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Coordinating independent non-dispatchable generation and energy storage systems

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ABSTRACT

Permission to connect a generator to the distribution system is generally obtained on the basis that the generator's effect is limited and that the network voltages and currents remain acceptable at all times. The capacity of generation that can be connected is limited by this firm access connection policy. Energy storage systems can facilitate the integration of additional generation that cannot be dispatched. The coordination of independent non-dispatchable generators and energy storage systems connected to the same circuit is presented. The coordination aims to maximise the production of the generators without exceeding the power limit of the circuit, so as to maximise their income. Energy storage systems are asked to change their schedule to allow generators to maximise their production. Additional income is obtained from additional energy production. The additional income obtained is allocated so that both generators and energy storage systems have an economic incentive to be operated in a coordinated manner.

Introduction

Large amounts of "fit-and-forget" connection of generation are spread in distribution networks – Distributed Generation (DG). In "fit-and-forget" connection, one generator's effect is assumed to be limited and network voltages and currents are expected to remain acceptable at all times. This firm access connection policy limits the amount of generation capacity that can be connected.

A number of approaches to allow the connection of increased capacity of Distributed Generation have been suggested. These include: voltage control strategies [1,2]; the provision of ancillary services by DG [3–5]; regulatory frameworks and modifications in electricity markets [6,7]. Non-firm access to the network which allows the connection of capacities above the amount defined by the "fit-and-forget" approach was proposed in [8]. Non-firm connection is generally permitted on the basis that when there is inadequate capacity in the network generators are constrained off on a "last-in, first-off" basis. The virtual power plant as a technical and commercial framework to aggregate a large quantity of distributed energy resources as a single operating profile was discussed in [9,10]. Coordination of the operation of generators owned by one large producer [11] or by a number of smaller independent producers [12–15] has also been investigated.

The flexibility of demand (e.g. energy storage systems) is being presented to allow the integration of additional amounts of generation that cannot be dispatched – non-dispatchable generation [16–18]. Energy storage systems aim to facilitate the integration of generation by: maximising the capacity utilisation of generators; attenuating the variability of the power output of non-dispatchable generators.

The figure of the "Aggregator" is being presented an intermediary between distributed energy resources (such as generation, energy storage systems and controllable load) and network/market operators [9,19–21]. The aim of the Aggregator is to manage and operate distributed the energy resources to maximise network/market efficiency and the income of those resources.

The coordination of independent non-dispatchable generators and energy storage systems connected to the same circuit is presented. The coordination is operated by an Aggregator, run by the generators and the energy storage systems. The Aggregator is a technical and commercial intermediary between generators and energy storage systems. The Aggregator schedules the generators and energy storage systems to maximise the income received by the generators without exceeding the power limit of the circuit. This is achieved by asking energy storage systems to change their charging/discharging schedule to allow the generators to maximise their production. Additional income is obtained for the additional

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energy produced in coordination. This additional income is allocated to the generators and the energy storage systems using a bargaining approach of game theory – Rubinstein bargaining [22].

Coordination modelling

The coordination of independent non-dispatchable generators and energy storage systems aims to maximise the income of the generators. The coordination is operated by an Aggregator run by the generators and the energy storage systems (see Fig. 1). The Aggregator is a technical and commercial intermediary equipment that allows the generators and energy storage systems to communicate. The operation of the Aggregator is summarised as follows:

- The charging of the energy storage systems is scheduled to allow the generators to operate.
- The discharging of the energy storage systems is operated in hours of reduced output of the generators.
- The generators are curtailed when the circuit rating limit is still exceeded, on a "last-in, first-off" basis.
- Additional income is obtained from additional energy production. The additional income obtained is allocated so that both generators and energy storage systems have an economic incentive to be operated in a coordinated manner.

Assumptions of the coordination

The coordination is formulated according to the following assumptions:

Related to the distribution network

- The distribution network considered is a two-busbar network.
- Losses are not considered (no voltage drop or rise).
- The distribution circuit current rating is fixed.

Related to the non-dispatchable generators

- Only non-dispatchable generators are considered.
- The installed capacities of the generators exceed the circuit limit.
- In case of curtailment, the production of the non-dispatchable generators is lost.
- The generators operate with unity power factor.

Related to the energy storage systems

- The energy storage systems are not owned by any of the generators.
- Charging and discharging is performed according to the price of electrical energy.
- The output of the energy storage systems can range from zero to the respective installed capacities.
- Round-trip storage efficiency is considered to be 100%.

Related to the optimisation

- The generators and energy storage systems are price takers.
- The forecasts considered (available power of the non-dispatchable generators and price of electrical energy) are entirely reliable.
- The non-dispatchable generators and the energy storage systems do not have costs of operation.
- Telecommunication facilities between the generators/energy storage systems and the Aggregator are available.
- The costs of forecasting and telecommunications are not considered.

Operation of the Aggregator

The Aggregator uses the following parameters for the coordination (see Fig. 1): distribution circuit limit; operating limits of the generators and energy storage systems; the order of connection to the network; time step and total number of time steps of the optimisation; energy capacity and maximum number of daily charge/discharge cycles of each storage system. The operation of the Aggregator is described as follows:

1. The Aggregator receives from the generators their anticipated outputs and the anticipated charge/discharge schedule from the energy storage systems. Generators make their projections based on power forecasts. Energy storage systems make their projections considering the prediction of the price of electrical energy.
2. The Aggregator assesses whether the circuit rating is exceeded by the anticipated outputs. If the limit is not exceeded, the Aggregator accepts the anticipated outputs and takes no further

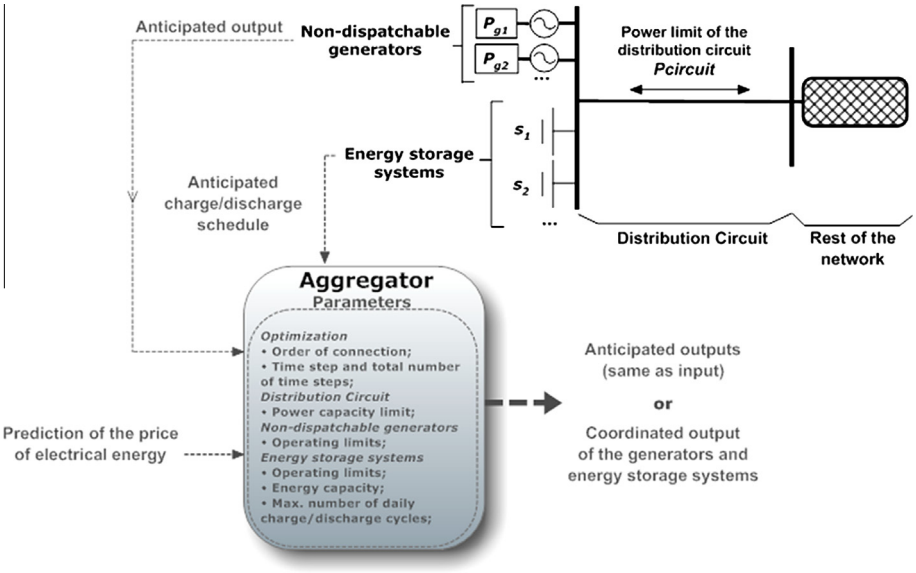

Fig. 1. The Aggregator operating the coordination of non-dispatchable generators and energy storage systems.