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# A review on compressed air energy storage – A pathway for smart grid and polygeneration

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ABSTRACT

The increase in energy demand and reduction in resources for conventional energy production along with various environmental impacts, promote the use of renewable energy for electricity generation and other energy-need applications around the world. Wind power has emerged as the biggest renewable energy source in the world, whose potential, when employed properly, serves to provide the best power output. In order to achieve self-sustenance in energy supply and to match the critical needs of impoverished and developing regions, wind power has proven to be the best solution. However, wind power is intermittent and unstable in nature and hence creates lot of grid integration and power fluctuation issues, which ultimately disturb the stability of the grid. In such cases, energy storage technologies are highly essential and researchers turned their attention to find efficient ways of storing energy to achieve maximum utilization. The use of batteries to store wind energy is very expensive and not practical for wind applications. Compressed Air Energy Storage (CAES) is found to be a viable solution to store energy generated from wind and other renewable energy systems. A detailed review on various aspects of a CAES system has been made and presented in this paper which includes the thermodynamic analysis, modeling and simulation analysis, experimental investigation, various control strategies, some case studies and economic evaluation with the role of energy storage towards smart grid and poly-generation.
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**Contents**



## 1. Introduction

The rapid increase of the demand to electrical energy in recent years along with the impact on the environmental deterioration has led to speed up the development of renewable power

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**Nomenclature**

| | |
|---|---|
| AA-CAES | Advanced Adiabatic Compressed Air Energy Storage |
| A-CAES | Adiabatic Compressed Air Energy Storage |
| CAB | Compressed Air Batteries |
| CAES | Compressed Air Energy Storage |
| CASH | Compressed Air Storage with Humidification |
| CCHP | Combined Cooling Heating Power |
| DCAES | Diabatic Compressed Air Energy Storage |
| DCS | Distributed Control System |
| FES | Flywheel Energy Storage |
| HEI | Harvest Energy Index |
| HTCAES | Hybrid Thermal Compressed Air Energy Storage |
| ICAES | Integrated Compressed Air Energy Storage |
| IESA | Indian Energy Storage Alliance |
| NETL | National Energy Technology Laboratory |
| PI | Proportional Integral |
| RES | Renewable Energy Source |
| SMES | Superconducting Magnetic Energy Storage |
| SOFC | Solid Oxide Fuel Cell |
| SS-CAES | Small Scale Compressed Air Energy Storage |
| TES | Thermal Energy Storage |
| TRNSYS | Transient System Simulation |
| VAWT | Vertical Axis Wind Turbine |

*Symbols*

| | |
|---|---|
| *Eturb* | energy generated from turbine in kJ |
| *Eq* | heat Energy in kJ |
| $m_c$ | air mass flow rate through the compressor (kg/s) |
| $n$ | polytrophic exponent |
| *Pin* | maximum operational internal pressure |
| *Ps* max | maximum pressure in the storage tank in bar |
| *P* | pressure in bar/pa |
| *Pout* | pressure outside the pressure vessel |
| $P_{s\ \mathrm{min}}$ | minimum pressure in the storage tank in bar |
| $PR_c$ | pressure ratio |
| $Q$ | heat, thermal energy (J) |
| $R$ | specific air constant |
| $t_{1p}$ | Process of the Duration time (sec) |
| $V_{adiabatic}$ | volume of tank in adiabatic condition (m$^3$) |
| $V_{isothermal}$ | volume of tank in isothermal condition (m$^3$) |
| *Wc* | work input to compressor |
| W*turb* | work output from turbine |
| wov | total energy density in a gas cycle (kg/m$^3$) |
| $\Upsilon$ | specific heat ratio at initial state |

generation and better value of renewable energy resources in the global scenario. The increase in demand with threatening price for power causes concerns over the security and reliability of power supply. Energy storage technologies are gaining a great deal of attention in addressing the challenging issues because of their potential roles in achieving load leveling, especially for matching intermittent source of renewable energy with customer demand and also to store the excess power during the daily cycle. Energy storage is not a new idea in itself. It has been a fundamental constituent of electricity generation, transmission and distribution systems. The storage ensures a supply of energy to offset the intermittent and thus potentially inadequate nature of the energy available, ensures that energy is available at occasional times of peak demand, and ensures a supply of energy in the event of a failure in the electrical system or poor energy quality in the local grid.

Conventionally, energy storage needs have been met by the physical storage of fuel for fossil-fueled power plants, by keeping some capacity in reserve and through large scale pumped hydro storage plants. Various energy storage technologies are available according to different physical principles, energy range and operation time. Though energy can be stored in different forms, it

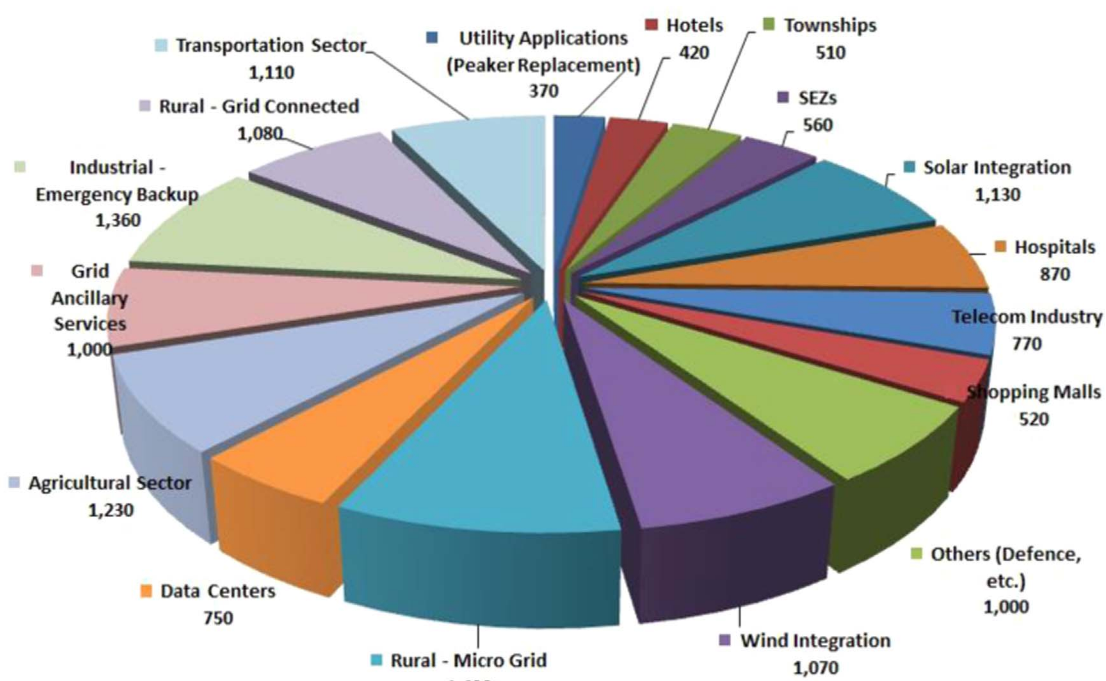


**Fig. 1.** Anticipated market size in MW by 2020 for Energy storage systems in India [IESA report].

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