The Impact of Energy Storage on the Stability of Renewable energy in a Micro Grid

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Abstract—Power fluctuations in a micro grid are caused by disturbances due to the connection and disconnection of distributed generators including the irregular input of the sun and wind renewable energy. The objective of this paper is to improve the unstable power output responses of a renewable energy micro grid by designing and analysing storage strategies intended at power wavering compensation which solely consists of battery/generator and capacitive energy storage.

Index Terms—Batteries, Capacitors, Energy Storage, Micro Grid, Renewable Energy, Simulink.

1 INTRODUCTION

The intermittency of renewable energy directly affects the input and resultant output power of a micro grid. Storage systems should be implemented to ensure the stability and reliability of the power supplied to the load.

This paper describes four electrical storage systems and focusses on some combined storage systems for effective grid control. Combined energy storage methods could compensate for power imbalances by providing excess stored energy to the micro grid.

Capacitors could be utilized for energy storage for a short period of time and batteries for longer periods of time. Pumped storage schemes could also store energy and release power through a coupled generator. Storage compensation methods were modelled and analyzed in Simulink.

2 STORAGE SYSTEMS

Energy storage systems (ESS) increases the consistency and viability of renewable distributed generators (DG's) like wind and PV generation. These aforementioned DG's produces irregular power due to their strong weather dependence and uncontrollable peak production that does not necessarily match the instant demand of the consumers.

An autonomous micro grid (MG) requires additional control due to the lack of the main grid frequency as a base support. Reliable main power sources are required to support stable frequency and voltage conditions.

ESS' can facilitate steadiness in terms of voltage and frequency instabilities and act as a base support [1]. Uninterruptable power supplies (UPS') plays a key role in stabilizing the power output in micro grids when the main supply is off.

An UPS is able to supply regulated and conditioned power to critical loads as well as assisting in a seamless transition from main power to back-up power and vice versa [2].

Research also has shown that 20-30% of energy consumed in buildings can be recovered by implementing optimized energy management without significant structural, hardware configuration and energy supply changes [3].

AC electrical energy cannot be stored directly as this energy is stored in different forms such as electrochemically, magnetically, kinetically as well as potential energy or as compressed air [4]. Energy storage technologies can be classified in terms of round-trip energy efficiency, maximum power and capacity rating, energy losses over time and capital costs involve.

3 STORAGE TECHNOLOGIES

3.1 Rechargeable Batteries

Battery storage of electrical energy can act as a good emergency power supply and operates without noise. A smooth and secure start-up can be ensured when sufficient energy is stored and harmful voltage perturbation can be avoided as required.

A vanadium redox battery (VRB) system consists of two electrolytes separated with a proton exchange membrane. The two vanadium based electrolytes are stored in separate tanks. The advantage of VRB is that both the electrolytes contains the same metal ions which illuminates cross contamination degradation.

3.2 Pumped Hydro Storage

Hydroelectricity is generated by water driven turbines that are connected to generators. The turbines convert the kinetic energy existing in the flow of water, either in a river or from a dam, into rotation of the turbine/ generator. Hydro pumped storage is considered as a more reliable standing reserve.

The amount of available storage depends on the previous operating management's stored energy and not upon the 100 % availability of fuel as used in gas turbines. A pumped storage scheme uses power from the grid to pump water vertically in reservoirs to be released when needed in order to generate electricity.

3.3 Compressed Air Storage

With compressed air energy storage (CAES), unused electricity is drawn from the grid to power large compressors. The compressors push pressurized air into storage, such plants that utilise underground salt caverns is relatively inefficient (< 50 %) and requires a specific location including the use of hydrocarbon fuel [5].

3.4 Mechanical Flywheel

Flywheels store rotational energy gained by rotational input speed [6]. A flywheel energy storage system contains a rotating mass powered by external energy source that is coupled to an electrical drive, converting electrical to kinetic energy and vice versa. The stored kinetic energy amount is proportional to the inertia moment of the flywheel and also the square of its angular velocity [7].

4 MICRO GRID CONTROL

The battery based ESS disintegrates faster the more frequently it is used. Mechanical ESS's such as pumped hydro and compressed air possesses a larger energy storage capacity with a slower response time [8].

Distributed energy storage systems (DESS) benefit the consumer in power quality and reliability as well as reducing the time related to the use demand charges. The smart grid operator can save in electricity prices by storing energy for the duration of off peak times and supply energy during peak load stages.

DESS reduces the need for of VAR generation from renewable energy systems [9]. Optimal battery sizing can increase efficient operation of the grid while reducing related costs [10].

4.1 Battery & Generator Compensation

4.1.1 First model

In the following model, a NI-MH battery is connected to an AC load of 6.5 A. A DC generator representing hydro power is also connected in parallel with the load with no initial torque. See figure 1 below. The current source drains the battery till the state of-charge is under 50 % (SOC).

The relay which is pre-set to 0.5 (50 % SOC) connects the negative torque to the DC machine, acting as a generator that starts to charge the battery. The relay is additionally pre-set to 0.9 in order to disconnect the DC generator from the circuit for an over charge protection mode. When the generator is disconnected, the currents source starts to drain the battery power again till 50 % SOC.

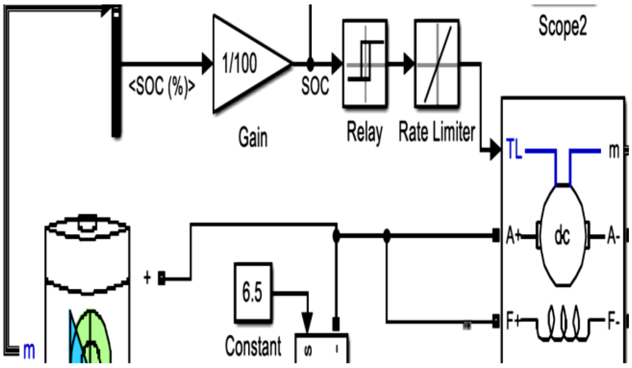

Fig. 1. Battery and DC Generator Model

The voltage is maintained above 200 V which is the rating of the battery bank via the DC generator. The value of the negative torque is 200 N (-200 N). The figure 2 below displays how the system voltage rises till 350 V and then disconnects from the DC generator to discharge the power rapidly at 1500 seconds.

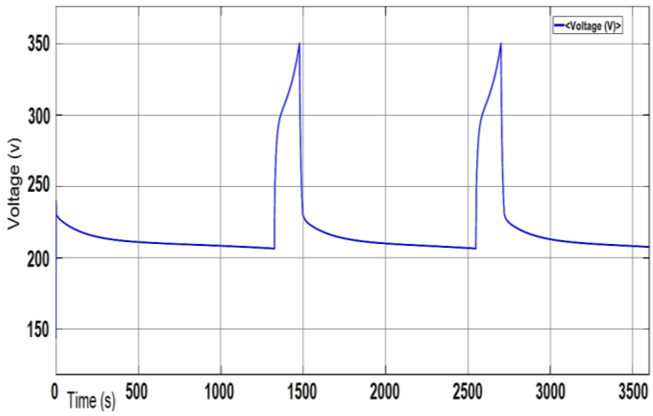

Fig. 2. Combined Voltage Output

As soon as the battery is drained till 50 % SOC, the DC generator compensates and charges the battery till 90 % SOC where it is disconnected again by the relay. See figure 3 below.

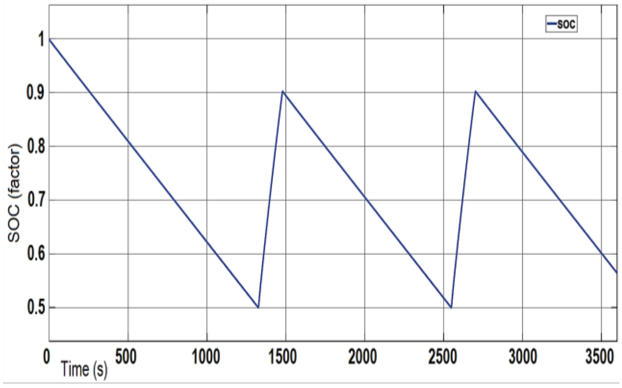

Fig. 3. Recovery of SOC Output

Note that in figure 4 and figure 5 there is a difference between the two torque settings. The first torque setting is -200 N where in the second simulation it is -1000 N. The higher the torque, the quicker the recovery time of the speed of the machine

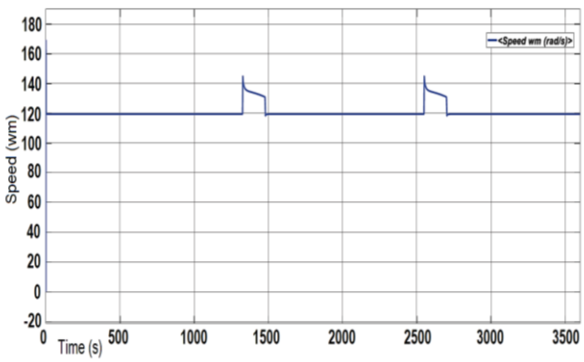

Fig. 4. Slower DC Generator Speed Recovery

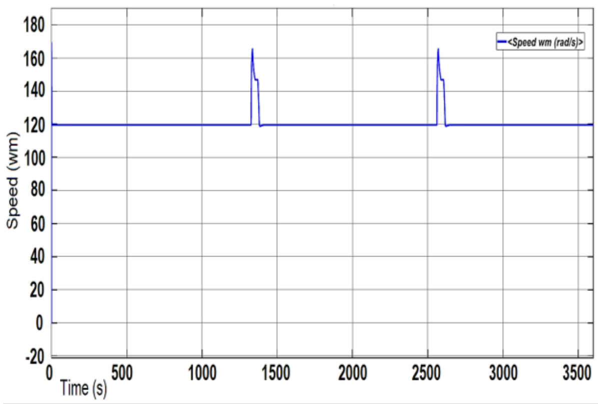

Fig.5. Faster DC Generator Speed Recovery

The previous two simulations illustrated the basic difference between a slower charge recovery versus a faster recovery, thus compensation for a power disturbance.

4.1.2 Second Model

The following control system illustrates the combination of two Solar Cell systems in a micro grid; one base battery, two current sources (one negative, one positive), one DC machine (generator) as well as measurement instruments and scopes.

The system battery and the two PV systems provide a base voltage of 14.75 V. At 2000s the top PV System disconnects using a breaker and the system voltage drop to under 14.5 V. At 4000s the first current source (negative) is added to the micro grid (representing an active load) and the system voltage drops to a further 13.25 V.

If the SOC reaches below 50 %, the relay switches the DC generator on, which generates a negative torque of 800N (generation mode) which then increases the system voltage every time the voltage drops below 12.4 V (50 % SOC).

When the system voltage reaches above 90 % of the SOC, the relay then switches the DC generator off and the battery gets drained again by the negative current source (load). The second current source (connected positive-positive) adds constant power to the grid at 8000 s. Note that the system voltage rises slightly and the rate by which the battery gets drained slows slightly down as shown in figures 7 and 8.

The SOC takes a longer period to reach its maximum and minimum levels. This is due to the second PV system that injects more power into the micro grid. The more power injected, the longer it takes for the batteries to discharge to their minimum set point. This simulation results of the SOC is shown in figure 9.

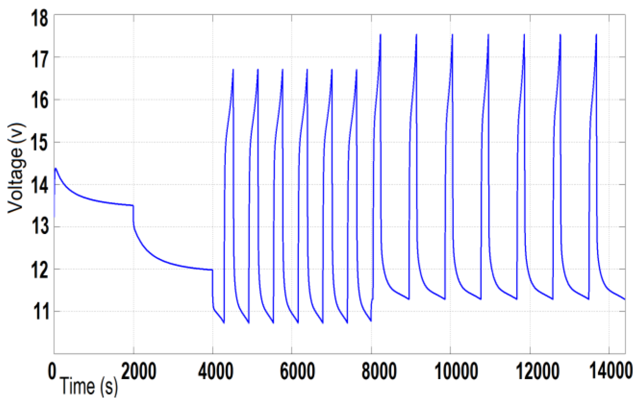

Fig. 7. Combined Micro Grid Voltage Output Results

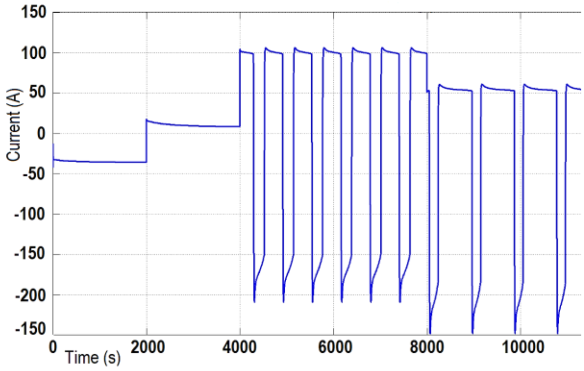

Fig. 8. Combined Micro Grid Current Output Results

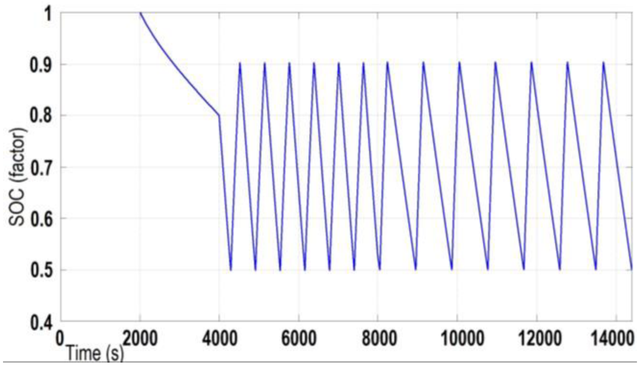

Fig. 9. State of Charge (SOC)

4.1.3 Third Model

In the following model, a battery and 10 x 250Wp PV panels are connected in parallel to an inverter. the irradiance of the sun fluctuates due to its intermittency as depicted in figure 10. The output is directly proportional to the fluctuation input. An additional battery is connected in parallel with the ten solar panels of 250watt each to absorb the PV panel's DC input in order to mitigate the volatile fluctuations.

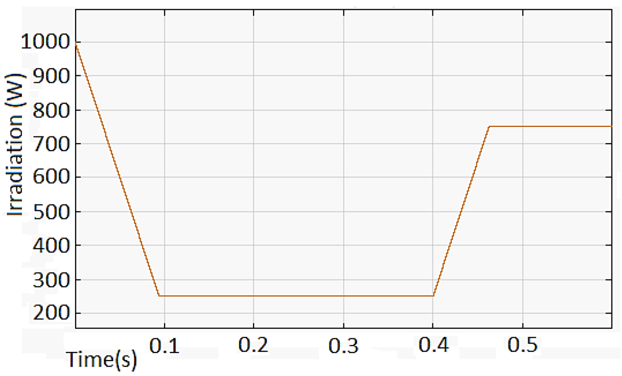

Fig. 10. Renewable intermitted property

The battery stays disconnected and the voltage measured before the power electronic conversion stays directly proportional to the intermitted simulated input power produced by the irregular irradiance as shown in figure 11 below.

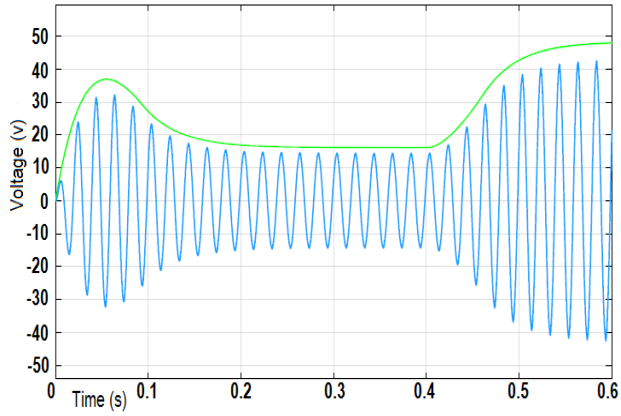

Fig. 11. Unregulated voltage output

Once the battery is connected to the circuit, it stabilizes the voltage output as it provides reverse capacity irrespective of the radial irregularity. This storage method acts as an input control method to help stabilize the power output in a micro grid as shown in figure 12.

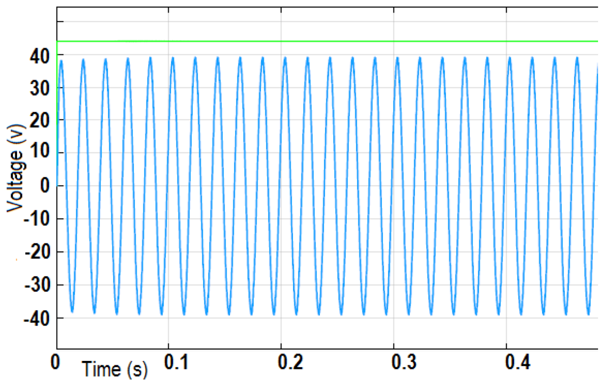

Fig. 12. Battery regulated input voltage

4.1.4 Fourth Model

In the following model, the 500kW load is connected to a battery and disconnected at [0,1 0,2 0,3 0,4] seconds respectively. An AC source represents the stable power output of an inertial generator which gets inverted to a DC voltage.

The DC output voltage fluctuates accordingly to the load changes that is implemented. As soon as the battery is connected via the breaker in parallel at 0.25 seconds, the excess battery power compensates for the disconnected load resulting in minimal voltage output variation. This behaviour is revealed in figures 13 and 14 below.

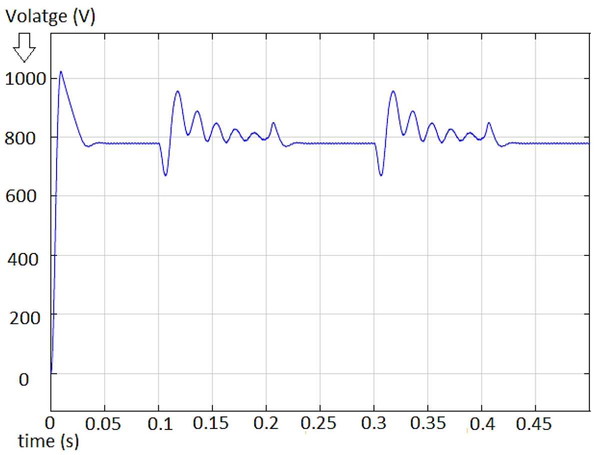

Fig. 13. Unregulated load change

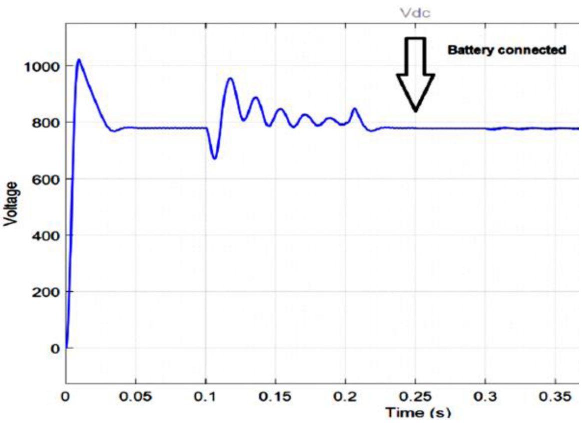

Fig. 14. Regulated load change

4.2 Capacitive Compensation

Ultra-capacitors are advantageous for micro grid control and also ideal for short-term energy storage or burst-mode power delivery. There are mainly three types: electrostatic double-layer capacitors, electrochemical pseudo capacitors and hybrid capacitors.

With the designed capacitor compensator depicted in figure 15, the starting controllable voltage source state is on, and switches off at 5 seconds. The voltage sensor disconnects the load as soon as the ultra-capacitor discharges till it reaches a value below 9.5 volts.

The second controllable voltage source is set as a back-up and switches on at 15 seconds. The ultra-capacitor compensates for the sudden voltage drop.

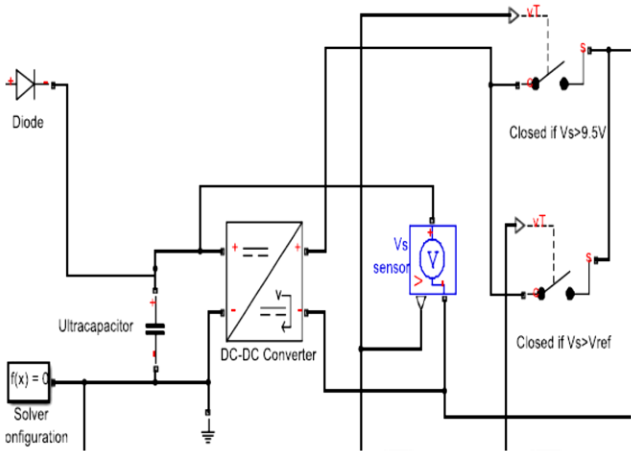

Fig. 15. Ultra-capacitor with Voltage Compensator

Note that the capacitor charges till 5 seconds when the source is disconnected, then it discharges till the load is disconnected. The capacitor charges again when the back-up source connects at 15 seconds. See figure 16.

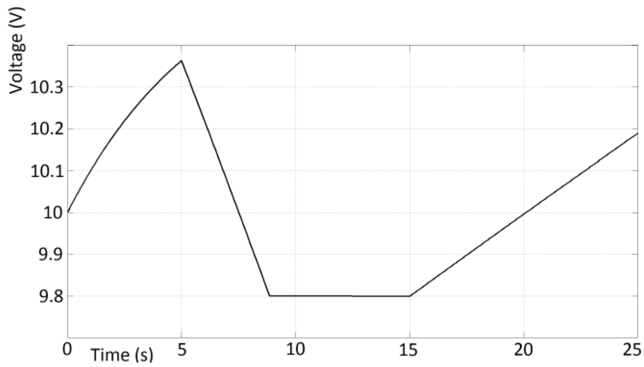

Fig. 16. Measured Voltage across the Ultra Capacitor

5 CONCLUSION

Energy storage plays a key role in maintaining a constant power output when the distributed generators fail. It can also act as an UPS system. A single battery connected to a solar panel would minimise power fluctuation to produce a stable voltage for rural or domestic usage, while a battery bank and pumped storage system on the other hand can maintain a steady and constant power output for hours if not days; depending on the volumetric capacity of the upper water storage dam and the size of the battery bank.

An additional ultra-capacitor could be added to the battery storage system to compensate for sudden fluctuations in order to preserve the life span of the battery

Storage methods such as batteries, capacitor banks and generators (pumped storage method) can be combined to form a multipurpose storage system, delivering short term as well as longer periods of power assistance. Hybrid energy storage system features high power density, large energy storage as well as good power performances

6 REFERENCES

[1] X. Tang, X. Hu, N. Li, W. Deng and G. Zhang, "A Novel Frequency and Voltage Control Method for Islanded Microgrid Based on Multi energy Storages," *IEEE Transactions on Smart Grid,* vol. 7, no. 1, pp. 410 - 419, December 2015.

[2] B. Zhao, Q. Song, W. Liu and Y. Xiao, "Next-Generation Multi-Functional Modular Intelligent UPS System for Smart Grid," *IEEE Transactions on Industrial Electronics,* vol. 60, no. 9, pp. 3602 - 3618, May 2013.

[3] X. Guan, Z. Xu and Q. Jia, "Energy efficient buildings facilitated by micro grid," in *IEEE PES General Meeting*, Minneapolis, MN, July 2010.

[4] V. A. Boicea, "Energy Storage Technologies: The Past and the Present," *Proceedings of the IEEE,* vol. 102, no. 11, pp. 1777 - 1794, Oct 2014.

[5] M. Saadat and P. Y. Li, "Modeling and control of a novel compressed air energy storage system for offshore wind turbine," in *2012 American Control Conference (ACC)*, Montreal, QC, June 2012.

[6] Y. Yuan, Y. Sun and Y. Huang, "Energy on the fly," *Electronics Letters,* vol. 52, no. 11, p. 890, May 2016.

[7] R. De Andrade, G. Sotelo, A. Ferreira, L. Rolim, J. Da Silva Neto, R. Stephan, W. Suemitsu and R. Nicolsky, "Flywheel Energy Storage System Description and Tests," *IEEE Transactions on Applied Superconductivity,* vol. 17, no. 2, pp. 2154 - 2157, July 2007.

[8] Y. Niu and S. Santoso, "Sizing and Coordinating Fast- and Slow-Response Energy Storage Systems to Mitigate Hourly Wind Power Variations," *IEEE Transactions on Smart Grid,* vol. PP, no. 99, p. 1, June 2016.

[9] G. Carpinelli, G. Celli, S. Mocci, F. Mottola, F. Pilo and D. Proto, "Optimal Integration of Distributed Energy Storage Devices in Smart Grids," *IEEE Transactions on Smart Grid,* vol. 4, no. 2, pp. 985 - 995, May 2013.

[10] I. S. Bayram, M. Abdallah, A. Tajer and K. A. Qaraqe, "A Stochastic Sizing Approach for Sharing-Based Energy Storage Applications," IEEE Transactions on Smart Grid, vol. PP, no. 99, p. 1, August 2015.

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