Bulletin of Electrical Engineering and Informatics
Vol. 12, No. 6, December 2023, pp. 3228~3237
ISSN: 2302-9285, DOI: 10.11591/eei.v12i6.4879

Integration of storage technology oversight: power system and computer engineering analogy

Mohan P. Thakre[1], Pranali M. Thakre[2], Pawan C. Tapre[3], Ramesh S. Pawase[4], Sunil Somnath Kadlag[5], Deepak Prakash Kadam[6], Satish N. Bhadane[7]
[1]Department of Electrical Engineering, SVERI's College of Engineering, Solapur, India
[2]Department of Master of Computer Applications, SVERI's College of Engineering, Solapur, India
[3]Department of Electrical Engineering, SND College of Engineering Education & Research Center, Nashik, India
[4]Department of Electronics and Telecommunication Engineering, Amrutvahini College of Engineering, Sangamner, India
[5]Department of Electrical Engineering, Amrutvahini College of Engineering, Sangamner, India
[6]Department of Electrical Engineering, MET Institute of Engineering, Nashik, India
[7]Department of Information Technology, Pune Vidyarthi Griha's College of Engineering, Nashik, India

Article Info

Article history:

Received Sep 25, 2022
Revised Feb 22, 2023
Accepted Mar 9, 2023

Keywords:

Battery storage
Cache energy
Cache-control
Multilevel energy storage

ABSTRACT

Energy storage, analogous to data storage in a computer system, is one of the enabling technologies that has emerged alongside the widespread use of renewable energy sources in the nation's power grid. This article shows that the underlying platforms for storing data and energy are quite similar. Batteries and hydrogen storage offer significant energy potential, much like a hard disk for storing vast amounts of data in a computer's central processing unit (CPU). A supercapacitor or flywheel storage device can be used to have emergency power on hand, with access times as fast as random access memory (RAM) in modern computers. In this study, we propose an energy-control scheme for caches that is akin to computer engineering and is used to coordinate the operation of multilevel storage systems that incorporate both capacity and access-oriented storage. By supporting the energy-management system, which in turn provides modern plug-and-play functionality, cache energy control helps optimise the system as a whole. Such an integrated system calls for renewable energy generation, local loads, fueling stations, and connections to gas and electric distribution grids. Distribution energy concepts with various storage systems can be easily grasped by drawing parallels between computer engineering and power system integration.

Corresponding Author:

Mohan P. Thakre
Department of Electrical Engineering, SVERI's College of Engineering
Pandharpur, Solapur, Maharashtra, India
Email: mohanthakre@gmail.com

1. INTRODUCTION

The energy department of the U.S. estimated the growth of the distributed energy resources (DER) capacity increase by 20 GW over the next decade [1]. The major part which is to be installed in DER units will be renewable energy conversion units of wind and solar which are abundantly available in nature [2], [3]. It will become progressively challenging to incorporate such units into the power grid as DER enter the market, which has previously been influenced by a handful of big power plants with controllable output [4]. So, for the integration of DER, it is required to introduce the concept of energy storage to solve these challenges. Hence in this area of power system education, energy storage is becoming a highly interesting technology. There are different features and applications of various energy storage technologies. Some of the energy storage technologies have high charge and discharge life cycles, which provide fast access to power, for example, super-capacitor (SC), superconducting magnetic energy storages (SMEs), and flywheel storage [5]–[7].

However, the cost of maximum energy stored in standard batteries is less. Energy storage to solve these challenges. Hence in this area of power system education, energy storage is becoming a highly interesting technology. There are different features and applications of various energy storage technologies. Some of the energy storage technologies have high charge and discharge life cycles, which provide fast access to power, for example, SC, SMEs, and flywheel storage [8]. However, the cost of maximum energy stored in standard batteries is less. For storing the data in the computer, various technologies are available. In the computer system, there are two types of storage technologies. The first is low-cost data storage, such as a hard disk, which can hold tens to hundreds of gigabytes of data. Second, random access memory (RAM), that's also supplemented by a hard disk with a few gigabytes of storage capacity and speedy data access [9]. Fast-access data storage is more expensive per bit of data stored. RAM, which is access-oriented storage, serves as a cache for hard disk storage that is capacity-oriented. This type of systems engineering results in higher effectiveness at a lower cost. Hence this contribution made an evolution of personal computers (PCs) everywhere. So, the analogous transition has taken place in the power infrastructure from a few plants of large size to integrated DER.

From this analogous transition, the results are explained in this paper. Major contributions are considered. The incorporation of computer and power systems has been mentioned, as well as the analogy between both data storage and energy storage. Overall, power system demonstration and multiple types of energy storage have been explored. Cache energy control has been developed that uses this analogy [10]. It is illustrated how the plug-and-play premise becomes analogous to a network of distributed renewable energy sources. Data and energy storage technologies are studied respectively in sections 2 and 3 data, then energy storage technologies are classified in section 4. By using this classification, the analogy is explained. The distributed energy system design with the application is illustrated in section 5. Section 6 represents the conclusions of this paper.

2. DATA STORAGE TECHNOLOGIES IN THE COMPUTER SYSTEM

A wide range of data storage options is available. The most cost-efficient storage devices are hard disk and digital versatile disk (DVD), which has large data storing capacity and the cost per bit of data stored is low. In modern computers, the data storing capacity of a hard disk is hundreds of gigabytes, while that of a DVD is multiple gigabytes. The data on the hard disk is accessed up to 5 to 10 ms, and that of the DVD is quite slow that is up to 100 ms [11].

In the central processing unit (CPU), static random access memory (SRAM) and dynamic random access memory (DRAM) are installed for fast access to data that is frequently used. For SRAM, access time is up to 10 ns for DRAM, it is up to 100 ns. Solid-state integrated circuitry is implemented in the CPU. As the access time for SRAM is high, so the cost per bit stored is high than that of DRAM. Hence for low capacities of up to a few megabytes, SRAM is implemented in mainstream PCs [12]. This paper discusses four common data-storage methods. Categorized by access speed and cost per bit stored.

2.1. Static random access memory and dynamic random access memory

Volatile SRAM latching circuitry flip-flops stores each data bit. Cache and CPU registers require faster and more expensive memory. Power loss erases SRAM data. SRAM costs more to implement since it requires more transistors per bit. Figure 1 shows six metal oxide semiconductor field effect transistor (MOSFET) based SRAM transistor ideas.

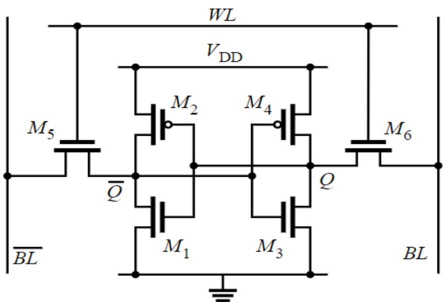

Figure 1. SRAM design

In Figure 1, M1, M2, M3, and M4 construct two cross-coupled converters, saving each cell bit in four transistors. Storage cells hold two stable bits, 0 and 1. Two more transistors manage storage cell availability during read-and-write activities in the SRAM paradigm. Its energy consumption depends on how often it can access data. It runs at 10 ns and is widely available. Cache memories in processing units use SRAM because speed is more essential than cost and size. Each bit of data is stored in a memory cell with a transistor and metal oxide semiconductor capacitor. Complex circuits with billions of memory cells can take up to 100 ns to operate. Digital electronics have used DRAM for low-cost, high-capacity memory. It loses data quickly when the power goes out. A rectangular array of charge storage cells with one capacitor and transistor per data bit. Word lines are the horizontal lines in the illustration, and each column has two-bit lines, with each storage cell linked to another in the column. The bit lines have a sense amplifier, a pair of cross-connected inverters. A first inverter's input is connected to a + bit line, its output to a - bit line, and vice versa for the second inverter. Hence, DRAM cells store data.

2.2. Hard disk and phase change digital versatile disk

Hard disk store data when the power is off. Hard disk store digital data on rigid, fast-spinning magnetic platters. Capacity and performance define the hard disk. Hard disk storage drives have 1,000x capacity. 1 TB storage has 1,000 GB and a 5-10 ms access time. The time to move the head to track the cylinder to retrieve data determines its performance. Airflow through the E-block excited by resonant vibrations as the disc rotates on the spindle motor. The flexible E-block supports the read-write head over the disc and stores data in the disc drive. High-capacity digital optical data storage. Its data storage cost and access speed are low. DVDs can be read or written at constant angular or linear velocity. Red light laser technology is used to rewrite phase change technology 500,000 times. The DVD's phase-changing spiral track reduces access time to under 100 ms.

3. POWER DISTRIBUTION ENERGY STORAGE ADVANCEMENTS

Energy storage technologies have various functional characteristics as per their types. The fast and frequently accessible storage technologies are SC and flywheel, which have higher round trip efficiency of up to 90% [12]. Both storage systems have high charge and discharge cycle life, and response time is up to a few milliseconds. Fly-wheel stores kinetic energy within a rapidly spinning wheel-like rotor. SC stores electrochemical energy between electrodes and electrolytic ions. In this flywheel and SC, the cost of stored energy is very high [13]. The cost of maximum energy stored in battery and hydrogen storage is low with space constraints. If space is readily available, a large amount of energy can be stored. From the electrolysis of the water, pure hydrogen is made available easily. The rating of hydrogen tanks gives the amount of energy stored. By taking hydrogen as an input, electrical energy is generated in fuel cell stacks, so the decoupling of energy and power ratings [14]. Flow batteries also have a lower cost of stored energy and high capacity. Research is ongoing to improve the roundtrip efficiency of hydrogen storage by up to 50%, which is lower than the roundtrip efficiencies for flywheel and SC. On increasing response time, charge, and discharge cycle life [15]. There are various energy storage technologies are discussed in this paper.

3.1. Super-capacitor

Electrochemical storage systems can store 10–100 times more energy per unit volume than batteries. Its high capacitance and low voltage make it an ultra-capacitor, bridging the gap between electrolytic and batteries. This SC is fast-access energy storage since it charges and discharges quickly. An electrochemical capacitor's ion-permeable membrane and paradoxically connected electrolyte distinguish two electrodes. When the electrodes are given a voltage, the electrolyte ions generate electric double layers with opposite polarity. Electrostatic energy stores the electric field, which takes milliseconds to access. Even at % efficiency, the capital cost per kilowatt hour of energy held is significant.

3.2. Flywheel energy storage system and superconducting magnetic energy storage

Flywheel energy storage system (FESS) uses a flywheel driven by a rolling-element bearing and coupled to a motor generator in a vacuum chamber to reduce friction and waste. The flywheel stores energy as rotational kinetic energy by quickly rotating a rotor. According to the rule of conservation, the flywheel's speed increases when energy is added to the system. It provides millisecond power access and 90% roundtrip efficiency. Flywheel storage is expensive per energy stored. Therefore, access-oriented storage. SMEs stores heat in the magnetic field using direct current passing through cryogenically cooled superconductivity coils below its critical temperature. Energy is available in milliseconds. SMEs storage systems can reach 90% efficiency and last a long period [16]. Higher power ratings have a high capital cost per maximum energy held.

3.3. Battery energy storage system and hybrid energy storage system

Battery energy storage system (BESS) can provide short-term peak power, spinning reserve, and frequency management to reduce power failures. Battery chemical reactions occur when voltage is applied between electrodes. Reversing it extracts energy. Battery storage systems feature 80% roundtrip efficiency and minimal charge and discharge cycles. Low capital cost per maximum storage. Milliseconds provide electricity for different uses. Like hybrid autos, the battery is only charged and discharged to extend its cycle life. Battery storage allows cache energy control. Hybrid energy storage system (HESS) uses increased pressures, colder temperatures, and chemical compounds that release H2 when needed. Esters are everywhere. Water electrolysis extracts hydrogen and oxygen.

Hydrogen and oxygen can be kept in tanks and fed to the fuel cell unit to generate electricity, notwithstanding the HESS. Cylinders, tubes, and cryogenic tanks can store and transport hydrogen as a compressed gas or cryogenic liquid for use in industries or space missions. Fuel cell type determines reserve time. Research is underway to improve hydrogen storage efficiency to 50%. When the hydrogen fuel plant has no space constraints, stored energy costs less.

4. IDENTIFICATION AND ILLUSTRATION OF ANALOGY

Data and energy storage are separately discussed in sections 2 and 3. According to this identification, analogies between these storages are explained. Table 1 provides a brief introduction to the categorization of data storage technological advances, which would be mentioned in section 4. Storage that is easily accessible access-oriented storage includes SRAM and DRAM. Hard disk and DVDs have a large storage capacity but a low cost per bit of data stored. Therefore, they are categorized as capacity-oriented storage [17].

As illustrated in section 3, the key characteristics for differentiating SC and flywheel, on one side batteries and hydrogen storage on another side are the access speed and cost per unit of energy stored. So, the classification is done based on access orientation and capacity orientation in Table 2. A similarity between data and energy storage is given in Tables 1 and 2, then highlighted the analogy between data and energy storage is in Table 3.

Table 1. Data storage classification

Class	Term	Cost per unit data	Access speed
Access orientation	SRAM	High	High
	DRAM	High	High
Capacity orientation	Hard disk	Low	Moderate
	DVD	Low	Low

Table 2. Classification of energy storage

Class	Term	Cost of capacity	Access speed
Access orientation	SC	High	High
	FESS	High	High
Capacity orientation	BESS	Low	Moderate
	ESS	Low	Low

Table 3. Data and energy storage analogy

Analogy	Data storage	Energy storage
Access orientation	SRAM	SC
	DRAM	Flywheel
Capacity orientation	Hard disk	Hydrogen storage
	DVD	Battery

Presume the computer stores 40 GB of data and has an access time of up to 10 ns. One such execution has been solely to use RAM as a faster processing storage methodology. Presume the cost per megabyte has been 0.1 US Dollars so that the PC's storage would then cost $4000 US Dollars. Even so, the utilization of cache storage allows for faster access to data at a cheaper price. The most frequently used data is nothing but a small amount of highly accessible data, which is known as a cache. RAM is implemented as only a fractional part of the overall storage of the system due to its higher cost. Comparatively, the bulk amount of data is stored on a hard disk, but it is accessed rarely. Cache-control is the process of the selection of data storage locations. In Figure 2, the hierarchy shows the cache-control methodology. A CPU restores the vast bulk of data through a bus from the smallest level of the hierarchy, recognized as a cache in RAM storage technology.

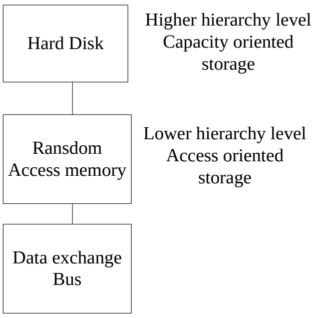

Figure 2. Cache-control hierarchy in computer systems

There is hard disk storage at the top of the hierarchy, which is used rarely. Nowadays, this hierarchy of storage technology improves the performance of PC at a given cost. So, the provision of a highly effective storage system in the PC is done by using the collaboration of both access and capacity-oriented storage [18]. The use of more than one storage orientation alone will lead to undesirable operations. Similarly, while designing an energy storage system, exploitation of both energy storage systems is necessary for a highly reliable system. In Figure 3, a combination of access of capacity orientation storage is given as an example of an interconnected system. The simulated power station, keep referred to as stochastic energy management, appears to include multilevel energy storage linked to a DC bus for predetermined power output with an integrative wind conversion system.

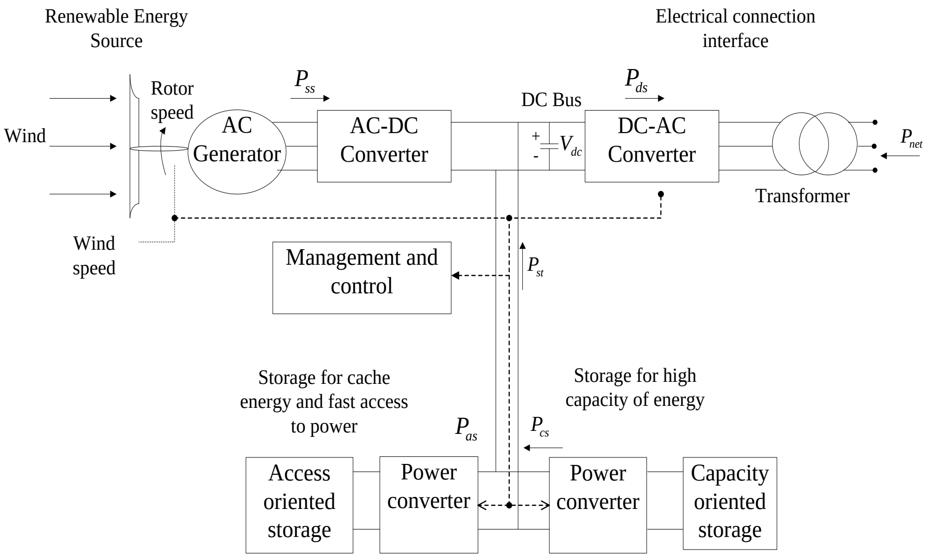

Figure 3. Multilevel energy storage system for a simulated power plant

Access-oriented storage improves the system's power quality. One such storage orientation responds to fast stochastic volatility in the renewable power converter's stochastic power [19], [20]. Utilizing capacity-oriented storage, the entire plant could be deployed. In Figure 4, multilevel storage composed of battery and SC is shown, which stores cache energy. Computer hierarchy is used to synthesize energy in this storage hierarchization. Over the interface of electricity infrastructure, this power plant operates efficiently, and the power flow is well-controllable over various periods. Even as the existing power system has been intended for the assimilation of a generalized power station, the system has easily incorporated the use of these advanced technologies [21]. The capacitor attached to the batteries in hybrid, as well as fuel cell vehicles, has been used to store cache energy and also is gaining popularity in power system transportation. Also, it is used to fulfil the power plant demand. For a multilevel storage system, SMEs are used to meet the power plant demand.

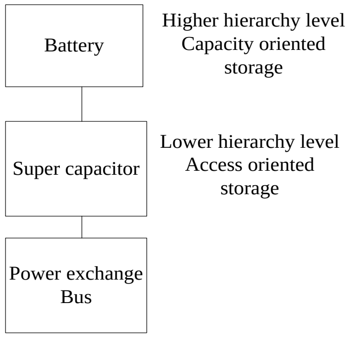

Figure 4. Throughout energy systems, a suggested cache-control organization in power systems

5. RESULTS AND DISCUSSION

Data storage and computer is familiar to most people nowadays. For explaining this energy storage, this computer analogy is the best suitable tool for engineers and managers. Various studies and presentations are used to prove that this analogy is best suitable to explain the analogous nature of flywheel storage and RAM storage. From the transmission of the data storage system in modern computers, this method of DER is designed is adopted. Power fluctuates throughout scenarios such as interrupted power from renewable sources, the beginning of large motors, delivery of backup services, vehicular fueling, or prudence of power swapped with the system. As a result, the multilevel storage system reacts to shifts in electricity variations over various periods, preventing the framework from experiencing rapid power changes [22]. Access-oriented storage for cache-control has a shock-absorbing functionality that protects equipment from quick volatility. Capacity-oriented storage is also utilized to balance long-term volatility. The DER network is linked in a plug-and-play fashion, equivalent to the plug-and-play system in use in computer systems, as shown in the study.

A 25-kW roof-mounted solar array is used to generate electrical power during daylight hours as illustrated in Figure 5. For the supply of 90 kW, only the photovoltaic system is not sufficient so DER is connected to the energy system for the net power P_{net} and natural gas as energy carriers. The gas shown here is used for industrial processes and also requires reform of the hydrogen gas. Here, a hydrogen storage tank with a capacity of 50 kg is employed to serve capacity-oriented storage [23]. To fuel continuous-duty vehicles such as forklifts with the around-the-clock operation, the hydrogen flow m_{fs} may be directed to a dispenser, so it requires short refuelling times. Also, the 100-kW fuel cell is supplied by hydrogen, and the efficiency of the fuel cell is about 50% [24], [25]. So, to increase the efficiency and life of the fuel cell, operational aspects should be considered, and the output of the fuel cell should be free from unpredictable changes in the system. Hence to control the fuel cell, its response time is limited to 250 s. To increase the response time up to 5 ms and the round-trip efficiency of about 90% of capacity-oriented storage that is 50 MJ flywheels with the rated output of 100 kW cache energy is used [26]. As a result, high-frequency volatility has been soaked up or provided by access-oriented storage for rapid response time as well as high round trip efficiency, as well as to embrace the high cycle life of both charge and discharge processes. Cache-control, which streamlines the operation of two different storage types, is employed to split the high-frequency power fluctuations from the rest of the spectrum [16]. This design largely corresponds to the configuration of the stochastic energy management plant shown in Figure 3. Only the difference is that the natural gas and electricity network connections are present, and for storing the cache energy, SC is used.

Approaches executed in MATLAB ® are employed to operate the DER throughout a loss of access to the electric distribution network via circuit breaker operating condition. The results of these operations are shown in Figure 6. Here the energy management concept is only designed in MATLAB. The electromagnetic transients resulting due to circuit breaker operation and switching of the power electronic components are not modelled. Most converters for power electronics are built with their standard models. The computation depicts a transformation from electricity transmission system power to local backup power over a 10-minute interval. Whenever the DER switches to recover data power after 100 seconds, there is a loss of power from the electric distribution system due to a fault upstream of the DER, causing the network connection to be interrupted due to a circuit breaker opening. The first three graphs throughout Figure 6 depict the subsequent power flows from the electric distribution system to the DER's local load as well as the multilevel energy storage.

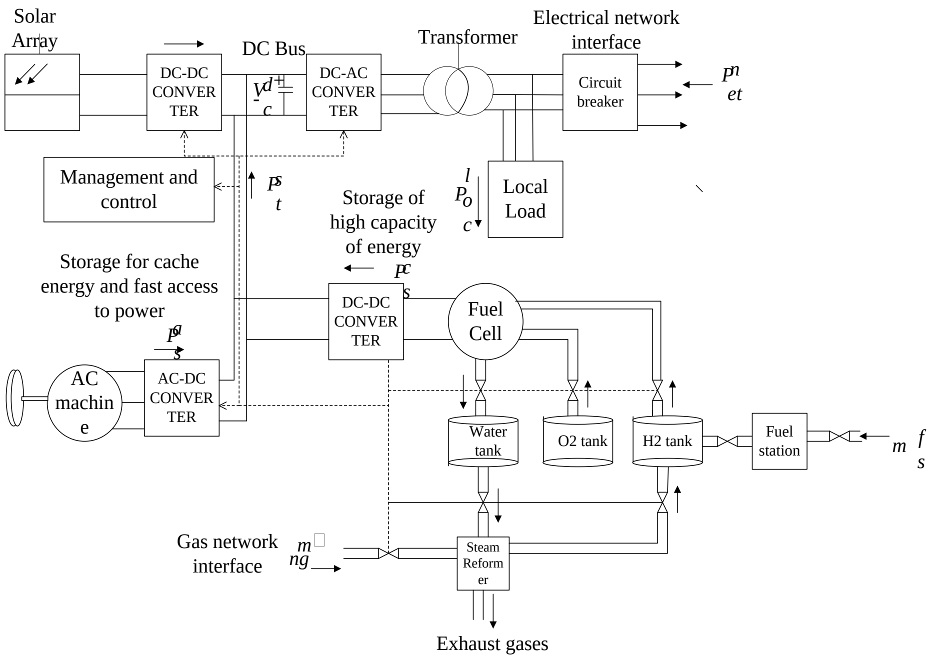

Figure 5. Design of distributed energy sources

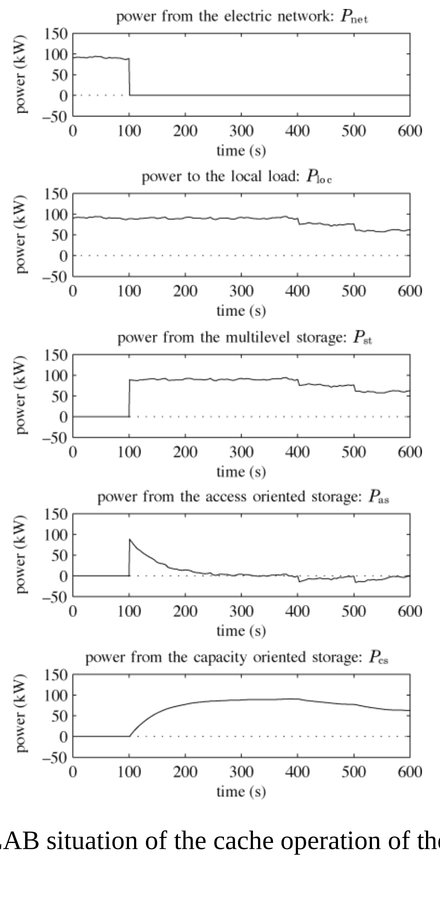

Figure 6. Results of MATLAB situation of the cache operation of the multilevel energy storage

Multilevel energy storage via the flywheel is the fourth defined consequence, while hydrogen storage is the fifth. It is assumed that the computation appears to occur when no power is supplied by the solar array, which helps to differentiate the use of backup power for multilevel energy storage. The load is expected to initially fluctuate by around 5 kW from its nominal value of 90 kW. In order to keep the distribution system running smoothly, it is set up to dump any surplus load that might otherwise cause frequent outages. Hence, it is manifested as a sharp decline in a load of 15 kW over 300 s after the connection is broken and another 15 kW over 100 s. Each time the local load requires 100 seconds of electricity, this type of multi-level energy storage device makes up the difference. As a result of its rapid response time, access-oriented storage powers numerous local loads until capacity-oriented storage appears to have sufficient time to raise its output within the designated operating restrictions.

Unlike flywheel storage, which response to short-term variations in load, fuel cell storage may adapt to longer-term shifts in energy demand or supply. In this scenario, local loads are not lost while the primary power source is gradually replaced by the secondary power source. Caching takes effect as the flywheel smooths out the peaks and valleys in power usage. To compensate for the energy delivered during the outage, the reformer at the hydrogen plant has been supplied with more natural gas, and the electrical distribution system will be restored only when the flywheel has absorbed the energy it has stored. The simulation findings show that the multilevel storage for the DER system is effective and reliable, able to smooth out power fluctuations. The DER-linked platform can plug into this and get power from it.

6. CONCLUSION

Energy management uses the representation and organisation of paper to store energy. Researchers are looking into the potential of computing systems to be used in power engineering after realising the similarities between data storage and energy storage. Cache energy is represented here. The ideas of energy and data storage are easily understood by the reader. The popularity of the research has increased thanks to the widespread adoption of the analogy's illustrative technology for distributed energy systems. This research illustrates the "plug and play" nature of a multi-tiered energy system with complementary access and capacity storage. A connection between computing and electrical engineering can be seen in the many forms of storage that focus on either access or capacity. Having a high storage reaction time and a long charge/discharge cycle life. Storage space is shared between the flywheel, the SSD, and the access-oriented RAM. High capacity can benefit from hard drives, batteries, and hydrogen storage because these can all be optimised for a low cost per media.

By combining access and capacity storage, multilevel storage boosts system performance. Instead of focusing on storage capacity, computers use a cache, which is designed to speed up data access. The integration of a distributed energy system in an industrial setting related to electric and gas distribution networks demonstrates the usefulness of cache energy control for shared energy systems in electrical networks. A hydrogen production facility can double as a filling station thanks to capacity-based storage. The ability to save data in advance minimises the need for longer outages. Fuel cell units need to be turned on so that the hydrogen plant can be supplied with energy and blackouts can be avoided. The flywheel improves both roundtrip efficiency and power quality due to its rapid start-up and ability to compensate for disturbances. The plant is running smoothly and power may be controlled from a central location in the distribution system's common coupling. Cache power is supplied via the battery-connected capacitor as well. This cache power management employs plug-and-play, analogous to the plug-and-play functionality of PCs. The advantages of combining data storage systems are illustrated through analogies in this paper.

REFERENCES

[1] M. H. Nehrir *et al.*, "A Review of Hybrid Renewable/Alternative Energy Systems for Electric Power Generation: Configurations, Control, and Applications," *IEEE Transactions on Sustainable Energy*, vol. 2, no. 4, pp. 392–403, Oct. 2011, doi: 10.1109/tste.2011.2157540.

[2] Z. Wang *et al.*, "Research on the active power coordination control system for wind/photovoltaic/energy storage," in *2017 IEEE Conference on Energy Internet and Energy System Integration (EI2), IEEE*, Nov. 2017, pp. 1-5, doi: 10.1109/ei2.2017.8245403.

[3] M. Raju and S. K. Khaitan, "System simulation of compressed hydrogen storage based residential wind hybrid power systems," *Journal of Power Sources*, vol. 210, pp. 303–320, Jul. 2012, doi: 10.1016/j.jpowsour.2012.02.050.

[4] M. Yang, C. Chen, B. Que, Z. Zhou, and Q. Yang, "Optimal Placement and Configuration of Hybrid Energy Storage System in Power Distribution Networks with Distributed Photovoltaic Sources," in *2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2), IEEE*, Oct. 2018, pp. 1-6, doi: 10.1109/ei2.2018.8582007.

[5] D. N. Huu, "An adaptive control of hybrid battery-supercapacitor storage for integration of wind and solar," in *2016 IEEE International Conference on Sustainable Energy Technologies (ICSET), IEEE*, Nov. 2016, pp. 157-162, doi: 10.1109/icset.2016.7811774.

[6] H. Wang and J. Zhang, "Research on charging/discharging control strategy of battery-super capacitor hybrid energy storage system in photovoltaic system," in *2016 IEEE 8th International Power Electronics and Motion Control Conference (IPEMC-ECCE Asia), IEEE*, May 2016, pp. 2694-2698, doi: 10.1109/ipemc.2016.7512723.

[7] Y. Yang, Y. Han, W. Jiang, Y. Zhang, Y. Xu, and A. M. Ahmed, "Application of the Supercapacitor for Energy Storage in China: Role and Strategy," *Applied Sciences*, vol. 12, no. 1, pp. 1-19, Dec. 2021, doi: 10.3390/app12010354.

[8] X. Zhang, L. Yang, and X. Zhu, "Integrated control of photovoltaic-energy storage system for power oscillation damping enhancement," in *2016 IEEE 8th International Power Electronics and Motion Control Conference (IPEMC-ECCE Asia), IEEE*, May 2016, pp. 1571-1575, doi: 10.1109/ipemc.2016.7512526.

[9] S. Mittal and J. S. Vetter, “A Survey of Software Techniques for Using Non-Volatile Memories for Storage and Main Memory Systems,” *IEEE Transactions on Parallel and Distributed Systems*, vol. 27, no. 5, pp. 1537–1550, May 2016, doi: 10.1109/tpds.2015.2442980.

[10] T. T. Teo, T. Logenthiran, W. L. Woo, and K. Abidi, “Advanced control strategy for an energy storage system in a grid-connected microgrid with renewable energy generation,” *IET Smart Grid*, vol. 1, no. 3, pp. 96–103, Sep. 2018, doi: 10.1049/iet-stg.2018.0024.

[11] T. M. Coughlin, “New storage hierarchy for consumer computers,” in *2011 IEEE International Conference on Consumer Electronics (ICCE), IEEE*, Jan. 2011, pp. 483-484, doi: 10.1109/icce.2011.5722696.

[12] M. Cheng, S. Kato, H. Sumitani, and R. Shimada, “Cache power for stand-alone power systems: Flywheel-based AC power solution,” in *The 2010 International Power Electronics Conference-ECCE ASIA, IEEE*, Jun. 2010, pp. 2508-2515, doi: 10.1109/ipec.2010.5542377.

[13] H. Sakuma, Y. Iwasaki, H. Yano, and K. Kudo, “Virtual integration technology of distributed energy storages,” in *2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe), IEEE*, Oct. 2012, pp. 1-6, doi: 10.1109/isgteurope.2012.6465819.

[14] Y. Zhu, “From Hydrogen Production to Storage: A Process for Sustainable Development of Underground Hydrogen Storage in Caverns,” in *2021 3rd International Academic Exchange Conference on Science and Technology Innovation (IAECST), IEEE*, Dec. 2021, pp. 1658-1663, doi: 10.1109/iaecst54258.2021.9695812.

[15] W. Jiang, C. Yang, Z. Liu, M. Liang, P. Li, and G. Zhou, “A Hierarchical Control Structure for Distributed Energy Storage System in DC Micro-Grid,” *IEEE Access*, vol. 7, pp. 128787–128795, 2019, doi: 10.1109/access.2019.2939626.

[16] N. Voropai, E. Ukolova, D. Gerasimov, K. Suslov, P. Lombardi, and P. Komarnicki, “Simulation Approach to Integrated Energy Systems Study Based on Energy Hub Concept,” in *2019 IEEE Milan PowerTech, IEEE*, Jun. 2019, pp. 1-5, doi: 10.1109/ptc.2019.8810666.

[17] J. Xiao, P. Wang, and L. Setyawan, “Multilevel Energy Management System for Hybridization of Energy Storages in DC Microgrids,” *IEEE Transactions on Smart Grid*, 2016, pp. 847-856, doi: 10.1109/tsg.2015.2424983.

[18] X. Xu, M. Bishop, O. D. G, and H. Chen, “Application and modeling of battery energy storage in power systems,” *CSEE Journal of Power and Energy Systems*, vol. 2, no. 3, pp. 82–90, Sep. 2016, doi: 10.17775/cseejpes.2016.00039.

[19] C. Tarazona, M. Muscholl, R. Lopez, and J. C. Passelergue, “Integration of distributed energy resources in the operation of energy management systems,” in *2009 IEEE PES/IAS Conference on Sustainable Alternative Energy (SAE), IEEE*, Sep. 2009, pp. 1-5, doi: 10.1109/sae.2009.5534858.

[20] M. M. Rahman, G. A. Ghazi, E. A. Al-Ammar, and W. Ko, “Techno-Economic Analysis of Hybrid PV/Wind/Fuel-Cell System for EVCS,” in *2021 International Conference on Electrical, Communication, and Computer Engineering (ICECCE), IEEE*, Jun. 2021, pp. 1-6, doi: 10.1109/icecce52056.2021.9514084.

[21] M. E. Şahİn, F. Blaabjerg, and A. Sangwongwanİch, “Modelling of supercapacitors based on simplified equivalent circuit,” *CPSS Transactions on Power Electronics and Applications*, vol. 6, no. 1, pp. 31–39, Mar. 2021, doi: 10.24295/CPSSTPEA.2021.00003.

[22] K. Johguchhi, “A Smart Hybrid Solid-State-Drive Storage System based on Nonvolatile Storage-Class-Memories: Device, Circuit Design and Architecture,” in *2020 International Symposium on Devices, Circuits and Systems (ISDCS), IEEE*, Mar. 2020, pp. 1-2, doi: 10.1109/isdcs49393.2020.9263016.

[23] J. A. Azzolini, M. Tao, K. Ayers, and J. Vacek, “A Load-Managing Photovoltaic System for Driving Hydrogen Production,” in *2020 47th IEEE Photovoltaic Specialists Conference (PVSC), IEEE*, Jun. 2020, pp. 1927-1932, doi: 10.1109/pvsc45281.2020.9300922.

[24] A. Moschetto, G. Giaquinta, and G. Tina, “Modelling of Integrated Renewable Energy Systems Supported by Hydrogen Storage,” in *2007 IEEE Lausanne Power Tech, IEEE*, Jul. 2007, pp. 2088-2092, doi: 10.1109/pct.2007.4538640.

[25] K. A. Kavadias, D. Apostolou, and J. K. Kaldellis, “Modelling and optimisation of a hydrogen-based energy storage system in an autonomous electrical network,” *Applied Energy*, vol. 227, pp. 574–586, Oct. 2018, doi: 10.1016/j.apenergy.2017.08.050.

[26] Z. Jiang and X. Yu, “Modeling and control of an integrated wind power generation and energy storage system,” in *2009 IEEE Power and Energy Society General Meeting, IEEE*, Jul. 2009, pp. 1-8, doi: 10.1109/pes.2009.5275753.

BIOGRAPHIES OF AUTHORS

Dr. Mohan P. Thakre received the B.Tech. and M.Tech. degrees in Electrical Power Engineering from Dr. Babasaheb Ambedkar Technological University (Dr. BATU), Maharashtra, India, in 2009 and 2011 respectively, and the Ph.D. degree in Electrical Engineering from Visvesvaraya National Institute of Technology (VNIT), Nagpur, Maharashtra, India in 2017. Currently, he is an associate professor at the Department of Electrical Engineering, SVERI’s College of Engineering, Pandharpur, Maharashtra, India. His research interests include FACTS and power system protection. He can be contacted at email: mohanthakre@gmail.com.

Pranali M. Thakre received the MCA degree from Rashtrasant Tukadoji Maharaj Nagpur University (RTMNU), Maharashtra, India, in 2013 respectively, currently, she is an assistant professor at the Department of Master of Computer Application, SVERI's College of Engineering, Pandharpur, India. She can be contacted at email: pranalimohanthakre@gmail.com.

Dr. Pawan C. Tapre received the B.E. and M.E. degrees in Electrical Power System Engineering from Sant Gadge Baba Amravati University (SGBAU), Maharashtra, India, in 1995 and 2002 respectively, and a Ph.D. degree in Electrical Engineering from Dr. C.V. Raman University (Dr. CVRU), Bilaspur, Chhattisgarh, India in 2022. Currently, he is an assistant professor at the Department of Electrical Engineering, S.N.D. College of Engineering and Research Center, Yeola (Nashik), Maharashtra, India. His research interests include deregulated power systems, FACTS, power systems, and power system protection. He can be contacted at email: pawan.tapre73@gmail.com.

Dr. Ramesh S. Pawase received the B.E. Electronics Engineering and M.Tech. at Department of Electronics and Telecommunication Engineering from Amrutvahini College of Engineering, Sangamner and Dr. Babasaheb Ambedkar Technological University (Dr. BATU), Maharashtra, India, in 2004 and 2009 respectively, and the Ph.D. degree in Department of Electronics and Telecommunication Engineering from Savitribai Phule Pune University, Maharashtra, India in 2019. Currently, he is an associate professor at the Department of Electronics and Telecommunication Engineering, Amrutvahini College of Engineering, Sangamner, Maharashtra, India. His research interests include MEMS sensors, CMOS-ASIC, power electronics. He can be contacted at email: rameshpawase@gmail.com.

Dr. Sunil Somnath Kadlag received B.E. in Electrical Engineering from Dr. received B.E. in Electrical Engineering from Dr. Babasaheb Ambedkar Marathawada University, Aurangabad (Dr BAMU) in 1997 and M.E. in Electrical Engineering (Control System) from Government College of Engineering Pune (Pune University) in 2005 and Ph.D. in Electrical Engineering from Suresh Gyan Vihar University Jaipur (Rajasthan) in 2021. His research area is electric vehicles. He is presently working as an associate professor and head of the Department of Electrical Engineering, Amrutvahini College of Engineering, Sangamner, Savitribai Phule Pune University, Pune, Maharashtra, India. He can be contacted at email: sunilkadlag5675@gmail.com.

Dr. Deepak Prakash Kadam received a B.E. from the Government College of Engineering, Amaravati, and M.E. degrees in electrical power systems from Walchand College of Engineering, Sangli, Maharashtra, India, in 1997 and 2005 respectively, and the Ph.D. degree in Electrical Engineering from Savitribai Phule Pune University, Pune Maharashtra, India in 2015. Currently, he is an Associate Professor at the Department of Electrical Engineering, Bhujbal Knowledge City, MET Institute of Engineering, Nashik, India. His research interests include renewable energy technology, power quality, and power system. His total teaching experience is around 23 years. He can be contacted at email: dpkadam@gmail.com.

Satish N. Bhadane received the B.E. degree in Computer Engineering from North Maharashtra University Jalgaon (MH) India in 2006 and M.Tech. degree in Dr. Babasaheb Ambedkar Technological University, Maharashtra, India in 2011. Currently, he is an assistant professor at the Department of Information Technology of Pune Vidyarthi Griha's College of Engineering, Nashik Maharashtra, India. He can be contacted at email satish.bhadane@gmail.com.