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Performance analysis of a small capacity compressed air energy storage system for renewable energy generation using TRNSYS

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Compressed air energy storage (CAES) is one of the most promising mature electrical energy storage technologies. CAES, in combination with renewable energy generators connected to the main grid or installed at isolated loads (remote areas, for example), are a viable alternative to other energy storage technologies. Indeed, because of the advantage of fast response, high economic performance, and small environmental impacts, CAES has an extensive application prospect in renewable power generation. In the present work, the thermodynamic response of the charging and discharging cycles in the storage tank is numerically analyzed for a 2 kW small capacity CAES. The prediction of the system parameters from the thermodynamic analysis is essential in designing the tank, compressor, and expander. The energy extracted from the CAES system is being used for several applications such as power, heating, and cooling. Hence the real time challenge is to quantify the energy utilized for the various services provided by the system to maximize the output and overall efficiency. A thermodynamic study on the proposed system optimizes and compares the charging and discharging characteristics for adiabatic and isothermal compression. The system performance is evaluated using the TRNSYS V17 platform for CAES direct usage (using the heat of compression before the expansion process and cool energy from expansion before the CAES tank), advanced adiabatic—CAES (AA-CAES), CAES with solar system under various parametric conditions. All necessary design parameters are studied and the optimum values are determined using TRNSYS software. *Published by AIP Publishing.* [http://dx.doi.org/10.1063/1.5000287]

I. INTRODUCTION

Renewable energy sources (RES) (e.g., solar and wind energy) exhibit remarkable and uncontrollable intermittency during power production. When such renewable energy sources are connected to an electrical grid, they can cause serious issues and problems to the grid. To solve this dilemma and for further development of renewable energy sources, a viable energy storage system is required. Such an energy storage system is provided by compressed air energy storage (CAES). The feasibility of using CAES to integrate fluctuating renewable power into the electricity grid systems has been proven. However, the thermal and economic efficiency of CAES is poor. Hence, its further development is restricted. To improve the CAES performance, the concept of Poly-generation (simultaneous generation of hot energy from heat of compression, cool energy from expansion, and power from an alternator) is introduced. In large scale compressed air energy storage, the off-peak power used from the grid is to compress the air and is pumped into a sealed underground reservoir to a high pressure. The pressurized air is then kept in the underground reservoir for the peak requirement. During the time of requirement, this high pressure air from the reservoir can drive the turbines and the subsequent power produced may be used at peak hours. Pazheri *et al.*[1] stated that the global exploitation of renewable energy technologies is increasing

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rapidly due to the concern in global warming and declining supplies of fossil fuels. Most of the countries in the world are blessed with two or more renewable energy sources (RES) and hence have articulated policies to boost the utilization of RES for their electricity production. They have also discussed about the recent developments in installation capacities, costs, and reductions in electricity costs of major RES based electricity generation methods. Pazheri *et al.*[2] stated that the electricity generation is a major source of pollutant emissions. Burning of oil, natural gas, and coal at power plants produces nitrogen oxides, sulfur dioxide, and carbon dioxide, etc. These emissions can lead to smog, acid rain, and haze. In addition, such power plant emissions increase the risk of climate change. Pollution control devices and use of available renewable resources along with such plants can help to reduce the amount of pollution emission. Pazheri *et al.*[3,4] stated that solving power system scheduling is crucial to ensure smooth operations of the electric power industry. Effective utilization of available conventional and renewable energy sources by tri-generation and with the aid of energy storage facilities can ensure clean and energy efficient power generation and they also stated that due to the increased awareness on the adverse effects of carbon dioxide emission on the environment, power plant operators are compelled to reduce emissions of pollutants during cogeneration. Venkataramani *et al.*[5] analyzed and reviewed the research works pertaining to the thermodynamic analysis, economic analysis, and design and performance analysis of the CAES system. The modeling and simulation analysis on the Huntorf plant in Germany by various researchers with proper mass and energy balance and by feeding the data from the results were compared for both isothermal and adiabatic models. The economic analysis of CAES and the Diabatic Compressed Air Energy Storage (DCAES) system in Alberta City was carried out by the researchers and concluded that there is an additional profit that is being observed in DCAES when compared with the CAES system. Also, there is a drastic reduction in the CO_2 emission that has further led to the economic enhancement. Wang *et al.*[6] published a chapter titled, "Study on a wind turbine in hybrid connection with an energy storage system," in the text book *Electrical Engineering and Applied Computing*. Hartmann *et al.*[7] analyzed the efficiency of one full charge and discharge cycle of several adiabatic compressed air energy storage configurations with the help of energy balance. Further, the main driving factors for the efficiency of the CAES configurations are examined with the help of sensitivity analysis. They concluded that the key element to improve the efficiency is to develop high temperature thermal storage and temperature resistant material for compressors. Kushnir *et al.*[8] studied the thermodynamic response of underground cavern reservoirs to charge/discharge cycles of compressed air energy storage plants. Based on the mass and energy conservation equations, numerical and approximate analytical solutions were derived for the air cavern temperature and pressure variations. Sensitivity analyses were conducted to identify the dominant parameters that affect the storage temperature and pressure fluctuations and the required storage volume. Safaei *et al.*[9] stated that CAES technology has gained momentum in recent years because of the rapid growth of solar and wind capacity. In this paper the authors have investigated the potential benefits along with the financial benefits associated with the heat recovery for space heating and water heating applications from the CAES plant. They have also made a detailed study on geological criteria for screening of a natural gas reservoir for air storage. In addition they have performed an optimization model for CAES and the Distributed CAES system. They have concluded that the economics of heat recovery from CAES facilities can be improved with the incorporation of a thermal energy storage (TES) system. Marano *et al.*[10] discussed that the CAES system has its own advantages, such as flexibility in matching the power fluctuation during the time of demand when they are coupled with renewable energy systems, and they developed a mathematical model along with a dynamic programming algorithm to achieve optimal management of the plant. Velraj *et al.*[11] developed a thermodynamic model and made a performance evaluation on the CAES system with and without TES and concluded that the overall turnaround efficiency of the system without considering the thermal energy storage (TES) system is 57% and with the TES system the efficiency is increased to 70%. Yongliang *et al.*[12] have proposed a novel micro trigeneration system based on compressed air with thermal energy storage technologies. They have also performed the thermodynamic analysis and found that the average comprehensive efficiency is around 50% and 35% in winter and summer, respectively, which seems to be much higher than the conventional trigeneration system. In recent years, attempts are made by the researchers to extend this technology for a small capacity system particularly owing to large scale promotion of a small capacity wind turbine. The present work is aimed at parametric analysis of a small capacity compressed air storage unit. The effect of incoming pressurized air on the tank pressure, temperature, energy stored, energy retrieved, and their corresponding efficiencies are evaluated for different air compression cycles. CAES assures reliability, increases the utilization of renewable resources, and also acts as a buffer to mitigate the fluctuations in the grid power output. In the last few years a lot of research has been conducted in the field of control and monitoring, development of novel power converters, cloud computing, and use of electricity for various applications like plug in vehicles during the off peak power, etc., which are emerging rapidly towards the development of smart grids. Among the various methodologies, the development of efficient energy storage technologies could be the ultimate solution to make the grid stable. The CAES system is more suitable for large capacity storage suitable for grid integration. However, the scope of the present study is to understand that the overall turnaround efficiency is less due to the dissipation of heat during compression and cool energy during expansion. Incorporating poly-generation by utilizing the heat of compression for some process industrial heating applications and cool energy generated during the expansion for some air-conditioning and chiller applications will improve the turnaround efficiency to a greater extent. Hence, the research focus in the future will be the introduction of the CAES system in the grid along with a poly-generation cascaded concept to improve the turnaround efficiency of the CAES system.

II. SCHEMATIC LAYOUT AND SYSTEM COMPONENT

The proposed system of the compressed air storage system consists of the following components:

- Wind turbine
- Compressor
- After cooler
- Waste heat recovery device
- Compressed air energy storage system
- Expander coupled with a generator
- Solar air heater
- Thermal Energy storage

A. Case: 1

In the proposed system of direct usage of hot and cool energy (poly-generation), as shown below in Fig. 1, during the off peak period wind power is employed to run the scroll compressor. The scroll compressor intakes the atmospheric air and compresses it to the required pressure level. During compression the air gets heated up and the heat of compression is used for a hot water system where the water is heated to a definite temperature as per the domestic requirement. The system is provided with waste heat recovery for the aforesaid purpose. The cool air is sent to the storage tank for later use.

When the energy is required for the period of peak load demand the compressed air from the reservoir is taken to the scroll expander and the essential power is obtained from the alternator coupled with the scroll expander. During its expansion process the pressure energy of the air is converted into kinetic energy of the moving scroll which supplies the necessary rotary motion to run the generator. During this process the temperature of the air decreases below the atmospheric temperature which is utilized for the cooling application.

1. Air compression and expansion unit

Scroll compressor is used in the proposed system as they are suitable for oil free air compression at smaller air capacities. The scroll compressor is a positive displacement and orbital

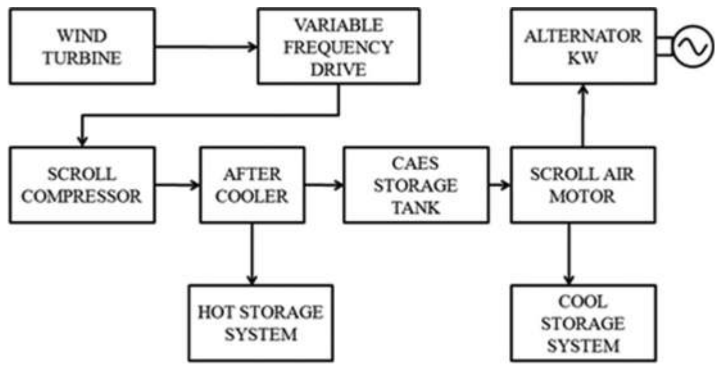

FIG. 1. Block diagram of the proposed system—poly-generation.

motion machine, which performs the process of compression by using two identical inter-fitting, spiral-shaped scroll elements, mounted inverted and rotated 180° in relation to each other.[13–23]

The scroll expander is the reverse of the scroll compressor where one scroll remains fixed; the other is attached to an eccentric that drives a generator shaft. The expander inlet is at the center of the scrolls. The entering gas is trapped in two diametrically opposed gas pockets and expands as the pockets move toward the margin, where the release port is located. No valves are needed, which minimizes the noise and enhances the durability of the unit.

As the scroll expanders employ true rotary motion, they can be dynamically balanced for nearly vibration-free operation. Power delivery is continuous, which almost removes pulsation and associated noise. Reliability is inherent, since there are only two primary moving parts, with no inlet or release valves to break or make noise, and no associated valve losses. The temperature of air coming out of the expander is below atmospheric temperature which is used for cooling application like space cooling, etc.

$$\mathrm{dWisen} = \big(\mathrm{n}/(\mathrm{n}-1)\big) * (\mathrm{Psuc}/\rho\mathrm{suc})^{*}[(\mathrm{Pdis}/\mathrm{Psuc})^{\wedge}\ (\mathrm{n}/\mathrm{n}-1)) - 1]^{*}\mathrm{dm}, \tag{1}$$

$$\mathrm{P} = \mathrm{Wisen}^{*}\eta\mathrm{comp.}, \tag{2}$$

$$\mathrm{Pmotor} = (\mathrm{M}^{*}\mathrm{n})/9550, (\mathrm{M} = \mathrm{Torque\,Nm},\ \mathrm{n} = \mathrm{RPM})\ @\ 6\,\mathrm{bars}, \tag{3}$$

$$\mathrm{Pact} = \mathrm{Pmotor}^{*}\eta\mathrm{motor}. \tag{4}$$

2. Storage tank

During a CAES plant operation, the recurring air injection and withdrawal produces temperature and pressure fluctuations within the storage tank.[8] The storage tanks are designed in such a way to withstand high pressure. The tank volume is designed for the total energy stored in the system.

$$\mathrm{P_1/T_1} = \mathrm{P_2/T_2}. \tag{5}$$

3. Energy recovery devices

Energy recovery devices are used in the system to capture the heat of compression which can reduce the losses reasonably during the storage of high pressure air. At the same time the cool air produced during expansion can also be recovered and utilized. The energy recovered is quantified by the following governing equations:

$$\mathrm{Q_{loss}} = \mathrm{d(mcp\Delta T)_{air}}, \tag{6}$$

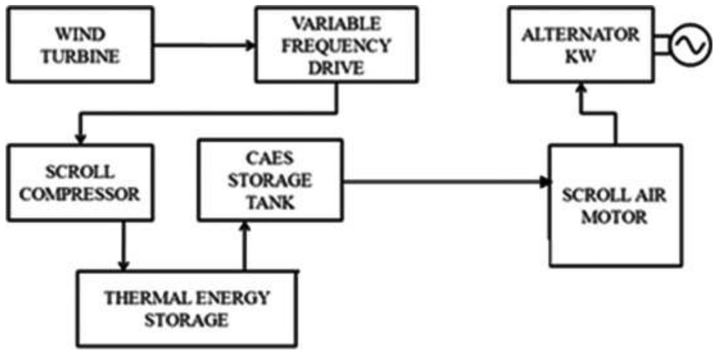

FIG. 2. Block diagram of the advanced adiabatic CAES system with TES.

$$Q_{gain} = 0.8^{*}\, d(mcp\Delta T)air = d(mcp\Delta T)_{water}, \tag{7}$$

$$d(mcp\Delta T)_{water} = (h\, A\, \Delta T)_{air}, \tag{8}$$

$$Q_{loss} = d(mcp\Delta T)_{air}, \tag{9}$$

$$Q_{gain} = 0.8^{*}\, d(mcp\Delta T)_{air}. \tag{10}$$

B. Case: II

In case 2, the conventional CAES is integrated with a thermal energy system, i.e., Advanced Adiabatic CAES (AA-CAES) shown in Fig. 2 and AA-CAES with solar air heater shown in Fig. 3, to improve the quantity of energy stored. Further, a comparative study is made in between CAES without energy recovery, CAES with direct energy usage (using the heat of compression before expansion process and cool energy from expansion before the CAES tank), isothermal condition, and CAES-AA with and without a solar heater.

III. SIMULATION

A. Case: 1

The overall system flow diagram and the processes which are used for developing the thermodynamic and mathematical model is schematically shown in Fig. 4. The flow diagram is typically the same as that of Fig. 1. The system works on the same principle and contains two main sections: a compression process to store energy in the compressed air storage tank and an expansion process to regenerate the stored energy.

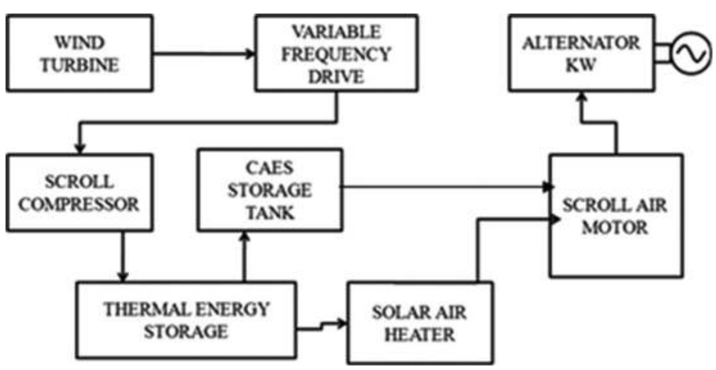

FIG. 3. Block diagram of the solar integrated advanced adiabatic CAES system with TES.

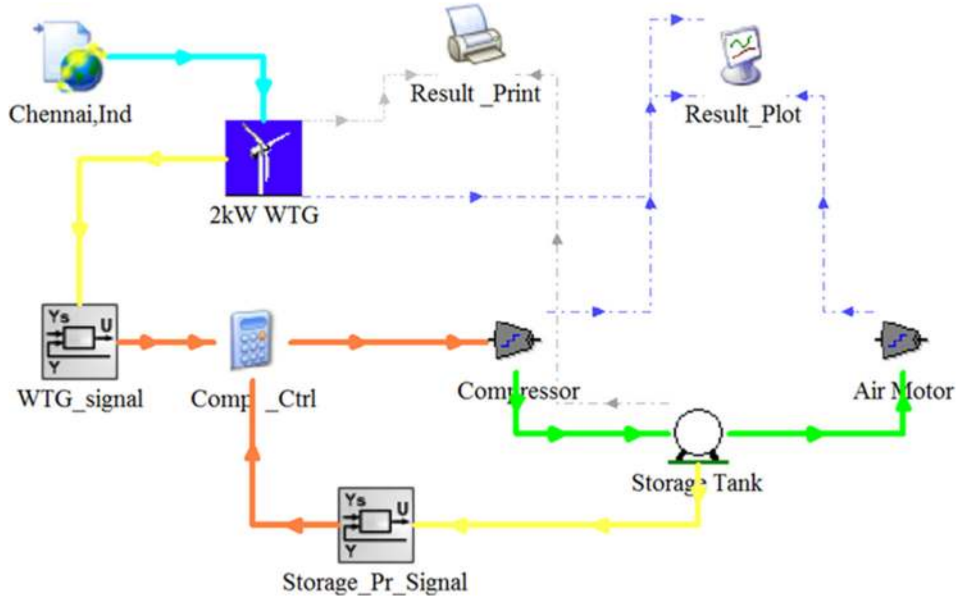

FIG. 4. Schematic layout of the CAES system in the TRNSYS V17 platform.

The governing equations of this model are the ideal gas equation and the mass and energy flow equation. The CAES system is simulated based on these equations in each time step for the charging and discharging cycles. The system is completely developed in the TRNSYS V17 platform and the simulation is carried out at various parametric conditions. The results are printed as an Excel file and are plotted into graphs in an hourly manner. Before analyzing the system, certain parametric conditions are mentioned below in order to establish a simple mathematical model of parametric analysis:

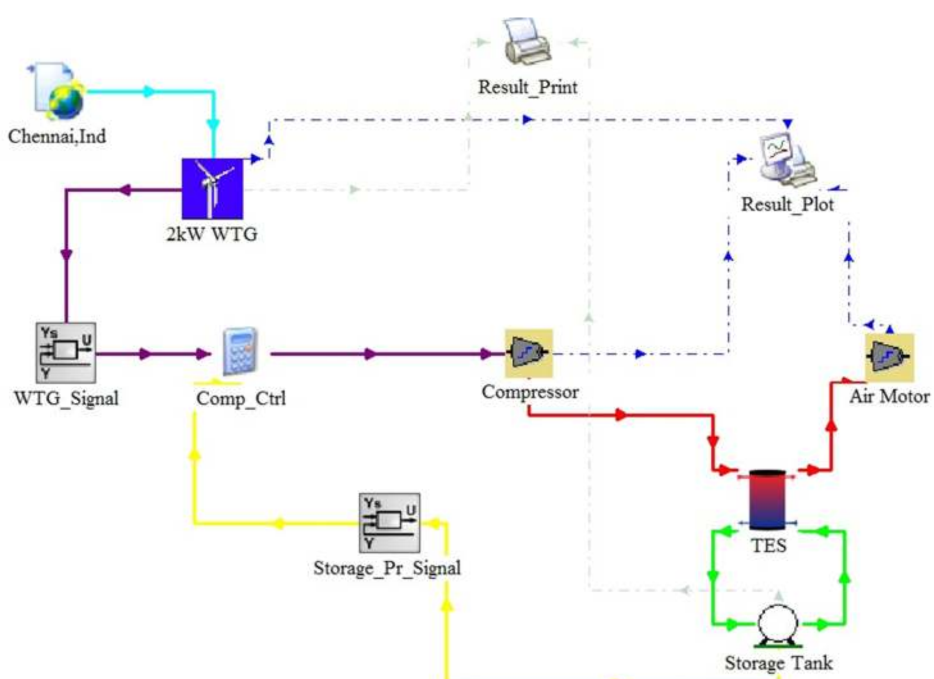

FIG. 5. Schematic layout of the CAES-AA system in the TRNSYS V17 platform.

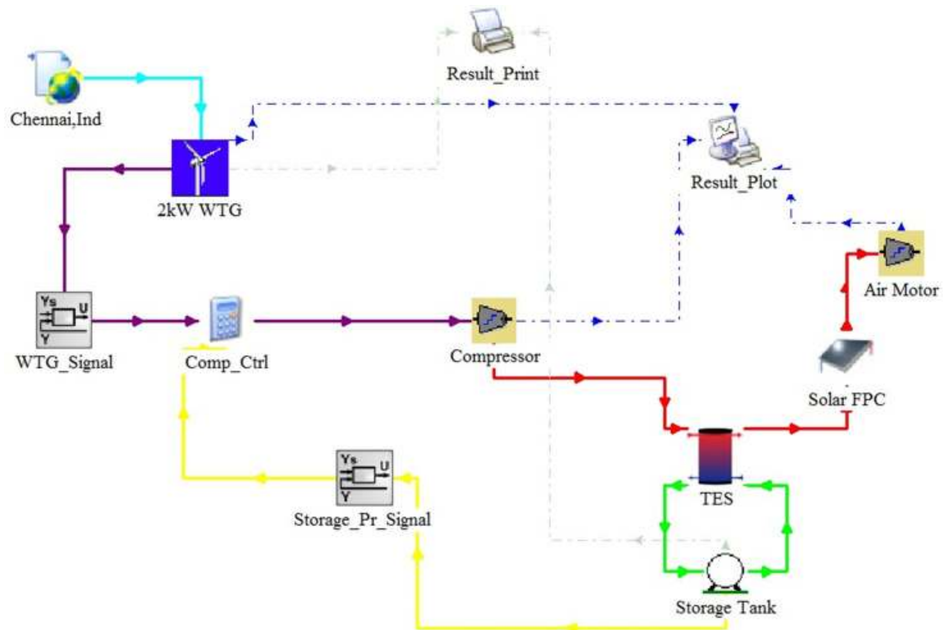

FIG. 6. Schematic layout of the CAES-AA-solar system in the TRNSYS V17 platform.

- The wind power utilized to compress the air is 2 kW.
- Scroll compressor capacity considered is 2 kW with after cooler.
- Initial pressure and temperature of the air supply is 1 bar and 303 K.
- A charging process in done for 8 h/day.
- Discharging is done for 6 h/day.
- Tank volume is considered from 2 m^3 to 100 m^3 for analysis.
- Scroll expander with 2 kW alternator/generator.
- Phase change material (PCM) based thermal energy storage with melting point of 42 °C.
- Solar heater of 1 kW capacity.
- The kinetic and potential energy of the system is neglected.

The system model is greatly simplified with these assumptions and leads to time dependent equations in one dimension.

B. Case: II

The overall system flow diagram and operation processes which are used for developing the thermodynamic and mathematical model for the conventional CAES system with Thermal Energy Storage (AA-CAES) is shown in Fig. 5.

The conventional CAES system is integrated with thermal energy storage (AA-CAES) along with the solar flat plate collector to improve the quantity of energy stored and the efficiency of the overall system is shown in Fig. 6. A comparison is made between these systems to understand the performance of each.

The governing equations of this model are the ideal gas equation and the mass and energy flow equation. The governing equation for each component is listed below in Table I. The CAES, CAES-AA, and CAES-AA-solar systems are simulated based on these equations in each time step for the charging and discharging cycles.

IV. RESULTS AND DISCUSSIONS

A novel small scale CAES system is proposed and thermodynamically simulated for various ranges of operating parameters. The charging and discharging characteristics are constantly

TABLE I. Governing equation for the modules in the CAES system.

S. No.	Component	Governing equation
1.	Wind turbine	1. Power in the Wind Ptotal = $\frac{1}{2}$Pav^3
		2. Pmax = 0.593 Ptotal
2.	Scroll compressor	1. dW$_{isen}$ = (n/(n − 1)) *(Psuc/ρsuc)* [(Pdis/Psuc)^(n/(n − 1)) − 1]* dm
		2. P = Wisen *ηcomp.
3.	Cooling system	
		1. dQ = d(mcpΔT)air = d(mcpΔT)water
		2. d(mcpΔT)water = (h A ΔT) air
4.	Storage tank	1. P1/T1 = P2/T2.
		2. dQ$_{loss}$ = dmcpΔT.
		3. T(t) − T(atm)/T(i) − T(atm) = e$^{(-bt)}$, b = hA/ρ*V*Cp
5.	Scroll expander	1. Pmotor = (M*n)/9550,(M = Torque Nm, n = RPM) @ 6 bars
		2. Pact = Pmotor *ηmotor.
6.	Generator	1. P = Pmotor *ηGen.
7.	Solar collector	1. dQ = d(mcpΔT)air_in = d(mcpΔT)air_out
		2. d(mcpΔT)air = (h A ΔT) air

analyzed for various time steps and the performance of the system is compared adiabatically and isothermally. The results are discussed in the following section under parametric analysis of the CAES system.

A. Parametric analysis

Simulation of the CAES system is performed using the TRNSYS software for different tank volumes ranging from 2 m^3 to 100 m^3 for a power input of 2 kW to the motor operating the scroll compressor. Figure 7 shows the peak pressure and temperature of the system for different tank volumes. As observed, there is a steep decrease in the temperature and pressure for variations in low volume ranges and after which it decreases steadily.

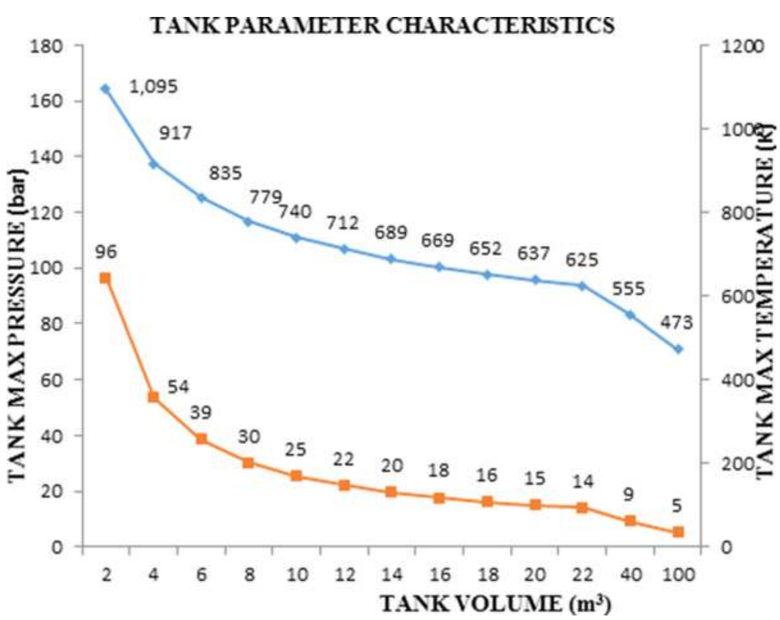

FIG. 7. Tank parametric variations for different ranges of tank volume.

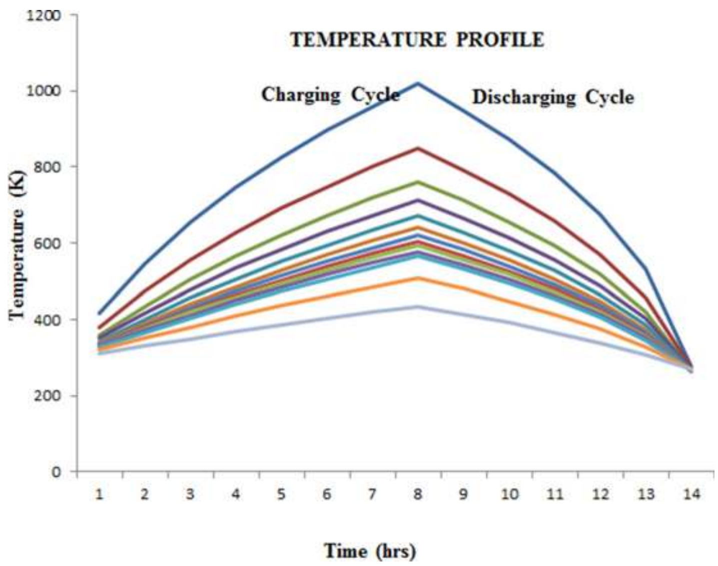

FIG. 8. Temperature profile for different tank volumes.

Figure 8 illustrates the temperature profile of the storage tank in charging and discharging cycles on an hourly basis, where the peak temperature is attained at the end of each charging cycle and then starts decreasing during the discharging cycle due to a reduction in the pressure inside the tank.

B. Performance analysis on adiabatic compression

The adiabatic analysis of the system is performed to obtain the guidelines for the selection of an appropriate CAES specification for the required application. The turnaround efficiency which is the ratio of total energy output to the total energy input is the indicator for the performance of the CAES system. The peak pressure, power output, power input, and turnaround efficiency for the variations in the tank volume are calculated. It is understood from the analysis that there is a variation in the efficiency from 50.6% to 43.8% for a given input with respect to the variation in storage volume. Another major factor to be considered while designing the system is based on the economic and operational safety of the CAES system.

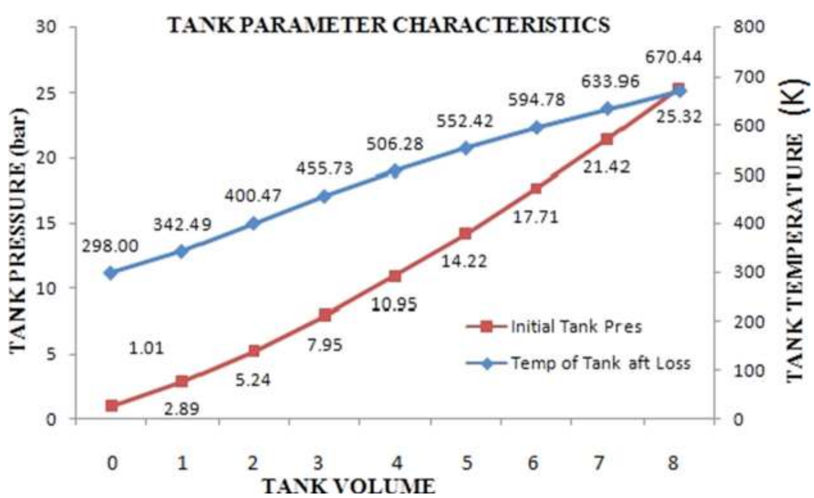

FIG. 9. Hourly parametric characteristics for the charging cycle.

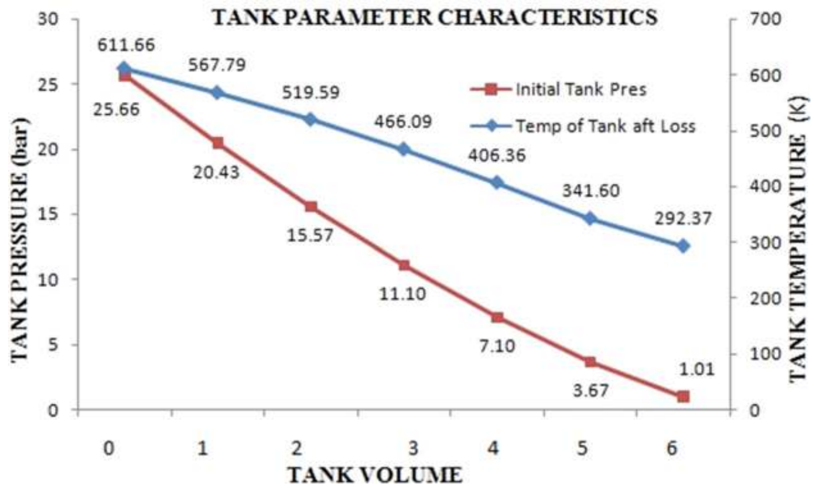

FIG. 10. Hourly parametric characteristics of the discharging cycle.

1. Effect of accumulation of free air on the storage tank

From the guidelines for selecting the tank volume, a tank size of 10 m^3 and 25 bars is taken for analysis in domestic operation. Figures 9 and 10 show the hourly based pressure and temperatures of the storage tank in adiabatic compression towards the accumulation of free air in every time step.

The above graph shows the transient simulation of the CAES system in which the peak temperature of 670 K is reached at 25 bars pressure. Such a high temperature contributes to the heat loss through the tank surface which sets a major challenge in the design and operation of the storage tank. To avoid this loss, the possible ways are isothermal compression or reducing the temperature of outlet air using a waste heat recovery device.

C. Performance analysis of isothermal compression

Isothermal analysis is carried out under the same boundary conditions as considered in the adiabatic analysis of the CAES system whereas the work input is calculated from the isothermal work done in principle and the temperature input to the tank is constant for the complete

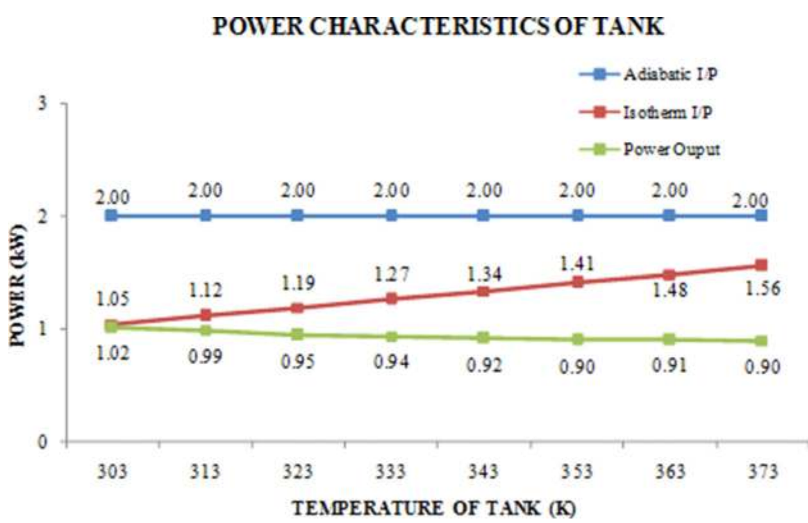

FIG. 11. Power characteristics of the CAES tank in an isothermal condition.

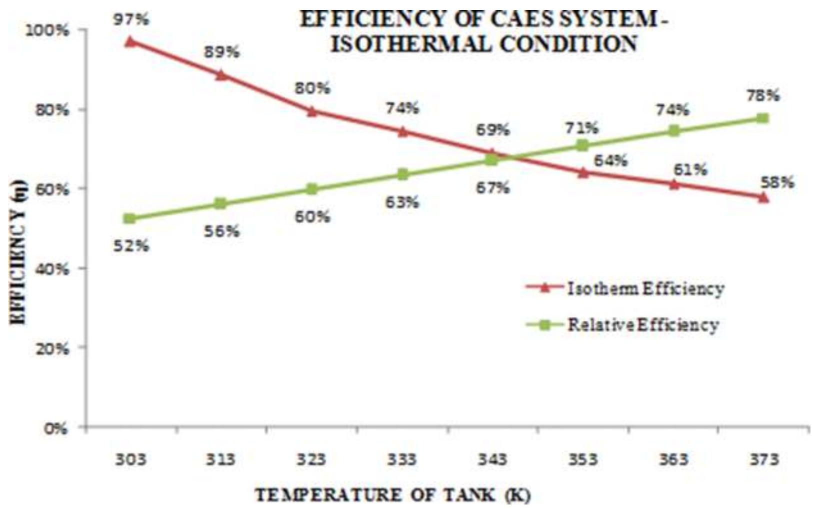

FIG. 12. Efficiency of the CAES system—isothermal condition.

charging and discharging cycles. Isothermal compression of air leads to the reduction in both storage tank volume and power input which indirectly reduces the capital cost and improves the overall performance of the system.

Performance analysis is studied transiently in the TRNSYS V17 platform for a tank size of 10 m^3 and 25 bars on an hourly basis. Figure 11 shows the isothermal, adiabatic work input and Fig. 12 shows their respective efficiencies for various isothermal temperatures from atmospheric until 100 °C as recommended by the tank design.

D. Poly-generation in the CAES system

In a conventional poly-generation concept the terminology was termed as co-generation. However, in the present system the heat of compression is used for a space heating application and similarly the cool energy generated out of the air motor/expander expansion is used for space cooling and power generated from an alternator/generator used for lighting load applications called CCHP (Combined Cooling, Heating and Power which is known as poly-generation). In addition to the power generated from the CAES system, other sources of energy that can be recovered from the system are heating and cooling loads. A proper device, such as a waste heat recovery device, is used to recover the heat of compression from the compressor.

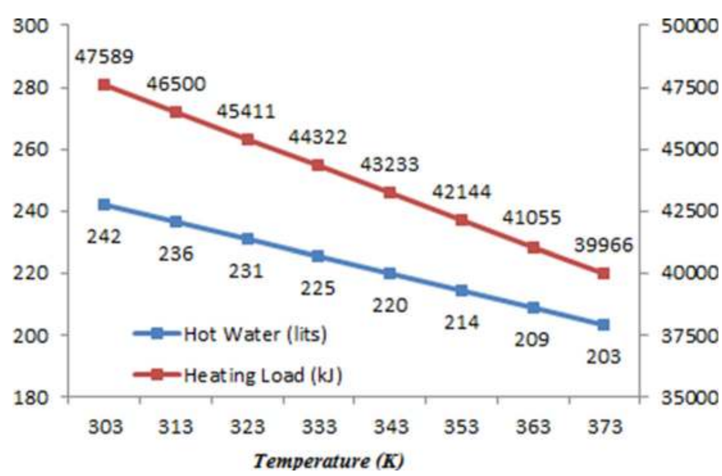

FIG. 13. Heating load calculation and hot water production from the CAES system.

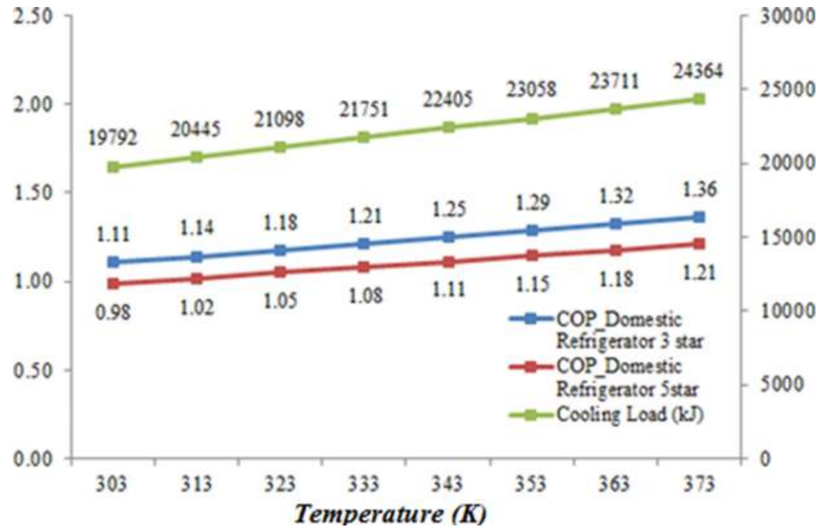

FIG. 14. Cooling load calculation and comparative electric load for a refrigerator.

Figure 13 shows the amount of heat load obtained for each isothermal temperature and if this heat is utilized for a hot water system with a heat exchange effectiveness of 0.8, the quantity of hot water at 70 °C produced from the system.

Similarly the cooling load produced during the expansion of air from the high pressure of 10 bars at atmospheric temperature to the atmospheric pressure is calculated. Figure 14 shows the conversion of the cooling load produced from CAES to the electric load by the same with the cooling load produced by a domestic refrigerator with 5 star and 3 star rating from their co-efficient of performance (COP's) recommended by Bureau of energy efficiency (BEE).

1. Coefficient of performance of the CAES system

The performance is measured in terms of the turnaround efficiency in a conventional CAES system whereas when we extract some other forms of energy in addition to the power generation in our proposed system, the system resembles and performs like a modified Bell-Coleman cycle and hence the performance could be indicated as COP. Figure 15 illustrates the COP of the CAES system for various isothermal temperatures maintained at the storage tank.

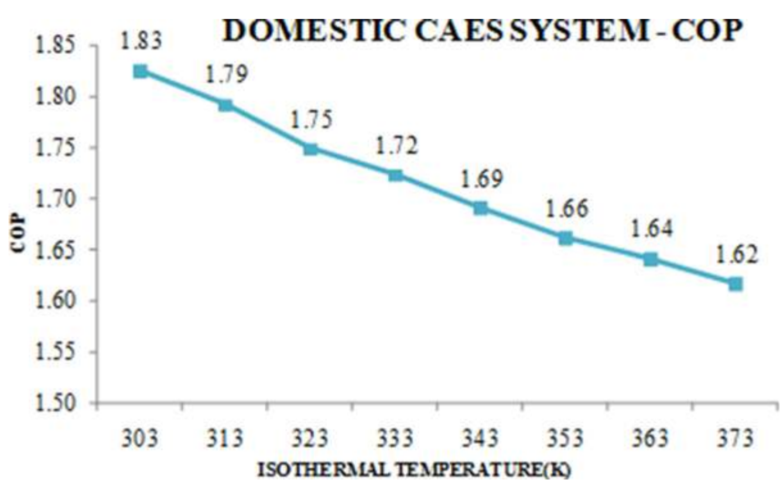

FIG. 15. Coefficient of performance for small scale CAES.

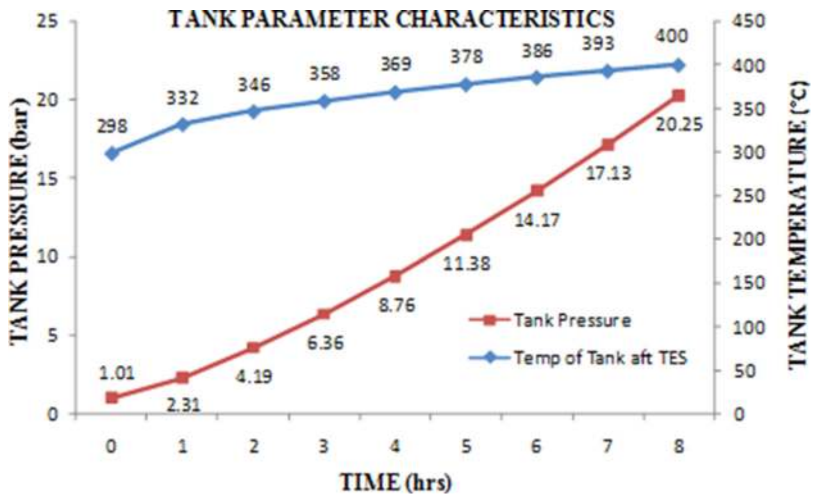

FIG. 16. Tank parameter for CAES-AA on an hourly based simulation during charging.

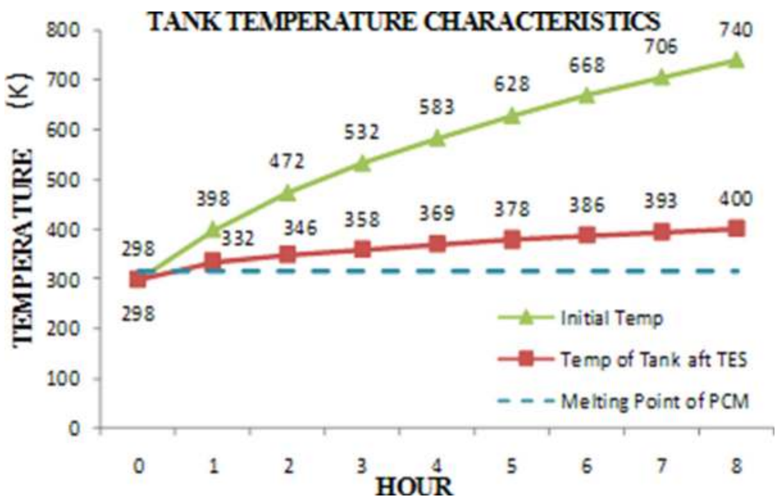

FIG. 17. Tank temperature for CAES-AA on an hourly based simulation during charging.

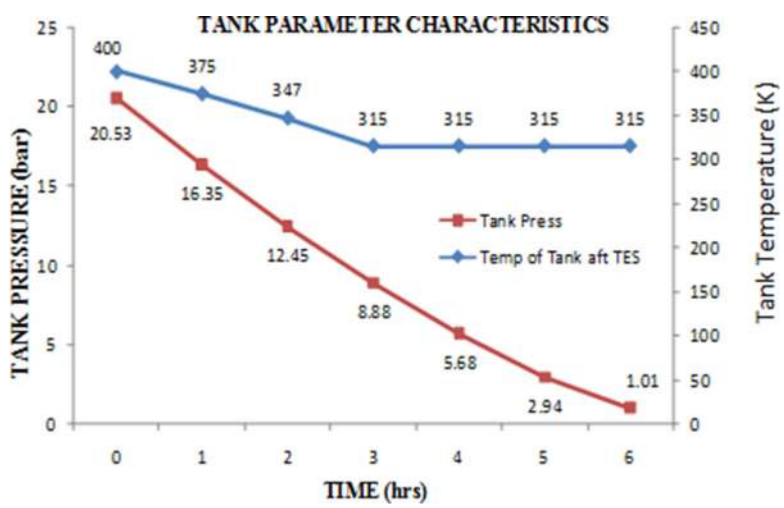

FIG. 18. Tank parameter for CAES-AA on an hourly based simulation during discharging.

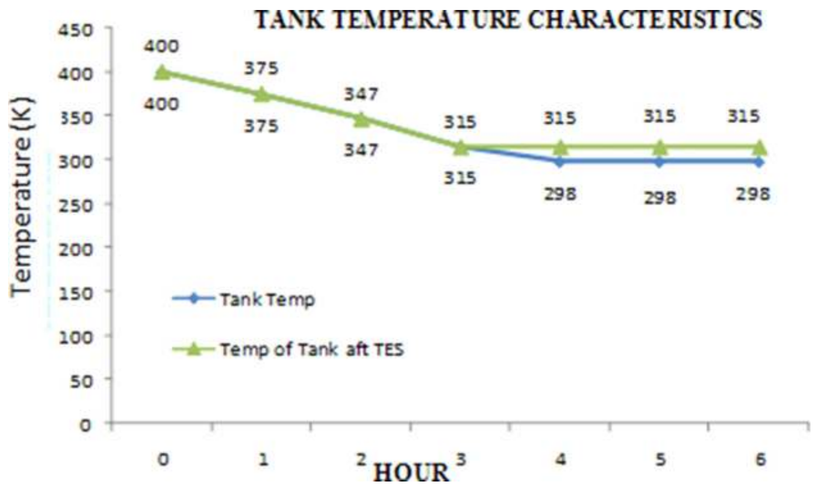

FIG. 19. Tank temperature for CAES-AA on an hourly based simulation during discharging.

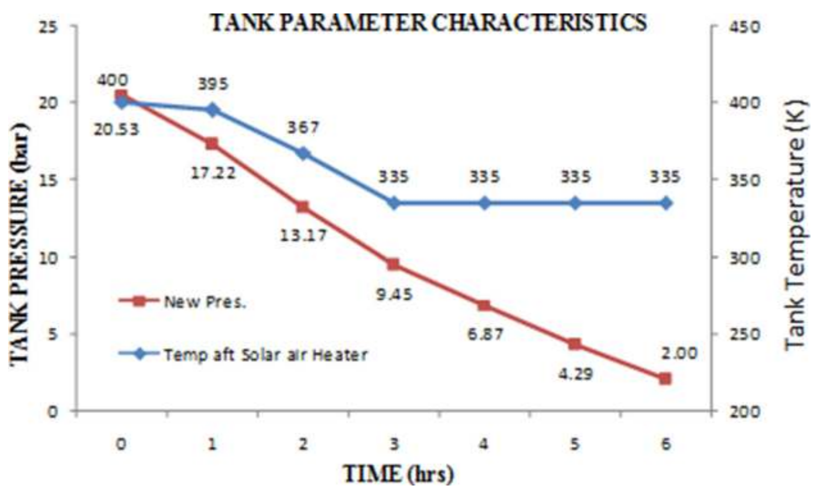

FIG. 20. Tank parameter for CAES-AA-solar on an hourly based simulation during the discharging cycle.

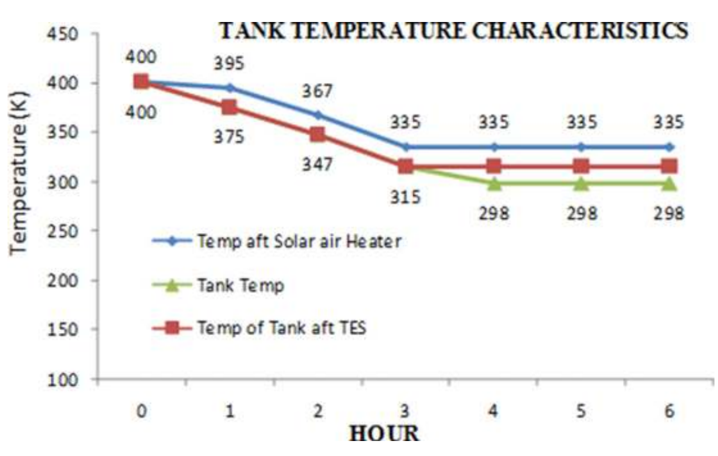

FIG. 21. Tank temperature for CAES-AA-solar on an hourly based simulation during the discharging cycle.

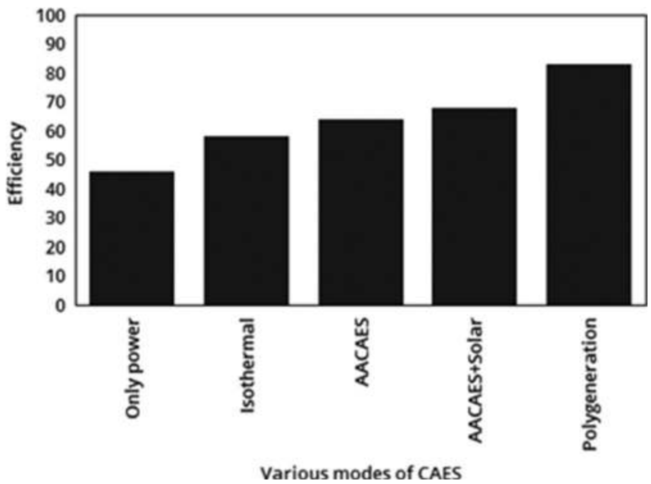

FIG. 22. Performance comparison of various CAES systems.

E. CAES-AA and CAES-AA-solar

Simulations of the CAES-AA and CAES-AA-Solar systems are performed using the TRNSYS software for a tank volume of 10 m^3 for a power input of 2 kW to the motor operating the scroll compressor. Figures 16–21 show the pressure and temperature of the system for the charging and discharging cycles on an hourly basis. This study is made to identify an optimum system with improved efficiency under various conditions.

It is understood from Fig. 17 that the maximum adiabatic temperature attained during the process is 700 K but the hot air coming out of the compressor is sent through a thermal energy storage where the heat of compression is recovered thereby reducing the temperature to 400 K.

As shown in Fig. 18 during the discharging cycle some amount of heat is recovered from TES which maintains the system above 315 K. This system helps to improve the energy recovery where there is no need for cooling load.

Figure 19 clearly narrates the difference in temperature of air in the tank and temperature after thermal energy storage during discharging cycle. The melting point of the PCM used is 42 °C.

The losses incurred during the charging and discharging of heat energy in the TES is not considered during the simulation of CAES-AA and CAES-AA-Solar.

There is no difference in the construction of CAES-AA and CAES-AA-Solar in the charging part whereas in the discharging part the 1 kW solar air heater is incorporated to improve the efficiency and net output of the system.

Figure 22 illustrates the performance comparison between various CAES systems which shows that the simple conventional CAES system reproduces 46% of input energy whereas when it is used for poly-generation is reproduces 83% of input energy.

CAES with isothermal work done on input is a theoretical or ideal cycle so practical systems such as CAES-AA and CAE-AA-Solar systems are analyzed to match the performance of it and found that the solar integrated CAES-AA system almost exhibits an equal performance.

V. CONCLUSION

The simulations are conducted to determine the performance of the CAES direct usage (poly-generation) system, CAES-TES, and CAES-AA-Solar under various parametric conditions using TRNSYS V17 software for both adiabatic and isothermal compression. The simulation study declares the possibility of implementation is more reliable and performance of the system is efficient. Some of the factors that we understand from this study are listed below.

- Very high pressure circuit and economic viability do not favor the usage in a domestic household purpose.
- High volume demands for more space and, in that case, transient heat loss from the tank surface reduces the efficiency appreciably.
- When the cooling load is also accounted to show the combined efficiency of the system then the performance should be in terms of COP instead of turnaround efficiency.
- Maximum energy recovery is obtained when the air is compressed isothermally at atmospheric condition.
- The advanced adiabatic system was less efficient compared to poly-generation of energy recovered because of loss due to conversion.
- Since isothermal work done at the input is an ideal case, CAES-AA-solar will be a best option for this.
- Heating, cooling, and power output applications from the system can be implemented in "NET ZERO ENERGY BUILDINGS" concepts.

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NOMENCLATURE

AACAES	Advanced adiabatic compressed air energy storage
BEE	Bureau of energy efficiency
CAES	Compressed air energy storage
COP	Co-efficient of performance
DCAES	Diabatic compressed air energy storage
PCM	Phase change material
RES	Renewable energy sources
TES	Thermal energy storage
TRNSYS	Transient system simulation

SYMBOLS

C_p	Heat capacity in kJ/kg K
dW_{isen}	Isentropic work done in kJ
m	Mass in kg
M	Torque in Nm
n	Speed in RPM
P_1	Initial pressure in bar
P_2	Final pressure in bar
Q_{loss}	Heat loss in kJ
T_1	Initial temperature in K
T_2	Initial temperature in K
ΔT	Change in temperature in K
η_{comp}	Compressor efficiency in %

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