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# Virtual Energy Storage System for Smart Grids

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**Abstract**

This paper forms a Virtual Energy Storage System (VESS) and validates that VESS is a cost-effective way to provide the function of energy storage through the utilization of the present network assets represented by flexible demand. As a solution to convert to low carbon cities, a VESS is firstly modelled to store and release energy in response to regulation signals by coordinating the demand response (DR) from domestic refrigerators in London and the conventional flywheel energy storage systems (FESS). The coordination of DR and FESS mitigates the uncertainties of DR and reduces the capacity of costly FESS. The VESS is applied to provide ancillary services to the power system and contributes to the reduction of carbon emission through the replacement of spinning reserve capacity of fossil fuel generators. Case studies were carried out to validate and quantify the capability of the VESS to vary the stored energy in response to grid frequency. Economic benefits of using VESS for frequency response services were firstly estimated and a potential saving of £91m-£103m is expected.


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Keywords: Virtual energy storage system, Low carbon cities, Smart grids

**Nomenclature**

*Abbreviation*

| | |
|---|---|
| DR | Demand Response |
| ESS | Energy Storage system |
| FESS | Flywheel Energy Storage System |
| RES | Renewable Energy Source |
| VESS | Virtual Energy Storage System |

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## 1. Introduction

Cities are rapidly integrating smart grid technologies to move towards an energy efficient future with lower carbon emissions. The increasing integration of renewable energy sources (RES), such as the photovoltaic and the wind, causes uncertainties in electricity supply. It is therefore more challengeable to meet the power system demand. More reserve is required from partly-loaded fossil-fuel generators which are usually costly and exacerbate the carbon emissions.

In addition, the integration of RES through power electronics reduces the system inertia. Frequency indicates the balance between generation and demand. A low inertia power system will encounter more severe frequency stability issues in cases of sudden changes in supply or demand [1]. Therefore, faster response to frequency changes is required.

Energy Storage System (ESS) is one solution to facilitate the integration of RES by immediately varying the stored energy. In terms of the functions of ESS, ESS is classified as high power rating for power quality applications and high energy rating for energy management applications. In terms of the forms of ESS, ESS is classified as mechanical, chemical, electrical and thermal categories [2]-[3].

However, ESS remains to be an expensive technology although in recent there is declination in the cost. For instance, the cost of installing a 20MW/10MWh Flywheel Energy Storage Systems (FESS) is approx. £25m-£28m [4].

Aggregated Demand Response (DR) can act as virtual energy storage because DR can provide functions similar to the energy storage by intelligently managing the power and energy consumption of loads. By utilizing the existing network assets, DR can be deployed at scale with lower cost. A cost of £1.97/household/year of using domestic refrigerators and freezers for frequency response is shown in [5] based on the 2013 GB electricity market rates. Considering the availability of refrigerators to provide frequency response [6], it is estimated that 20 MW of response requires approx. 1.5m refrigerators. Therefore, the total cost of 20 MW of DR is 3m. This is far smaller than the cost of FESS (approx. £25m-£28m [4]) to also provide the 20 MW of response. It is estimated in [4] that DR has the potential to reduce the ESS market size by 50% in 2030.

However, the challenges of DR include the uncertainty of the response and the consequent reduction in the diversity amongst loads [6]. Simultaneous connection of loads may occur in several minutes after the provision of response to a frequency drop. This will worsen the system stability.

In this paper, a VESS is formed as a single entity to provide functions of energy storage. The VESS utilizes the capacity of DR to reduce the capacity of costly ESS whilst reducing the impact of DR's uncertainties. A VESS consisting of DR from domestic refrigerators in London and of FESS is modelled and controlled. The proposed control of VESS maintains the load diversity and the primary functions of cold storage of refrigerators, and reduces the number of charging and discharging of each FESS. Case studies were carried out to quantify the capability of VESS for frequency response services and to compare the capability of VESS with FESS. The potential economic benefit is also estimated.

## 2. Virtual Energy Storage System

### *2.1. Concept*

A VESS aggregates a cluster of flexible loads, ESS and can also extracts energy from Distributed Generators via smart grid technologies. Through the coordination of each unit, a VESS acts as a single high capacity ESS with lower capital costs.

A VESS allows the small-capacity ESS, flexible loads and distributed energy resources to get access to the wholesale market and to provide transmission level services to the power system. Because VESS forms a synthetic ESS at the transmission/distribution level through the aggregation, the high power and