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Aggregated applications and benefits of energy storage systems with application-specific control methods: A review

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ABSTRACT

Distributed energy storage systems (ESSs) are becoming essential components for the operation of the increasingly complex electricity grid, where dispersed generation is causing power-flows occurring both top-down and bottom-up. Specifically, the combination of ESSs coupled with application-specific control methods can achieve the interdependent objectives of system stakeholders such as the system operator, electrical utilities, retailers, equipment vendors, the government and the electricity customers. The necessity for an accelerated rate of transition to a multi-directional grid arrangement has been exacerbated by the rapid proliferation of distributed renewable energy sources (RESs) that are now price comparable to traditional supply sources. While there are review articles covering ESS technologies and applications as well as the plethora of future advanced grid arrangements that may eventuate, there is none which comprehensively covers individual and aggregated ESS applications and the corresponding benefits, comparing different technology selection methods and providing application-specific controls. Both operational and monetary benefits are identified and critically reviewed from the perspective of the aforementioned stakeholders. Wholesale and retail energy market regimes are also considered for monetisation of the benefits. The control methods that are provided cover both balanced and unbalanced grid conditions. This comprehensive review paper will be of immense value to researchers and practitioners seeking to understand and unpack the aggregated benefits of ESS in the electricity grid.

1. Introduction

There is a growing interest in the role of ESSs integrated into the electricity grid due to a number of different drivers, such as improvements in power electronics and storage technologies, more stringent operational requirements of the electricity grid (e.g., in terms of power quality), deregulation of the electricity market, continuous load growth leading to higher regional power transfers, variability in load profiles and most importantly the rapid growth of distributed RESs [1–6].

On a global level, efforts are progressing in order to further increase the deployment of RESs and decrease greenhouse gas (GHG) emissions as a measure to tackle climate change impacts [4,7,8]. There are many recent examples of RESs promotion in the United States (US), Europe and Australia. In the US, the state of California has committed itself to reach 33% renewables participation in its energy mix by 2020 [9], Wisconsin's target is 10% by 2015 [10] while the state of New York has a more ambitious short-term goal of a minimum of 30% renewably generated electricity by 2015 [11]. The European commission has established a roadmap for reducing GHG emissions by 80–95% by 2050 and a key factor in achieving this target is further deployment of RESs in the countries belonging to the union [7]. In Australia, organisations have been established such as the Australian Renewable Energy Agency (ARENA) and the Clean Energy Council (CEC), which have the aim to support further RESs deployment either by government partial funding of RESs ventures (i.e., ARENA) or by developing and advocating clean energy policies (i.e., CEC) [12,13].

The enhanced presence of RESs in the electricity grid is grist to the mill of environmentally friendly energy. However, if renewables are not properly integrated into the grid, they can have an adverse impact on its operation in terms of voltage rise at the feeder terminals, overloading of grid components at times where there is a high amount of reverse power-flow, voltage fluctuation where RESs are connected, increased spinning reserve requirements in the case of sudden loss of renewable generation, additional difficulty in generation dispatch and unit commitment, effect on electricity market trading, to name a few. Due to these unintended impacts on the grid from RESs, a number of measures have to be taken to ensure normal grid operation can be reinstated in the presence of the evolving, intermittent and distributed RESs generation [1,2,4,10,14–18]. It should be noted that these mitigating measures introduce a considerable additional cost. For

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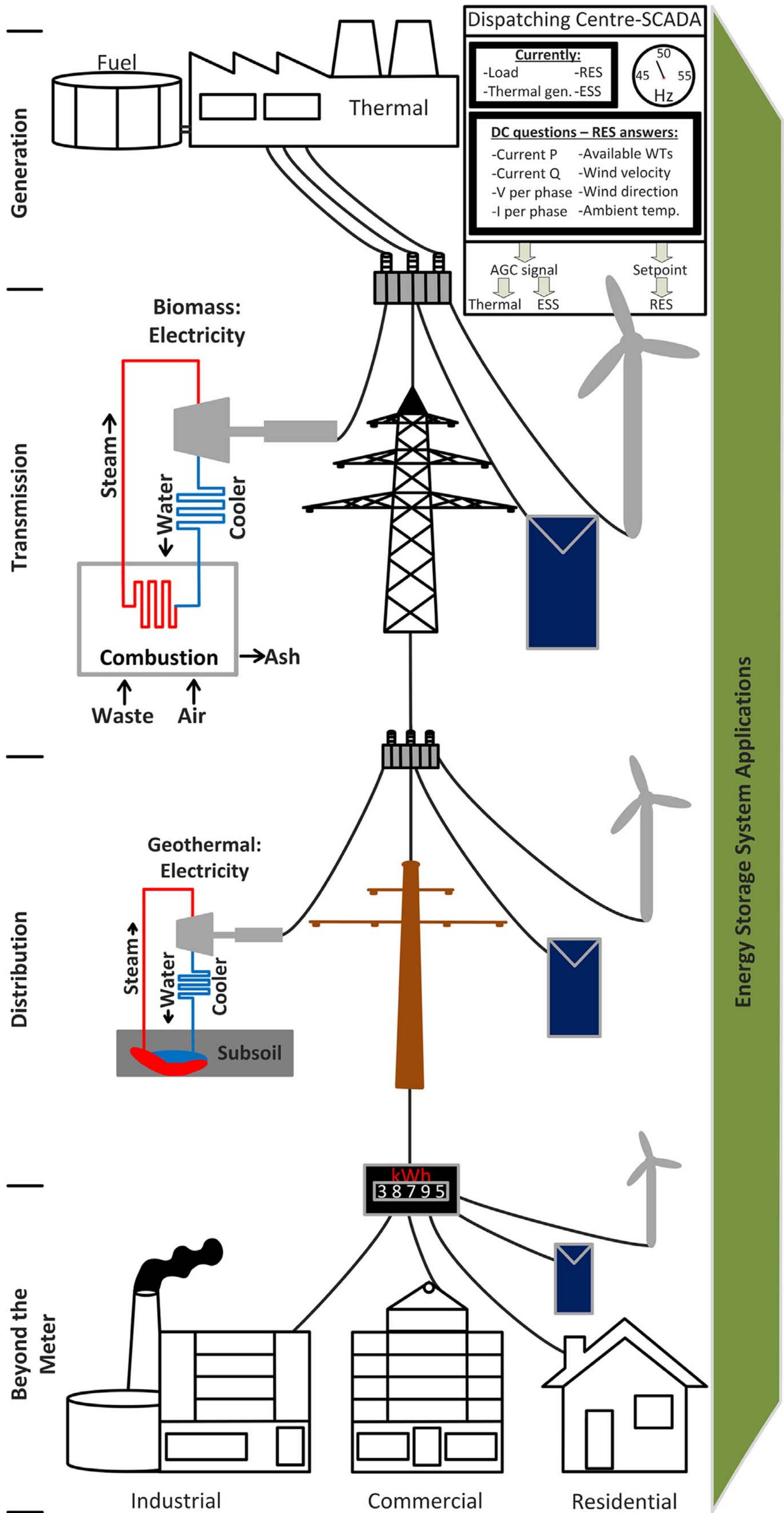

Fig. 1. ESS applications across the grid levels including RESs and the SCADA at the dispatching centre (DC).