Power Flow Management for Smart Grids: Considering Renewable Energy and Demand Uncertainty

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Abstract--**The increase in distributed energy resources using renewable energy such as photovoltaic and wind generation systems require new strategies for the operation and management of the electricity because of their intermittent nature. The high proportion of distributed energy resources and uncertainty of power loads makes the power flow and energy management complex. Due to the uncontrollability of power devices, power imbalance between generation and consumption is an important issue to be solved. Hence, there is a need to develop sophisticated power flow control systems which can control power flows from distributed power sources to power loads in real-time. This paper presents the power flow control mechanism, which assigns power to controllable power sources and loads, and connections between them to absorb the power fluctuations caused by fluctuating power sources and loads.**

I. Introduction

With the ever increasing demand for low-cost energy and concerns about environmental costs of non-renewable energy resources, a new trend is developing towards distributed energy generation in diverse applications both at domestic and commercial levels. This is primarily because these areas represent major part of power demand and gas emissions and partially because small-scale power generating systems and storage batteries have been introduced into houses, factories, offices, and local communities [1].

The large scale integration of small-scale distribution energy resources ends in extreme changes in the structure of residential and commercial areas [2]. Community-grids and Micro-grids are the examples for such modified structures, which include various power generating sources, energy storage facilities, in-house/building power distribution system, and a variety of consumer electronics. Changing the structure of power systems provides lots of opportunities for the operation of system [3]. Based on the controllability of power devices, the direction and amount of power flow at each power source and load can be controlled, which provide the technical foundation for the realization of our proposed power control. The electricity generated by renewable energy sources fluctuates depending on its intermittency and change of weather conditions. Similarly, power demand also vary a lot due to its operation modes, user preference etc. In this fluctuating environment when power supply and demand both change dynamically, a real-time power flow control algorithm is required. To manage fluctuations effectively, cooperation with controllable power devices seems to be the promising technology. Hence, goal of this power flow control problem is to find the power levels for controllable power devices, and power flow for each connection between them.

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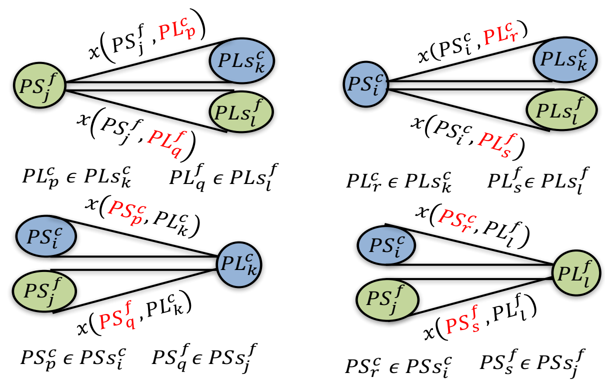

Fig. 1. Representation of power sources and loads with power flows.

II. Characteristics of Power Devices

The proposed system consists of distributed power sources, power loads, and connections between them. All power devices are divided into two types based on their features, and functionality such as, controllable source/load, PS_i^c/PL_k^c, and fluctuating source/load, PS_j^f/PL_l^f. A controllable device can control its power against power fluctuations whereas, fluctuating power device cannot control its power. For the representation and categorization of power devices, please refer to Fig. 1. A connection can be described as power flow from a power source to a power load. Each connection, $x(PS_i^c, PL_k^c)$, is assigned with some power level, which shows the amount of power from power source to a power load. Moreover, all power devices are bounded between minimum and maximum power generation/consumption limitation, which shows the capacity of each power device as,

$$PS_i^{c-min} \leq PS_i^c(t) \leq PS_i^{c-max} \quad (1)$$
$$PS_j^{f-min} \leq PS_j^f(t) \leq PS_j^{f-max} \quad (2)$$
$$PL_k^{c-min} \leq PL_k^c(t) \leq PL_k^{c-max} \quad (3)$$
$$PL_l^{f-min} \leq PL_l^f(t) \leq PL_l^{f-max} \quad (4)$$

III. Problem Description

As it is well known that the power supply/consumption of a fluctuating device changes dynamically due to the physical constraints, operation modes, weather conditions etc. This means that the power levels on each connection need to be assigned at each time instance according to the surrounding fluctuating environment. Here, it is assumed that the power levels of fluctuating devices are measured at each time.

To accommodate power change in power levels of fluctuating devices, power levels for controllable devices and connections need to be computed. The power fluctuation/ change can be positive (power level for next time instance is increased) or negative (power level for next time instance is decreased) as shown in Fig. 2. In order to adapt practical situations of power fluctuations, a control algorithm is proposed in this paper.

IV. Power Control Algorithm

It is necessary to combine controllable power devices with fluctuating power devices since no renewable power source is sufficient to be able to supply stable power to connected loads. At first, the proposed power control algorithm finds a control path to search which controllable device can accommodate power change under the power limitation constraints given in Eqs. (1)-(4). Secondly, control algorithm computes power change to be compensated and then assigns the power levels for controllable devices and connections. That is, total power supply and demand are always same as,

$$\sum_{i=1}^{I} PS_i^c + \sum_{j=1}^{J} PS_j^f = \sum_{k=1}^{K} PL_k^c + \sum_{l=1}^{L} PL_l^f \qquad (5)$$

A. *Control Path*

The control path is a path consisting of collection of connections used to find appropriate power devices among several (connected power devices) for the power fluctuation management. Let PS_j^f be the fluctuating power source with power change i.e., $+\Delta/-\Delta$. The control path starts with the device experiencing power change and ends on the power device which compensate for the power change. This process continues until the power change is compensated.

B. *Control Algorithm Description*

After finding the control path, the control algorithm assigns power level. Since power levels for fluctuating devices are measured for each time instance, this information is used to compute the power change for the next time instance. Based on power generation/consumption capacity of next connected device along the control path. The power change would be compensated by the other power device(s).

It is also possible that one power device may not enough to accommodate the power change alone, in that case the power change would be distributed among one or more controllable power devices. The ability for accommodation for each power device depends on its capacity, power generation/consumption limitation, and the operation mode. There are several choices of control path and each path gives a unique solution independent from the other path solution. The choice of the control path can affect the quality of the solution e.g., choice of low cost power source, usage of renewable power source as much as possible to reduce gas emissions etc. In Fig. 3, both situations (positive or negative) of power change are presented with examples. In case of positive power change (Δ) at the power source the amount of outgoing power flow of attached connection would be

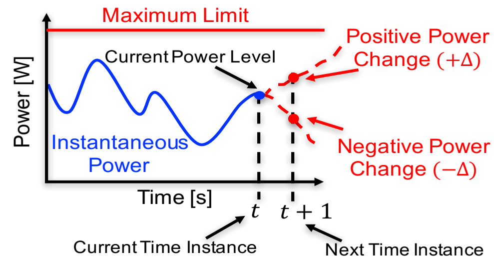

Fig. 2. Power profile of fluctuating power devices.

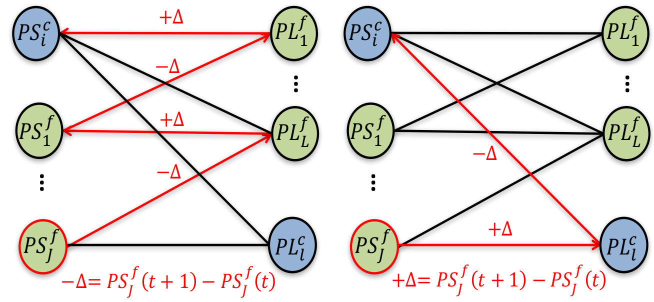

Fig. 3. Control Algorithm with (a) Negative change, (b) Positive change.

increased by Δ. The demand of power load on the other side of the connection would also be increased. Since a power load can receive power from multiple power sources, the power supply of the other connected power source along the control path would be decreased by Δ. In this way, the generated power of fluctuating power source is used as much as possible. In Fig. 3 (b), control path is represented for negative power change management. The power change is increased and decreased alternatively on each connection to accommodate power change along the path. The power flow on each connection of path would be increased or decreased to find the best match for power change. The control algorithm assigns power levels continuously to achieve balance between power generation and demand.

V. Concluding Remarks

With the increase of renewable energy sources in the future power network systems, the increase of power fluctuation gives cause for anxiety. Since the power fluctuations can deteriorate the stability and quality of the power network, this paper discusses the use of controllable power devices to absorb the power fluctuations from fluctuating power sources and loads. The effectiveness of the proposed control algorithm will be presented at the time of conference presentation.

References

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