Agent-Based Feedback Control for Fluctuating Power Sources and Loads: Watch TV with PV Power

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Abstract— The presence of renewable energy sources with large power variations, dynamic power consumption behaviors of appliances, and power usage patterns of storage battery yield in development of sophisticated power control with diverse and versatile components. Our proposed agent-based feedback control method can manage power flow streams with diverse characteristics e.g., the power generated by a photovoltaic is characterized by power fluctuations and available time periods. A power with dynamic fluctuations can directly flow into load without effecting other power flows. Consequently, we are able to use variety of power sources with diverse characteristics.

I. Introduction

Taking into account the present market trends and future opportunities, a major growth in small scale power generation is observed [1]. This is mainly because residential and commercial areas represent a major part of power consumption and carbon dioxide emissions and partly because small-scale photovoltaics, wind turbines, fuel cells, and storage batteries have been introduced into houses, factories, and in office building. This results in drastic change in structure of residential and commercial areas [2].

Hence, we need to have a sophisticated control method of multiple power sources and storages so that they can cope with dynamically changing power consumption patterns and power supply conditions. This paper particularly focuses on power flow streams between fluctuating power devices, for example, a user can watch TV with PV generated power.

II. Representation and Compilation of a Power Flow Pattern (PFP)

A power flow is defined as the power flowing from a specific power source (PS) to a specific power load (PL) with some power level in Watt. A PFP consists of multiple power flow streams between multiple PSs and PLs and specifies which PS should supply how many Watt to which PL.

A. Categorization of Power Devices

All power devices (PSs/PLs) are classified into two categories based on their types, characteristics, and functionalities (see Fig. 1). These categories of power devices are: *controllable and fluctuating*. A controllable PS^c/PL^c can control its power (supply/consumption) against the power fluctuation whereas, fluctuating PS^F/PL^F cannot control its power. A power agent (i.e., source agent, SA or load agent, LA) is attached to each PS and PL, which measures and controls supply/consume power of the attached power device. The power agent associated with controllable power devices and

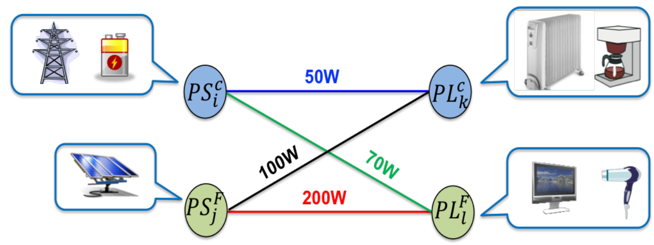

Fig. 1. Categorization of power devices: controllable and fluctuating.

fluctuating power devices are represented as; SA^c/LA^c and SA^F/LA^F, respectively. It is assumed that the system can design a consistent and realizable PFP, which satisfies all constraints on power supply and consumption including capacity, minimum/maximum power limitation and maximum power flows from/to each power device with both types.

B. Compilation of a PFP

The compilation of a PFP is defined as a process which uses given PFP and measured power levels of fluctuating power devices (PS^F/PL^F) and compute power levels for controllable power devices (PS^c/PL^c) under the power balance constraint such that the total power supply from a PS is equal to the total power consumption of PL(s) attached with particular PS.

This paper focuses on power flow streams between fluctuating power devices only. Since both power devices are fluctuating and vary a lot due to the nature or operation modes of power devices, it is not possible to maintain specified nominal power levels (Watt) in PFP. Therefore, there is a need to design a compilation algorithm which can link between physical power levels by power devices and nominal power levels in PFP.

Our idea to control the power flow between fluctuating power devices (PS^F/PL^F) is to ask cooperation from the controllable power devices (PS^c/PL^c). As these power flow streams cannot be controlled by fluctuating power devices alone, the support from controllable power devices can make it possible to control the power fluctuations. This idea implies a constraint that each fluctuating power device involved in this type of power flow, must be directly attached with at least one controllable power device (see Fig. 2) otherwise it is not possible to control power supply or consumption of the fluctuating power device. Then, attached controllable power devices on both sides of the power flow can control the power fluctuations of the fluctuating device. In case of multiple power flow streams between fluctuating devices, system solves conflict one after the other.

C. Compilation Algorithm

As is well known, the power supply and consumption by fluctuating power devices fluctuates. This means that the

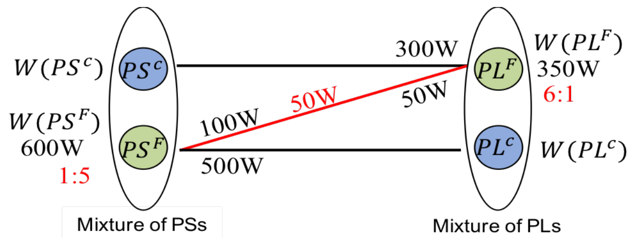

Fig. 2. Compilation of a PFP between fluctuating PS and fluctuating PL.

nominal power levels in PFP are just the reference and hard to maintain physically. To bridge between these nominal and physical power values, system converts given PFP into power ratios and then sends computed power ratios to each power agent for the realization of agent-based feedback control.

Fig. 2 shows a power flow between PS^F and PL^F. The PFP specifies that the total power supply of PS^F, $W(PS^F)$, is 600W and power ratio is computed as 1:5. According to power ratio, PS^F will supply $W(PS_1^F) = 100W$ for the power flow with PL^F and $W(PS_2^F) = 500W$ for the power flow with PL^c.

On other hand, the total power consumption of PL^F, $W(PL^F)$, is specified as 350W supplied by two PSs (PS^c and PS^F) and power ratio is computed as 6:1. That is, PL^F will consume $W(PL_1^F) = 300W$ supplied from PS^c and $W(PL_2^F) = 50W$ supplied from PS^F. The given algorithm is used to compute power levels for controllable power devices when PFP and measured power levels of attached fluctuating power devices are given.

Algorithm: For power flow between PS^F and PL^F

if $W(PS_1^F) \neq W(PL_2^F)$ **then**
$W_{min} = Min\,(W(PS_1^F), W(PL_2^F))$
$W_{diff}^{ps} = W(PS_1^F) - W_{min}$
$W_{diff}^{pl} = W(PL_2^F) - W_{min}$
if $W_{diff}^{ps} > W_{diff}^{pl}$ **then**
$W(PL^c) = W_{diff}^{ps} + W(PL^c)$
else
$W(PS^c) = W_{diff}^{pl} + W(PS^c)$
end if
end if

The power flow between fluctuating power devices has two power ratios (one is computed from PS side and other is computed from PL side) which introduces a conflict of power levels for the given power flow. In order to solve the conflict of power levels, the difference of power supply (W_{diff}^{ps}) and consumption (W_{diff}^{pl}) would be computed by taking the minimum power level (W_{min}) on both sides of the power flow. The controllable power device attached with fluctuating power device with higher difference will compensate (supply/absorb) for the power imbalance on the power flow.

Note that, the assignment of power levels according to power ratios would be assigned to fluctuating power devices first than the controllable power devices. This is the conflict resolution for the static system, for practical situations an agent-based feedback control protocol is introduce in next section.

III. Agent-Based Feedback Control (ABFC) Method

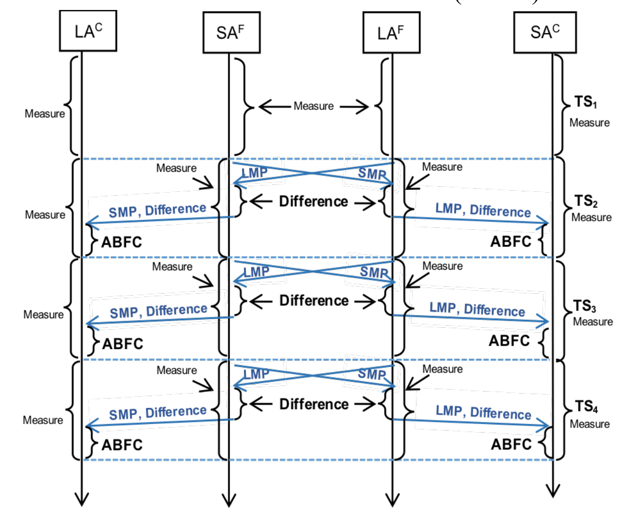

Fig. 3. Agent-Based Feedback Control Protocol.

For practical situations, we introduced a system protocol, which can realize static algorithm for power fluctuations and make the power system work continuously without being effected by communication and computation delays.

At first, the time axis is partitioned into a series of time-slots (TSs) with a fixed length. The system designs a PFP and compute power ratios which then broadcasts to all power agents. During TS_1, all power agents just measure power supply and consumption by their corresponding power devices.

In TS_2, power agents attached with fluctuating power devices exchange measured power levels (of previous TS) with each other. Based on received power information, each fluctuating power agent computes difference between received power level and its own measured power level, which is then sent to attached controllable power devices along with measured data. This exchange of power levels is done by message transmission. The message transmission from SA^F is shown by source measured power (SMP) while from PL^F is shown as load measured power (LMP) in Fig. 3. The algorithm for each controllable power agent is addressed to compute power levels for controllable devices with ABFC method based on the received measured power information during TS_{t-1}.

The $TS_t, t \geq 3$ realizes the feedback control with computed power levels for controllable power devices. We conducted couple of experiments with multiple PSs and PLs with both types which will be presented at conference presentation.

Acknowledgement: This work was supported by JSPS Grants-in-Aid (KAKENHI) Grant Number JP16K12394.

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