Using Coalitions of Wind Generators and Electric Vehicles for Effective Energy Market Participation*

(Extended Abstract)

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ABSTRACT

Wind power is becoming a significant source of electricity in many countries. However, the inherent uncertainty of wind generators does not allow them to participate in the forward electricity markets. In this paper, we foster a tighter integration of wind power into electricity markets by using a multi-agent coalition formation approach to form virtual power plants of wind generators and electric vehicles. We identify the four different phases in the life-cycle of a VPP, each characterised by its own challenges that need to be addressed.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Intelligent agents, multiagent systems*

General Terms

Algorithms, Experimentation

Keywords

Energy and emissions, Coalition formation, Organisations

1. INTRODUCTION

Installed wind power capacity has been constantly growing in the last decade. However, due to the inherent uncertainty of wind power generation, this kind of energy is usually accommodated in day-ahead markets without imbalance penalties. Wind generators are not allowed to place bids in the electricity market, as they are taken into the system as and when their power is available. This means wind generators are not able to gain the advantage of participating in an open market to maximise their revenue.

To achieve better integration of wind power into electricity markets, we propose using the concept of virtual power plant [4]. A virtual power plant (VPP) is here viewed as a cluster of wind farms and electric vehicles collectively acting as a single virtual entity. Though any means of storage would satisfy our requirements of a VPP, in this work we consider electric vehicles because they present a readily available resource that is expected to grow considerably in the near future. Since any conventional privately-owned vehicle is usually parked for 96% of the time [2], and given that for an electric vehicle "parked" eventually means "plugged", the electric vehicle pool represents a set of batteries whose capacity can be made available for electricity storage.

The idea of using electric vehicles to stabilise the grid and support renewable energy is a quite recent concept that has been envisioned, under the name *vehicle-to-grid* (V2G), by [2]. In their work, the authors demonstrate that the economic motivation for V2G power is compelling, making V2G another driver for the penetration of these cleaner vehicles in our society.

Although the benefits of V2G and VPP have been extensively assessed, the application of agent-based techniques as the means of realising these concepts is still in its infancy. However, given that VPPs involve several distinct players with their own capabilities and preferences, multi-agent system techniques provide a convenient method to develop such systems.

Approaching from an agent perspective, we contend that wind generators and electric vehicles could profitably form a coalition of agents that acts as a single entity in the market. The main benefit of this approach is that the available storage will help reduce the variability and uncertainty of wind power, as well as increase its revenue potential, thereby facilitating the integration of this kind of energy into the existing electricity market. Furthermore, joining such a virtual power plant should also be profitable for electric vehicle owners as they will earn money for the energy storage service they offer. This could then help compensate for the investment in this type of vehicle which is usually more expensive than a conventional one, thereby promoting

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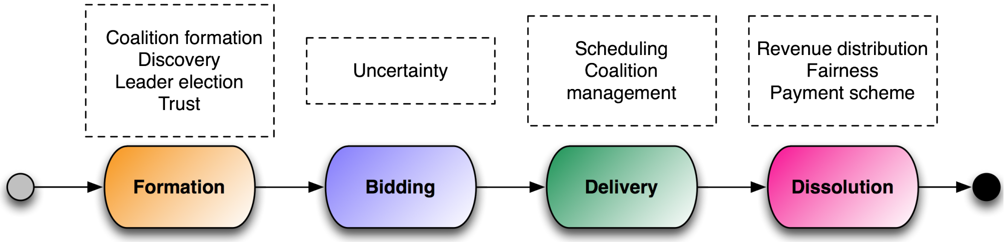

Figure 1: Life-cycle of a VPP.

the adaptation of these more environmentally-friendly vehicles. Now, given that these wind generators and electric vehicles will be owned by separate actors with their own individual interests (seeking to maximise their own revenues), the problem of forming VPPs reduces to a coalition formation problem between self-interested agents of different types (either production or storage) with varying capabilities (the amount of production/storage).

2. VIRTUAL POWER PLANTS

In our context a virtual power plant is composed of some wind generators that produce electricity and some electric vehicles that store it and supply to the grid later. Simply stated, the main purpose for the creation of a VPP is to be able to participate in the electricity market and maximise profits by delivering wind energy reliably. Now, since the actors that would come together to form a VPP are heterogeneous and self-interested, an agent-based approach is a natural way of addressing this problem. Being owned by different players, each of the wind generators and electric vehicles are represented as self-interested autonomous agents, that coalesce to form a virtual organisation (as a VPP) to participate in the market.

We look at the VPP being formed to participate in the day-ahead electricity market for the next day. Therefore, designing such a VPP will involve modelling both the members (wind generators and electric vehicles) and the workings of the VPP like scheduling storage and bidding in the market. In this section, we identify the four different phases in the life-cycle of a VPP, each characterised by its own challenges that need to be addressed (see Fig 1):

1) Formation

On day n, wind generators join with electric vehicles to form a VPP, that is, a coalition of agents that cooperate to accomplish a volatile goal [3]. The coalition formation process will require modelling agents to represent the individual wind generators and electric vehicles participating in the coalition. These agent-based models will then enable the definition of the *value of the coalition*. Given this notional coalition value, distributed and dynamic algorithms are needed to efficiently create and maintain coalitions [3] as the conditions change day-to-day and there is no obvious centralised coordinator. Moreover, the issue of trust on potential coalition members will also be fundamental to the creation of effective coalitions as the members need to believe in the others' truthfulness and capabilities [1]. Finally, the formation phase needs mechanisms for the discovery of potential coalition members and the election of the VPP representative agent or *VPP leader*.

2) Bidding

Once the VPP has been formed, the VPP leader is in charge of bidding in the day-ahead market, which takes place on the day n, in order to deliver the electrical energy on day $n+1$. The VPP leader must submit a 'supply curve' that defines the price that the VPP is willing to demand for a specific quantity of delivered electricity. The bidding strategy must take into consideration several aspects of the VPP including the the electricity production forecasts of the member wind generators and the expected available storage provided by the member electric vehicles. Applying an operational model based on linear programming, electricity generation and storage can be optimally scheduled.

3) Delivery

At the time of market closure on day n, the VPP will have committed to deliver a certain quantity of electricity on day $n+1$ adhering a certain schedule. On day $n+1$, to actually deliver the electricity as per the contract, the VPP must be efficiently operated at run-time, scheduling electricity generation and storage as per the plan, maintaining the structure of the VPP and coping with any unpredictable events (say, if several electric vehicles are unexpectedly unplugged).

4) Dissolution

At the end of day $n + 1$, the VPP, having accomplished its purpose, would dissolve or at least cease its activities for the day. In either case, this involves distribution of the revenues among the VPP members, according to a clear, pre-determined, and possibly fair, payment scheme.

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