ISSN 2347 - 3983
Volume 8. No. 7, July 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter34872020.pdf
https://doi.org/10.30534/ijeter/2020/34872020

Compressed Air Energy Storage System for Wind Energy: A Review

Ahmad Abid Mazlan[1], Norzanah Rosmin[2*], Anita Ahmad[3], Aede Hatib[4]
[1,2*]Centre of Electrical Energy System (CEES), POWER Department, School of Electrical, Engineering Faculty, Universiti Teknologi Malaysia, Johor, Malaysia, norzanah@utm.my, maherah@utm.my
[3]Control Department, Engineering Faculty, Universiti Teknologi Malaysia, Johor, Malaysia, anita@utm.my
[4]School of Education, Engineering Faculty, Universiti Teknologi Malaysia, Johor, Malaysia, aede@utm.my

ABSTRACT

This paper presents a review on the past and present methods of the compressed air energy storage (CAES) system. In this paper, the CAES processes will be classified and compared. Then, a comprehensive review on the suitability of CAES theories towards renewable energy system is given. Finally, the evaluations on the CAES application in wind energy system is also discussed, after assessing the CAES concepts' individual strengths and weaknesses.

Key words: Compressed air, energy storage, wind, solar, diabetic, adiabetic, isothermal.

1. INTRODUCTION

Renewable energy (RE) is known for its fluctuating problems due to its stochastic nature and this problem depends on the condition of the environment [1-3]. For an example, RE such as wind can only produce energy from the wind turbine when the surrounding wind speed are within the cut-in and cut-out wind speed [4]. Therefore, to solve the fluctuation problems, energy production that uses RE as its source are usually equipped with energy storage (ES). Currently, there are different types of ES which widely been implemented in RE conversion system, for instance battery, flywheel, super capacitor, pumped hydro, fuel cells and compressed air energy storage (CAES) system. Among these ESs, CAES is known as one of the most effective method compared to other ESs [5].CAES is one of an attractive option as ES in large scale application due to its fair round trip efficiency and recharging time, long lifetime, large power capacity, low maintenance and offers low operational costs [6]. The basic concept of CAES system is based on the compression of air and storage in geological underground voids. When the stored energy is needed, the released air is heated via combustion using natural gas or fuel and is expanded to drive a gas turbine to generate electricity [7].

There are three types of CAES, namely Diabetic CAES (D-CAES), Adiabatic CAES (A-CAES) and Isothermal CAES (I-CAES). The operational work of these CAES systems are similar. The only difference that classify the types of CAES is how the heat is handled during compression and expansion process. D-CAES type is the very basic types of CAES while A-CAES and I-CAES is an upgraded type of D-CAES. A-CAES utilizes the heat from compression for the expansion process, thus offers a great choice. It has an advantage in reducing the heat of energy wastage during the compression process, more efficient and environmentally friendly, compared to D-CAES. However, it requires higher capital and installation costs due to the requirement of thermal energy storage. Meanwhile, I-CAES provides lower operational cost due to no combustion is required during the expansion process, and environmentally friendly as well. However, I-CAES is less popular compared to A-CAES since the operating conditions of the surrounding area need to be considered carefully as condensation effect can affect the CAES' efficiency greatly.

Figure 1 shows the typical CAES system, in which consisting three important stages; compression stage, air storage and expansion storage.

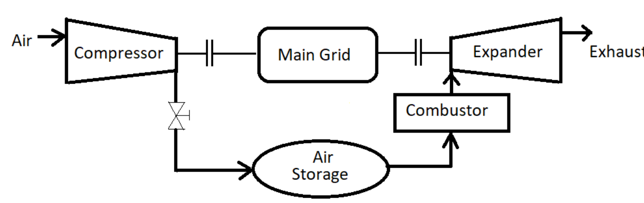
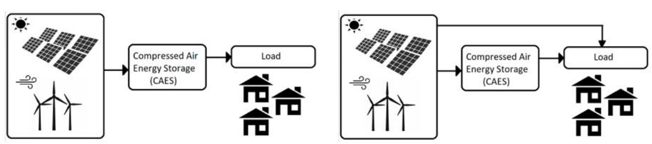


Figure 1: Basic Concept Diagram of CAES [10]

As shown in the figure, air is the main input of the CAES where air will be compressed in an intercooled compression train until it reached a high-pressure level (between 60-100 bar) [8]. Before entering the storage tank, the compressed air must be cooled down first to maximize the air that can be stored in the storage tank. Typically, the process of compressing and cooling down the air will be repeated two times before entering the storage tank to maximize the amount of absorbed air. As ES system, CAES is typically require electricity to run the compressor and expander, to enable the operational of charging and discharging the stored energy. Thus, various sources can be used to supply the active power such as the electrical grid [5], and RE sources such as wind turbine, hydro and solar power plant [9].

For CAES system supplied by RE sources, such as wind turbine and solar photovoltaic, there are two types of connection is generally used; direct connection and hybrid connection, as depicted in Figure 2(a) and (b), respectively. Both connections are electrically linked with each other where the generated electrical output from the RE sources will be used to run the CAES. For direct connection, the RE sources will be used directly to charge the CAES and the then the CAES will supply the load when needed. While in hybrid connection, RE sources will be used to supply energy direct to the load, but if fluctuation occurs, CAES will be used to cover the loads. On the other hand, in the situation of RE source can produce more electricity required than the load, the auxiliary electricity will be used to charge the CAES.



(a) Direct Connection (b) Hybrid connection

Figure 2: RE-CAES Connection

Presently, there is a new method that has been proposed for hybrid wind turbine (WT) and CAES system. In [11], a new approach on hybrid connection has been tested analytically and experimentally by combining the compressor and expansion process using one generator only. In conventional CAES system, two generators are used for the compression and expansion, but in [11], the cost for the extra generator can be eliminated. Meanings, a single device that operates as both compressor or expander causing charging and discharging process are unable to be done simultaneously. If the discharging process occur too long, it will be emptying the storage tank in CAES system and hence causing the electricity generated to the load to be interrupted.

2. SIGNIFICANCE OF REVIEW WORK

Fluctuation behavior of the wind has opposed an issue to the existing WT-CAES systems. A sudden change of the unpredictable wind power available will reduce the generated power and system's frequency to the load. Most of the WT-CAES systems are relying on auxiliary energy generated to charge the CAES to solve the fluctuations problem. However, during a situation where the wind power is not enough or can barely support the load demand for a long time, the CAES will be emptied and hence need time to recharge while load demand could not be supplied for a period of time. The system's frequency response will also be degraded which will affect the CAES ability to operate again. As can be depicted from Figure 3, the existing WT-CAES system is unable to fully support the load demand during low wind power [12]. So far, most of the published publications on WT-CAES case, the generator used in WT-CAES used two generators; generator for WT system and generator for CAES unit, working separately. This system has a good potential to solve the problem of wind's fluctuation behavior, however it leads to the increment of the total system's costs. Hence, through this paper, the compact details on the CAES types will be explained briefly, along with the works related to each system. It is hoped that this will give the readers quick information about the details, challenges and opportunity when use WT-CAES system.

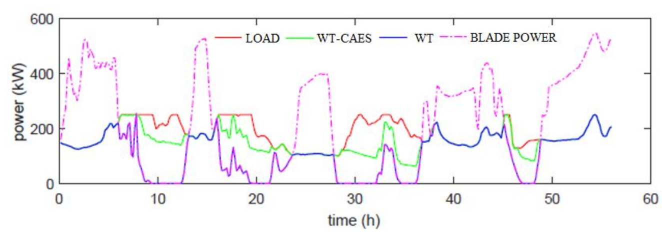
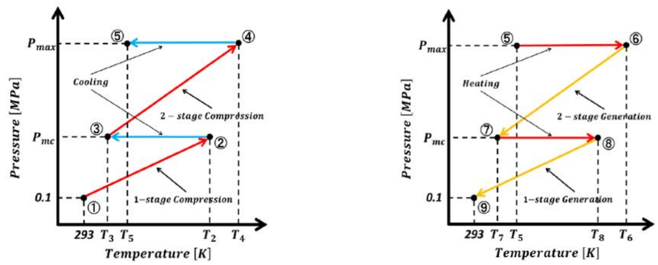


Figure 3: Generation versus load curve of a WT-CAES System [12]

3. CONVENTIONAL CAES SYSTEM

As mentioned in section 1, typical CAES system has three important stages; compression stage, air storage and expansion storage. To understand these three processes, please refer to Figure 4. As shown in Figure 4(a), for the compression process, the air at 293˚K (ambient air temperature) will be sucked into the compressor and compressed to the pressure Pmc and temperature will rise to T2. Pmc will be determined based on the Pmax which is the maximum pressure that the tank could handle mechanically while T2 is determined based on the pressure Pmc. Afterwards, the air will be cooled down to the temperature of T3 by the heat exchanger while the pressure remains at Pmc. Next, in the second stage, the air will go through a second compressor which both the pressure and temperature will be increased to Pmax and T4 respectively. Finally, the air will be cooled again until T5 while the pressure remains at Pmax. After that, the pressured air will be emitted to the compressed air storage tank. Practically, a slight drop of pressure during the cooling is expected. But, in many works, the drop is always neglected because the drop range is very small [13].



(a) Compression process (b) Expansion process

Figure 4: Compression and Expansion process [13]

The air storage can either be an aboveground storage or an underground storage. The underground storage is targeted for a large-scale system such as 100kW and above [5]. Meanwhile, the aboveground storage is targeted for a small-scale system (10kW) [5]. For underground storage, salt cavern is usually chosen to serve the purpose of storing the air due to its very high withdrawal and injection rates which can help to serve a high peak demand at short time duration, and has low cushion gas. The storage capacity of the CAES can be determined by the size of the cavern itself. The salt cavern is formed by drilling conventional well and fresh water will be pumped into the cavern. The water will dissolve the salts and the water will saturate. The water is then returned to the surface and this process will be repeated until the desired volume and shape is obtained. This is the main reason that geographical analysis needs to be done thoroughly before selecting the location for a CAES plant. After the air is stored into the energy storage, the expansion process will take place when energy is needed to be withdrawn from the storage so that electricity can be generated.

Expansion process as shown in Figure 3(b) is similar to the compression process. In this process, the air will be heated to a certain temperature and expanded. This process is usually repeated twice just like the compression process. The air from the compressed air tank will be heated from T5 to T6 while the pressure remains at Pmax. Then, the air is expanded for the first time until both pressure and temperature decreased to T7 and Pmc. Afterwards, the expanded air will be heated again until it reaches the temperature of T8. Lastly, the air is expanded for the second time until the temperature and pressure drop to 293˚K and 0.1 MPa. The expanded air will be released and produce mechanical power that will be used to run the generator's rotor so that the mechanical power will be converted into electric power.

There are three types of CAES which are Diabatic (D-CAES), Adiabatic (A-CAES), and Isothermal (I-CAES) [8]. The only difference that classify the type of CAES is how the heat is handled in the compression and prior to the expansion process. For D-CAES type, the compressed air needs to be cooled down until it reaches the ambient temperature. Afterwards, for the expansion process, combustion of fuel is needed to increase the temperature. During the compression process, the heat is removed by the cooler causing a complete wastage since that later, the expansion process requires heat. The world's first CAES plant is D-CAES type and it started to operate in 1978 near a German Village of Huntorf, with output power of 290MW [7]. Afterwards, second CAES plant which is also D-CAES type was built in McIntosh/Alabama in USA in 1991 with the power capacity of 110MW [14]. Both plants use salt caverns as the energy storage.

Conversely, A-CAES will not let the heat that was cooled down from the compression process to go to waste. The heat from the compression process will be reused again during the compression stage. A-CAES can be operated by two ways either with or without thermal energy storage (TES) [14]. A-CAES plant with TES will consist of two storages which is for the air and heat. The heat from the compression process will be stored inside the TES and will be used when the expansion part will take place. Meanwhile, A-CAES without TES will use air for expansion by storing hot air in the air storage without cooling it during the compression process. However, compressed ambient air can be heat up to 277˚C of moderate pressure of 10 bar. Most of the air storage available are unable to withstand this high temperature causing A-CAES without TES can only be used with low storage pressure and consequently to low energies as well. A-CAES system is more suitable for distributed generation power plant instead of large-scale power plant due to the cost air storage pressure tank [13].

Figure 5 shows the simplified process scheme of CAES system installed at Huntorf Plant and was first build with power of 290MW. It is categorized as D-CAES type as the heat from the compression is not utilized to serve the purpose of expansion process. The compression of air in an intercooled process is executed using two separate turbo-compressor to maximum of 72 bar. Before storing the compressed inside the compressed air storage, the air will be cooled again. This 2-stage compression is done to limit the exergy losses. However, due to the cooling process, almost 25% of exergy supplied is wasted during the compression. The compressed air storage at the plant consist 2 caverns with the total storage of 310,000 m^3. During operation, the caverns will never reach ambient pressure again where it will be maintained around 46-72 bar except for an emergency cases where it can be used below 46 bar. The expansion part also consists of 2-stage where the air will be heated first before it will be expanded, and the process is repeated twice. The air will be heated up to 490˚C and expanded down to 10 bar. Then, it will be heated again up to 945˚C before it is expanded again, and the mechanical energy produced will be used to run the generator.

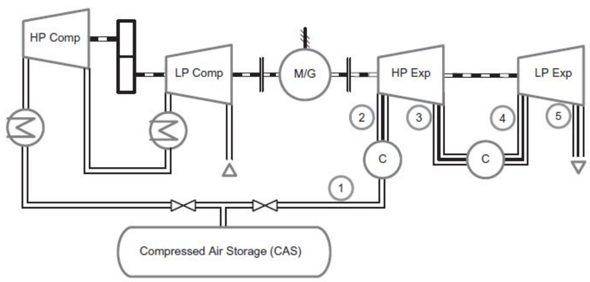


Figure 5: Simplified Process Scheme of Huntorf Plant [15]

After 28 years of operation, the whole expansion train was retrofitted, and the power output increased from 290 MW to 321 MW. One of the retrofitted done was the temperature of heated air on the first heating process was reduced from 550˚C to 490˚C. Then, another retrofitted was done where the first expansion pressure was set from 10 bar to 13 bar and the second heating process was increased from 825˚C to 945˚C. In recent years however, the plant was used for tertiary control reserve and for internal portfolio optimization. It also has a black start capability that able to provide reactive power.

McIntosh is a second large scale CAES plant that was built in the world with output power of 110MW with the simplified process scheme shown in Figure 2.3. Like Huntorf plant, it is also a D-CAES type. The difference of these plant is McIntosh Plant uses only one cavern instead of two with the volume of 538,000m^3. It also uses multiple stage intercooling during the compression process. The main advance of this plant is the usage of exhaust-heat recuperator. During expansion, a still hot exhaust gas of LP expander (370˚C) used to pre-heat the compressed air flowing out of the cavern. The compressed air will be heated up to 295˚C before expanded. Then, the air will be heated again and expanded again by the low-pressure expander. This process is shown in Figure 6. The exergy remains in the exhaust gas increased as well because pressure ratio of low-pressure expander is too small to reduce the heat in the exhaust gas. The plant is mainly designed to serve the demand load shifting on weekly basis.

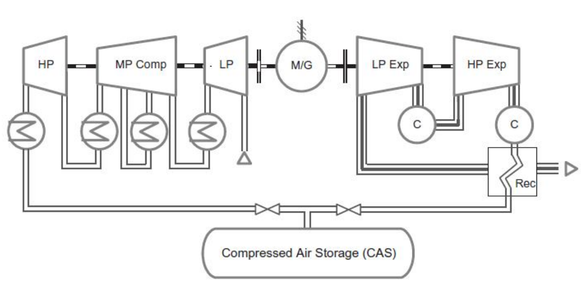


Figure 6: Simplified Process Scheme of McIntosh Plant [15]

4. RENEWABLE - CAES SYSTEM

Energy storage are needed in most renewable energy (RE) generation system due to its fluctuating problem. Fluctuation in RE occurs because it is highly dependent on the condition of the environment. For a bulk energy system, compressed air energy storage (CAES) is preferable because it can provide constant active power to grid if a suitable control system is applied to the system [5]. Theoretically, CAES can be connected electrically with any RE system such as solar, wind, hydro, tidal, etc. with the process shown in Figure 7. The RE will produce electricity either using generator, photovoltaic, etc., based on the RE source used. The electrical energy generated will run a series compressor to store air into the air storage. The air storage can either be above ground or underground. Above ground storage are used for small scale system 10KW and underground storage used for large scale system 100KW and above. When electricity is needed, the air will be withdrawn from the storage and will be expanded by the expander. The expanded air will then be released and the mechanical power by the air will run the generator's rotor to convert the mechanical power into electrical power.

Practically, implementing CAES onto all types of RE will be very challenging. Mainly it is because of the geographical factor that needs to be considered before using CAES. Large-scale CAES requires an underground air storage (mostly underground salt cavern) which requires a large area. Therefore, the location where the RE source is selected, and the space needed for the CAES must be considered. Most research done for RE-CAES are mostly focusing on using wind and solar energy.

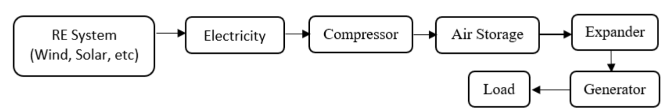


Figure 7: RE-CAES System Process

4.1. Wind Turbine - CAES System

Wind turbine-CAES (WT-CAES) concepts are quite established in wind energy power plant. In the WT-CAES context, as presented in the literature in [9, 16-22], the main challenges are regarding the power fluctuations problem due to wind speeds variation, in particular when wind speeds are at low wind conditions, where wind farm is unable to supply the required demand from the load sides. For wind application, there are two methods used for the WT-CAES system, namely WT-CAES direct connection and WT-CAES hybrid connections, as shown in Figure 8 and Figure 9, respectively. For the direct connection used for a WT-CAES system as shown in Figure 8, the wind turbine will be connected to the CAES only with no direct connection to the load. Therefore, the wind turbine will always run the compressor when the wind speed is the same or greater than the rated wind speed value. The load will continuously be supplied by the CAES. The biggest disadvantage of this type of system is the excess electricity produced will be wasted.

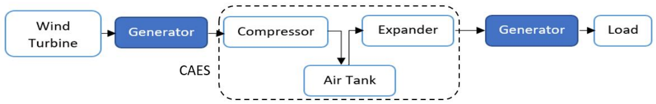


Figure 8: Direct connection WT-CAES

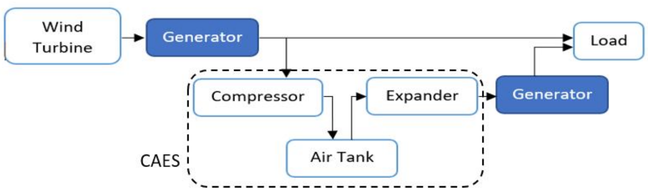


Figure 9: Hybrid connection WT-CAES

In hybrid connection of WT-CAES system, the wind turbine will serve the load directly. When the wind speed is high, excess electricity produced by the wind turbine will be used to drive the compressor (charging CAES). When the wind farm is unable to supply the load demand, the CAES will be used to supply electricity shortage so that the load demand can be met continuously. The drawback for this system is if load demand is within the rated value of the wind turbine for a long time, the CAES cannot be charged. If the wind speed dropped below the rated value and the load demand stays constant for a long time, the CAES tank will be emptied and power supply to the load will not be sufficient. To solve the problem, a higher rated value of wind turbine and its' generator may be used so that the CAES can still be charged when load demand is within the rated value but this will increase the cost of the system. Another method that can be use is by using another power source to run the compressor, but it will also increase the cost of the system.

Besides above, there is another approach that has been introduced in WT-CAES system where a mechanical approach is used to transfer the power from both wind turbine and CAES to the generator. The main advantage of this approach is the number of generators used by the aforementioned WT-CAES (wind turbine's generator and CAES' generator) can be reduced to one. Figure 10 shows the connection of the WT-CAES system by using the mechanical approach. The wind turbine and CAES mechanical power output will be used to supply a generator through a mechanical power submission device. The mechanical power submission device will sum up the output mechanical power from both wind turbine and CAES to supply the generator. The control strategy of this system is when wind speed is within the rated value, the generator will be fully operated by the wind turbine. If the wind speed is low, the remaining power needed for the generator to operate at a rated value will be supplied by the CAES. There are variety of mechanical power submission device used in recent studies such as variable displacement machine (VDM) [4], clutch [23], and power split device (PSD) [11].

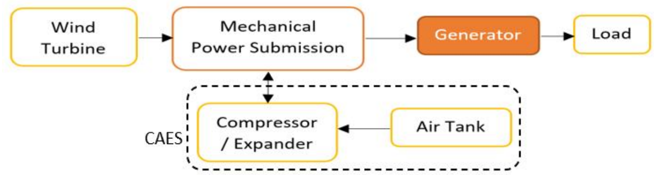


Figure 10: Hybrid connection WT-CAES using mechanical approach

In the recent studies, most of the hybrid WT-CAES systems that use mechanical approach are using a single device that can operate as both compressor and expander. Capital cost can be reduced when uses this single device, but the drawback is the charging and discharging process cannot occur at the same time. This will cause a problem when wind speed is low for a long time and air will emptied due to the discharging process causing not enough power to supply the load demand.

4.2 Discussions on WT-CAES

Based on the mentioned existing CAES systems, all these methods have their own advantages and disadvantages in providing the practical energy storage support. The comparison details on these three type CAES is summarized in Table 1.

Table 1: Comparison on CAES Types

Types of CAES	Comparison on the Operational Working Principle
D-CAES	• The compressed air will be cooled down since the air storage cannot store air in high temperature. • The heat released from the cooling process is wasted. • The compressed air needs to be reheated first before entering the expansion process. • The heating process will require combustion of fuel to increase the expanded air temperature.
A-CAES	• The compressed air will be cooled down. • The heat from the cooling process will be stored in a Thermal Energy Storage (TES). • The air needs to be heated before expanded so that efficiency can be increased. • The heating process will utilize the heat stored from the heat stored in TES

I-CAES	• Can only be used on piston machinery type compressor and expansion where the process is slow. • The slow response of the expansion and compression process will leave enough time for the air to undergo heat exchange process such as spraying liquid into the plug room of common piston machine. • The piston for the compressor and expanders must be modified so that it can withstand water. • Not a lot of I-CAES is used due to a lot of considerations need to be accounted such as the humidity of the ambient air.

Based on the published works that have been presented in this paper, few conclusions regarding the existing CAESs are drawn as follows:

- Most of the CAES strategies that have been published are focusing on improving or smoothing the continuous power supply to the load during energy supply interruptions. Thus, some rooms of improvement are still required in terms of designing air storages for CAES to enable to be used for more broaden cases.

- I-CAES has a good potential in various applications and need to be investigated further for its additional advantages as it can cool and heat the compression and expansion process respectively, without the need of TES so that the cost can be reduced.

- When electrical approach is considered in the hybrid connection of WT-CAES, CAES only can be charged when excess energy is available.

- Different to electrical-based hybrid WT-CAES system, hybrid WT-CAES based on mechanical approach provides more cost effective but has a limitation where the CAES can be emptied if fluctuation occur for a long time.

- Renewable sources other than wind energy that uses generator to generate electricity can use the mechanical approach with CAES.

Among the three CAES types, from the author's view side, D-CAES believed presents a well-established technology though its system is simple, more controllable, more reliable, and very cost effective. For the power smoothing strategy towards the wind speed fluctuation issues, it is expected that separating the compression and expansion process may provide more limitless supports to the system frequency by charging and discharging the energy more effectively, compared to the combined process. Hence, it can provide continuous supported torque to the generator under variable wind speed conditions. Other than this, considering split power device also may further smoothing the power supplied where using this approach, the charging and discharging process of the storage tank can be done simultaneously. This is more practical whereby energy flow can be managed more reliable where the energy stored can be used and surplus power can be stored anytime [33]. Therefore, combining these two characteristics is projected may promise a more reliable approach in the power smoothing purpose. It is expected that system is compatible for small to large scale wind turbine systems for broader wind speed regions; from low, medium and to high wind speed regions. The proposed mechanical method (split device) tends to smooth the power transferred to the loads as the air expander provides additional power from CAES when wind speed is not high enough to maintain the power balance between the supply and load sides. The air in the energy storage tank will never experiencing the shortage problem since it will be supplied by the main grid. Using the proposed approach, sufficient power can be supplied continuously in any conditions. For more sophisticated control, programmable integrated circuit can be integrated in the system for more controllable progress [34].

8. CONCLUSION

This paper provides a review on the operating system of three types of compressed air energy storage (CAES) system, namely adiabetic-CAES (A-CAES), diabetic-CAES (D-CAES) and isothermal-CAES (I-CAES). System capability to stabilize power response in grid systems for each these three concepts has been discussed, in different ways based on their storage characteristics. The issue and challenges towards each concept have been demonstrated, specifically in wind energy system. In the future, the effectiveness of combining the CAES concept with mechanical approach (split device) may be investigated further, via small emulator system or through the simulation platform. The technical feasibility and reliability should be explored further, as well as the cost techno economic assessment.

ACKNOWLEDGEMENT

The authors would like to thank the Ministry of Higher Education of Malaysia for the financial funding of this project under Q.J130000.3551.06G65, ICF (4S142) and CRG10.3(04G96), the Research Management Centre (RMC) of Universiti Teknologi Malaysia, Centre of Electrical Energy Systems (CEES), School of Electrical Engineering, UTM, UTM for their support for the research management.

REFERENCES

1. Shu, L., et al. **Control strategy of energy storage station to smooth real-time power fluctuation**. *In 2015 International Symposium on Smart Electric Distribution Systems and Technologies (EDST)*, 2015.
2. Miyagi, D., et al., **Experimental Research on Compensation for Power Fluctuation of the Renewable Energy Using the SMES Under the State-of-Current Feedback Control**. *IEEE Transactions on Applied Superconductivity*, 25(3), pp. 1-5, 2015. https://doi.org/10.1109/TASC.2014.2368051
3. Sheng, L., et al., **Stand-alone island daily power management using a tidal turbine farm and an ocean compressed air energy storage system**. *Renewable Energy*, 10, pp. 286-294, 2017.
4. Cheng, J. and F.F. Choobineh. **A comparative study of the storage assisted wind power conversion systems**. *In 2017 6th International Conference on Clean Electrical Power (ICCEP)*, 2017. https://doi.org/10.1109/ICCEP.2017.8004751
5. Hasan, N.S., et al., **Review of storage schemes for wind energy systems.** *Renewable and Sustainable Energy Reviews*, 21, pp. 237-247, 2013.
6. Akinyele, D. and R. Rayudu. **Review of energy storage technologies for sustainable power networks**. *Sustainable Energy Technologies and Assessments*, 8, pp. 74–91, 2014. https://doi.org/10.1016/j.seta.2014.07.004
7. Rublack, L., et al. **Sensitivity analysis of adiabatic compressed air energy storage**. *In 2016 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe)*, 2016.
8. Budt, M., et al., **A review on compressed air energy storage: Basic principles, past milestones and recent developments**. *Applied Energy*, 170, pp. 250-268, 2016.
9. Rampurkar, S., K.S. Sandhu, and R. Kumar. **Performance of parallel connected compressed air energy storage for proper utilization of wind energy**. *In 2017 International Conference on Advances in Mechanical, Industrial, Automation and Management Systems (AMIAMS)*, 2017.
10. Liu, W., et al., **A Novel Hybrid-Fuel Storage System of Compressed Air Energy for China**. *Energies*, 7(8), pp. 4498-5010, 2014. https://doi.org/10.3390/en7084988
11. Krupke, C., et al., **Modeling and Experimental Study of a Wind Turbine System in Hybrid Connection with Compressed Air Energy Storage**. *IEEE Transactions on Energy Conversion*, 32(1), pp. 137-145, 2017.
12. Cheng, J., et al., **Dispatchable Generation of a Novel Compressed-Air Assisted Wind Turbine and its Operation Mechanism**. IEEE Transactions on Sustainable Energy, 2018: p. 1-1.
13. Takagi, Y., A. Minami, and K. Sakamoto. **A dynamic simulator of adiabatic compressed air energy storage (A-CAES) plant — Heat medium control simulations**. *In 2017 11th Asian Control Conference (ASCC)*, 2017.
14. Budt, M., et al., **Compressed Air Energy Storage – An Option for Medium to Large Scale Electrical-energy Storage**. *Energy Procedia*, 88, pp. 698-702, 2016. https://doi.org/10.1016/j.egypro.2016.06.046
15. Wolf, D., **Methods for design and application of adiabatic compressed air energy storage based on dynamic modeling**. Verlag Karl Maria Laufen, Oberhausen (Germany): Germany, 2011.
16. Nguyen, T.V. **Integration of compressed air energy storage with wind turbine to provide energy source for combustion turbine generator**. *In IEEE PES Innovative Smart Grid Technologies, Europe*, 2014.
17. Sedighnejad, H., T. Iqbal, and J. Quaicoe. **Performance evaluation of a hybrid wind-diesel-compressed air energy storage system**. *In 2011 24th Canadian Conference on Electrical and Computer Engineering(CCECE)*, 2011.
18. Kwong, K.H., H. Sun, and J. Wang. **An initial study on alleviating wind power output variability via Compressed Air Energy Storage systems**. *In UKACC International Conference on Control 2010*, 2010.
19. Zhang, Y., et al., **Thermodynamic analysis of energy conversion and transfer in hybrid system consisting of wind turbine and advanced adiabatic compressed air energy storage**. *Energy*, 77, pp. 460-477, 2014.
20. Mahmoudi, I.R.H. **The control strategy for a hybrid wind-photovoltaic system with compressed air storage element**. *In 2016 International Conference on Electrical and Information Technologies (ICEIT)*, 2016. https://doi.org/10.1109/EITech.2016.7519568
21. Saadat, M., F.A. Shirazi, and P.Y. Li, **Modeling and control of an open accumulator Compressed Air Energy Storage (CAES) system for wind turbines**. *Applied Energy*, 137, pp. 603-616, 2015.
22. Succar, S., D.C. Denkenberger, and R.H. Williams, **Optimization of specific rating for wind turbine arrays coupled to compressed air energy storage**. *Applied Energy*, 96, pp. 222-234, 2012.
23. Sun, H., X. Luo, and J. Wang, **Feasibility study of a hybrid wind turbine system – Integration with compressed air energy storage**. *Applied Energy*, 137, pp. 617-628, 2015. https://doi.org/10.1016/j.apenergy.2014.06.083
24. Hasan, N.S., et al. **Mathematical model of Compressed Air Energy Storage in smoothing 2MW wind turbine**. *In 2012 IEEE International Power Engineering and Optimization Conference Melaka*, Malaysia. 2012.

25. Sun, H., et al., **Study on Energy Storage Hybrid Wind Power Generation Systems**. *Proceedings of the World Congress on Engineering 2010*, 2010.
26. Sun, H., X. Luo, and J. Wang. **Simulation study of energy efficiency for a hybrid wind turbine system**. *In 2013 IEEE International Conference on Industrial Technology (ICIT)*, 2013.
27. Sun, H., X. Luo, and J. Wang. **Management and control strategy study for a new hybrid wind turbine system**. *In 2011 50th IEEE Conference on Decision and Control and European Control Conference*, 2011. https://doi.org/10.1109/CDC.2011.6161059
28. Pillay, P. and R. Krishnan. **Modeling, simulation, and analysis of permanent-magnet motor drives**. *IEEE Transactions on Industry Applications*, 25(2), pp. 265-273, 1989.
29. Cheayb, M., et al., **Modelling and experimental validation of a small-scale trigenerative compressed air energy storage system**. *Applied Energy*, 239, pp. 1371-1384, 2019.
30. Wang, J., et al. **Mathematical Modeling Study of Scroll Air Motors and Energy Efficiency Analysis—Part II**. *IEEE/ASME Transactions on Mechatronics*, 16(1), pp. 122-132, 2011.
31. Wang, J., et al. **Mathematical Modeling Study of Scroll Air Motors and Energy Efficiency Analysis—Part I**. *IEEE/ASME Transactions on Mechatronics*, 16(1), pp. 112-121, 2011. https://doi.org/10.1109/TMECH.2009.2036608
32. Benford, H.L. and M.B. Leising, **The Lever Analogy: A New Tool in Transmission Analysis**. *SAE Transactions*, 90, pp. 429-437, 1981. https://doi.org/10.4271/810102
33. Swapnil A, et. Al. **Solar PV System for Electric Traction Application with Battery Backup**. *International Journal of Emerging Technologies in Engineering Research (IJETER)*, 7(1), pp. 1-4, 2019.
34. Aaron Don M. Africa, Darlene Alyssa P. Abaluna, Kyle Daniel P. Pimentel. **Monitoring and Control Systems in Agricultural Machineries and Equipment with a Low-Power Smart Antenna System**. *International Journal of Emerging Technologies in Engineering Research (IJETER)*, 8(5), pp. 1860-1868, 2019.