conditioner) or nature of power sources and loads. Due to dynamic power fluctuations, these assigned

Methods for The Power Flow Coloring	Factors Considered and Controlled	Terminal Control and Scalability	Power Fluctuation Control
Power Switching	[3] implement routing by switching lines on grid between a group of power sources and a group of loads and maintain power balance - Need dedicated power line between a power source and load - No storage mechanism is required - Cannot scale up without changing existing grid structure - Cannot handle power flows from multiple sources to one load	- Used for small-scale power grid - No Terminal Control	No explicit power fluctuation control
Power Routing	[4], [5] proposed a method which can send power from particular source to particular load in packets by appending header and footer - Multiple power sources and loads over a shared power line - Each power router should be equipped with storage battery - Support all connection types (one-one, one-many, many-one) - Change existing grid structure	- National wide grid only - No Terminal Control	No explicit power fluctuation control
Cooperative Distributed Control Method	[1], [2] Our proposed method uses co-operative distributed control (CDC) methods to implement power flow coloring - Manage all types of connections between power sources and loads - No change in existing grid structure - Instantaneous power supply and consumption control - Maintain voltage stability with master/slave architecture	Handle power fluctuations - Noisy fluctuations - large power variations Can be used for any type of grid (small-scale grid, large-scale grid)	
Consignment of Electricity	Efficient power supply system for multiple power sources and loads - Manages volumes of power i.e., no real-time control - Voltage Stability is not required	Used for national wide grid only	Out of scope consignment power supply

Table. 1 Classification of The Power Flow Coloring.

nominal power levels are hard to maintain physically by power sources and loads.

To deal with practical situations, there is a need to manage power fluctuations of power devices. The main idea to deal with power fluctuations is through message exchange between power agents. When the power consumption of a power load fluctuates, its associated power load agent measures the power fluctuation and sends that data to its power supply agent(s), which then controls the amount of power supply. On the other hand, when the power supply fluctuates, its associated power source agent informs the fluctuation to its related power load agent(s) so that their power consumption match with the fluctuating power supply. The presence of power fluctuations leads us to another problem for maintaining the voltage stability of the entire power system. To maintain the voltage stability of the entire power system against power fluctuations, the master and slave role assignment scheme has been proposed among source agents.

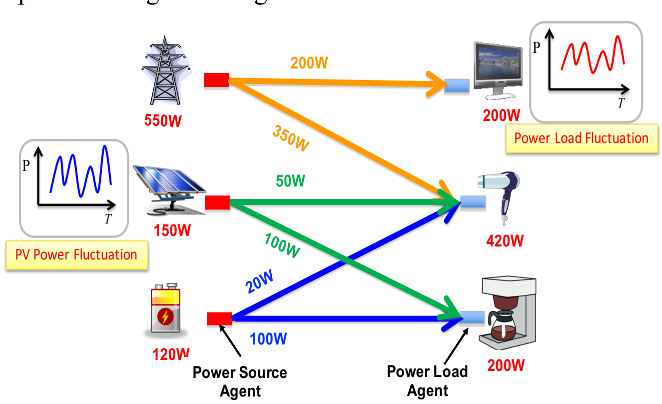

Fig. 2. Realization of The Power Flow Coloring with CDC Method.

III. Concluding Remarks

In this paper, the concept of the power flow coloring along with the classification of different implementation methods is presented.

A cooperative distributed control method is proposed to implement the power flow coloring for power fluctuation management caused by power sources and loads. Our proposed method is already implemented in real physical world with various home appliances and distributed power sources. In future, our target is to scale up our proposed system to realize the power flow coloring over a national wide grid. The real world experimental results will be given at the conference presentation to show the effectiveness of our proposed method in managing dynamic power fluctuations of fluctuating power sources and power loads in real-time.

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