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Thermal Energy Storage for the Complex Energy Systems

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Abstract: Thermal energy systems (TES) systems contribute to the on-going process leading to greater integration between different energy systems in order to achieve cleaner and more sustainable use of energy resources. This paper reviews the current literature showing the development and deployment of TES-based solutions in power grid-connected systems. These solutions integrate the energy system to gain new potential for energy management, make better use of renewable energy (RES) resources, modernize energy system infrastructure, facilitate network operation practices that include energy conversion and service delivery. The network is cost-effective, facilitating. This paper provides a complementary look at other investigations into energy storage technologies and materials for TES and TES building applications and electrical energy storage aids for network applications. The main aspects discussed are the features, parameters, and models of TES systems, the deployment of TES in variable RES systems, small networks, multi-power networks, and emerging trends for TES applications.

Keywords: Thermal Energy Storage; Energy Storage; Integrated Energy systems; Hybrid Renewables; TES.

1. Introduction

Energy storage is an essential aspect of continuous transfer to more efficient and sustainable energy systems. This depends on the ability to control the transmission or control of all or part of the energy flow to the appropriate storage system and then use the stored energy if needed. Without storage, the traditional view of energy services is one commodity at a time, as production seeks load (also reducing energy losses). Introducing storage at various levels through energy exchange (in the injection mode) in the grid changes the model from a timely commodity to a commodity that is produced in almost real-time in an adjustable state with the consequent load generation (also Given the uncertainty, that should be reduced (fluctuation with reserve). This wide range of applications permits consumers to also participate from domestic energy producers (i.e., consumers) in providing energy services to a variety of energy markets, including new forms of local energy markets and energy communities [2]. That is predicted. Energy storage is also a key component of decarbonization scenarios, such as the elements defined in the European Roadmap to 2050 [3], whose main objectives include high energy, diversification of sources of production, and increasing the percentage of renewable energy sources (RES). Is. On the roadmap, renewables are involved in scenario development, and at least in 2050, they will receive at least 55% of the energy required. Various types of storage (not just energy) are considered, such as pumping water storage, hydrogen storage, recording, and carbon storage.

Healthy development of intelligent infrastructure, including energy storage. The main goal is to increase the availability of different points

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of view of the system, namely energy improvement (as well as multiple energy systems and markets) and energy grid management (dealing with system planning and reinforcement, provisioning, increase sustainability, reduce vulnerability, increase vulnerability, control Frequency, energy efficiency, etc.). Voltage control and network disturbance reduction). Other goals include achieving environmental goals to reduce greenhouse gas emissions and improve air quality as well as social goals, for example, empowering consumers as described in the Clean Energy for All Europeans package [4]. Alternatively, the achievement of the Sustainable Development Goals issued by the United Nations General Assembly. The best combination of technology to power systems needs to be identified to achieve this end. The existence of storage systems increases the demand variability at power grid stations. The pattern of net demand patterns becomes more variable and, in principle, more variable and less predictable. On the supply side, the evolution towards higher renewable energy creates more fluctuations in the outputs of the RES system that require sufficient storage to facilitate these fluctuations, with additional energy storage generated and released upon over-demand to the generation that is now available. Energy storage is useful to reduce peak demand, backup power during power outages, and more efficient networking (with the lowest current in-network branches, thereby reducing network losses).

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2. Materials and Methods

TES is a technology that allows the temporary storage of energy at low or high temperatures by cooling or heating a storage device (in a heat sink/tank) over a given period. The stored energy is used later, for hours, days, or months in heating, cooling, and power generation programs. Storage temperature is maintained at a higher (hotter) or lower (cooler) temperature than the ambient temperature. Benefits of TES are low carbon emissions and energy demand, low cost and maintenance cost of TES system; low pollutant emissions; good performance; superior thermal storage capacity per unit weight, and energy from any heat or electric source if required [21]. Disadvantages of TES, the relatively low efficiency of the TES system and thermal readiness losses (heat losses between storage and environment) [11]. The characteristics of TES systems vary in different forms of storage. As such, the types of services provided are only those that are TES specific. In particular, with respect to electrical energy storage, which can provide relatively fast secondary service, for example, quality improvement, network stability, and standby power in the short term [22,23], the system TES has a slower response. Because of its inherent thermal capability, it can affect thermal transfer [24]. At the same time, heat (or cooling) cannot be stored for a long time due to the heat losses caused by the work of removing storage media. For long-term seasonal storage, TES can be inappropriate or at least a low priority option for surplus energy storage from the electricity grid and a high priority for batteries, pumped water storage (PHS), or compressed air energy storage (CAES), energy. Gas (P2G) or hydrogen, and is used in electric pumps [25]. Natural gas may also be considered for storage that emits carbon dioxide due to the use of natural gas in boilers [26]. TES systems are found to reduce peak energy demand in centralized systems (with CHP, significant district heating and cooling, industrial plants, or RES) or distributed systems (for residential or commercial buildings) [27]. In order to extend the lifetime of TES, control options coordinated with several CHP systems can be adjusted by reducing TES involvement in system performance [28]. Cold-TES is a distributed TES type that uses refrigeration and air conditioning technologies controlled by a virtual station to transport cargo. TES has been significantly managed to convert maximum applications into commercial buildings and cities with semi-arid areas [30].

Three essential parameters are used to illustrate TES technologies:

Energy storage temperature compared to indoor temperature: For this purpose, there are low-temperature TES materials and high-temperature TES materials. Examples include building heating (25–50 ° C), building cooling (0–12 ° C), industrial cooling (less than 18 ° C) and industrial heat storage (over 175 ° C) [31].

TES mode: Distinguishes between reasonable heat storage and latent heat storage. Reasonable temperature is the temperature that determines the temperature change (increase or decrease) in the heat storage of the material without altering its chemical composition or phase. Latent heat is the heat that determines the phase change (transition from solid to liquid or from liquid to vapor) in a heat storage medium without changing the temperature of the storage material (Figure 1). Phase change in heat storage occurs during heat exchange without any difference in the chemical composition of the material. During the phase change, heat can be absorbed (in the melting process) or released (in the freezing process).

Duration of stored thermal energy: The periods are short term (daily heat storage) and medium or long term (seasonal or annual heat storage) [12]. Short-range TES is used to convert maximum energy loads from two hours a day, to reduce system size and to obtain economic benefits from changing energy prices over time or prices. The term TES in the medium to long term refers to seasonal energy storage, as the delay is from a few weeks to a few months [32] (See fig. 1 and 2).

The main performance parameters of the TES system are:

Wattage (W) is the maximum power provided by the vacuum system when discharging. The energy density (W / l) is the ratio between the power capacity and the capacity of the energy storage system.

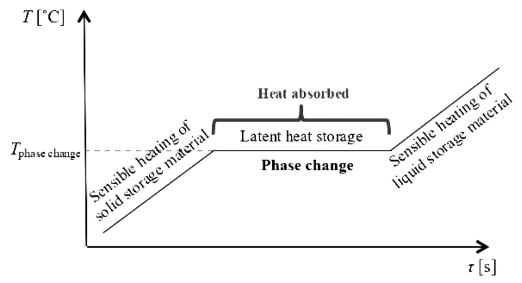

Figure 1. Phase change phenomena of thermal storage material (Melting process)

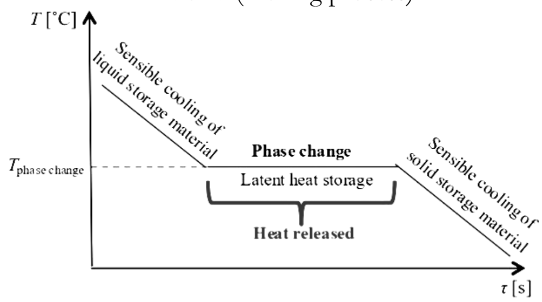

Figure 2. Phase change phenomena of thermal storage material (Freezing process)

Energy capability (Wh), as well as the ability to select energy and energy absorption from the energy absorbed in the storage system when charging under nominal conditions. Energy density or volume heat capacity (Wh / L or Wh / m3) is the ratio between the energy stored and the volume of the energy storage system.

Shelf life (from hours to months) Indicates the shelf life.

Response time (from seconds to minutes) is the speed at which energy is absorbed or stored. Bicycle capacity (number of cycles) is the number of times a storage system releases energy after each charge.

Life Cycle The maximum number of discharge cycles under certain conditions.

Discharge Rate The amount of energy discharge is stored.

The discharge itself is the amount of energy stored at the beginning and after the loss during a particular non-use period.

The travel cycle or electronic cycle is defined as = Eout / Ein, where Ein represents the energy required to charge the system, and Eout is the energy remaining after the loading and unloading cycle. If the storage system is selected in sleep mode, there is no damage during unloading.

Costs are determined by storage capacity (€/kWh) or energy capacity (€/kWh) for the storage system, taking into account capital costs, operating costs, and lifetime storage of storage equipment. Be.

Energy cost is the result of the (utility) energy cost per unit divided by storage efficiency.

Cycle cost is the cost per unit of energy divided by cycle life [12,35].

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Interventional studies involving animals or humans and other studies require ethical approval must list the authority that provided approval and the corresponding ethical approval code.

The main uses of TES are peak conversion, heat transfer, renewable, heat loss, or cold [36]. TES systems are used to store heat lost in the form of thermal energy to supply the energy needed [10]. TES systems are used to correct the difference between thermal energy load and supply and are, therefore, important for RES integration [8]. Also, TES systems are useful for reducing peak demand, carbon dioxide emissions, energy demand, and energy system costs while improving endurance. ATES uses three performance modes: charging, storage (standby), and discharge (Figure 3).

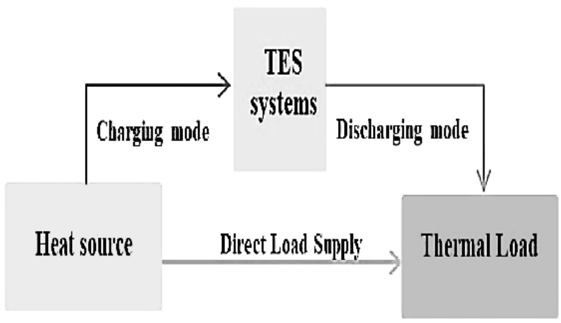

Figure 3. System framework

In charging mode, the power is supplied to the TES system. In storage mode, the energy is stored in the TES system (with associated internal losses), while in the discharge mode, the TES system is released into the heat load for further use. Energy storage must be of sufficient capacity and capacity [12] (Fig. 3). Essential energy services provided by TES technologies include [4]:

Loss of production and demand for heat and cooling due to electricity demand.

Increase energy efficiency in the energy system, for example, by storing heat that otherwise would be destroyed by industrial waste.

The reduction of greenhouse gas emissions in the heating and cooling sector is made possible by the greater use of renewable energy from wind, solar and photovoltaic technologies, biomass, and geothermal technologies.

The increase in flexibility and security of supply, because of the availability of supplying heat and power in the term of high demand and low cost

Increased flexibility and security of supply, due to the availability of heat and power when demand is increasing, at relatively low cost in this segment reflect different modes of operation (charging, discharging and idle).

The general deterministic storage model [37], the TES model is formulated with a sequence of time steps k = 1, ..., K with the regular time steps Dtk, according to the following inputs: Ek energy stored in The time step k is the power of Pch, k which is the storage unit in step k that is charged by the efficiency of ηch, and the power represents the same aspects of modeling.

The energy stored at the successive time step k + 1 in the storage device is then expressed as:

$$E_{k+1} = (1 - u_k \iota_k)E_k + \eta_{ch} P_{ch,k} \Delta t_k - \left(\frac{P_{dch,k}}{\eta_{dch}}\right) \Delta t_k \quad (1)$$

Ek energy also corresponds to the charge state (SoC) of the storage system, which may be expressed by dividing it by the E capacity of the storage system in units (or in percent):

$$SoC_k = \frac{E_k}{E} \quad (2)$$

Introducing the storage capacity P of the storage system, load limitations, and discharge values by:

$$P_{ch,k} \leq u_k P \quad (3)$$

$$P_{dch,k} \leq (1 - u_k) P \quad (4)$$

The impact of the ramping constraint Rk (in per units) on the charge and discharge during the time step Δtk can be expressed in terms of the SoCk as in [39]:

$$-R_k \Delta t_k \leq \mathrm{SoC}_{k+1} - \mathrm{SoC}_k \leq \mathrm{R}_k \Delta \mathrm{t}_k \quad (5)$$

The idle operation of the TES is modeled by assuming uk = 1 and Pch,k = 0 so that the reduction in the energy stored is represented by the effect of the per-unit internal losses `k. Furthermore, the minimum limit EK and the maximum limit ˆ EK are imposed on the final energy stored in the TES at the end of the study period (k = K):

$$-E_k \leq E < E_k \quad (6)$$

The general model (6) is used when the intention is to detect the same energy constraint at the beginning and end of the study period and use outside sources, for example, [40-42]. This extended model is more suitable for use in computational tools that use uncertain or expected values, for example, in a model-based predictive control (MPC) approach. Detailed TES models were formulated to heating transfer constraints in [43,44]. These models can be used to store sensitive heat and latent heat storage (see Section 3.1) with various parameters. The existence of nonlinear heat transfer constraints is solved by repetitive calculations. The results showed that latent heat storage could provide more potential than appropriate heat storage, especially with low initial thermal energy levels. For a TES consisting of a water reservoir, the model shown in [45] is the amount of water in the reservoir as an energy equilibrium variable, assuming that the hot and cold water temperatures are constant during the NaOH phase. Another detailed model of TES consisting of a high-temperature section and a low-temperature section is described in [38].

3. Thermal Energy Storage

3.1. The categorization of the TES Technologies

TES technologies can be partitioned into three categories:

3.1.1. *Sensible heat storage*

In heat-sensitive storage (SHS), thermal storage materials store heat energy at their specified thermal capacity by changing temperature [15]. The storage medium can be liquid (water) or solid (rock, earth). In this case, sensible heat storage materials are heated during heat storage and cooled by heat release [36]. Reasonable temperature changes in storage depending on the temperature change and the specific heat capacity of the storage material. Express a reasonable heat storage amount or heat capacity Q:

$$Q = m.c_p.\Delta T = V.\rho_{energy}.\Delta T \quad (7)$$

3.1.2. *Latent heat storage*

In latent heat storage (LHS), heat storage materials store their latent heat during a phase change from solid to liquid [46, 47]. The latent heat is released by the different phase shift process (from liquid to solid). Latent heat also appears in the phase change from liquid to gas, but this solid phase change is not used to store thermal energy because it requires large volumes or high pressures to store heat in steam or gas [48]. Besides, the latent heat from the solid phase change to the steel is generally low so that thermal energy storage cannot be considered [48]. LHS is a purely physical process and has no chemical reaction when charging or discharging. LHS is suitable for applications where temperature stability must be maintained [36]. Given the specific latent heat L [kJ · kg - 1], the heat energy stored by latent heat is expressed as follows:

$$Q = m.L \quad (8)$$

Phase change materials (PCM) can be used in LHS. PCMs are divided into organic (para, stearic acid), inorganic (moistening salts), and eutectic (a mixture of organic or inorganic PCM) at the required melting temperature of 20 to 100 ° C: • Cooling applications up to 21 ° C. 22-28 ° C for comfort in building applications • 29-60 ° C for hot water applications • High-temperature applications requiring PCM range from 61 to 120 ° C.

3.1.3. *Thermochemical storage*

Thermal Chemical Energy Storage (TCS) or THC requires a reversible chemical reaction [50-52]. THS is divided into three processes: charging, storing, and discharging. In the charging process, heat absorbed from an energy source (e.g., conventional energy sources or RES) separates the thermocouple A in the heat reaction and the heat in the B and C reactors [53]:

$$A + B\ heat + C \quad (9)$$

After this process, the reactants B and C with different properties are stored independently at ambient temperature without loss of heat. Internal losses occur when materials break down [50]. In the vacuum process, stored products B and C are mixed in a heat reaction. In this case, a chemical reactor A is formed, and heat is released for use as an energy source [10]:

$$B + C \rightarrow A + Heat \quad (10)$$

In various references dealing with TES, the broader class of TCS using THS and energy storage absorption has been considered. Adsorption depends on chemical processes and is divided into adsorption and adsorption. Absorption occurs when a substance is divided into a solid or a liquid. Absorption occurs when a substance (liquid or gaseous) accumulates on the surface of the adsorbent (solid or liquid) and forms a molecular or atomic layer [50]. More adsorption energy storage is shown for applications at lower temperatures, such as seasonal energy storage and cooling [55]. THS systems exhibit positive aspects that make them more durable than SHS and LHS, higher density for energy storage (due to higher reaction enthalpy), long-term storage, and long-range transport at ambient temperature [56]. Some barriers to defining THS were identified in [4]. This technology needs to reduce the volume and improve materials. More demonstrations are needed to assess their commercial use. Once the volume of THS "heat batteries" reaches the household level, they can create more barriers to the type of enterprise that creates barriers for consumers who want to become more independent of external energy sources. Today, these barriers are partly due to the drive to create energy communities in which consumers play an active role, as predicted by consumer empowerment already in some global trends (Table 1).

Table 1. Comparison of the three available technologies for TES

	Sensible	Latent	Chemical
Storage medium	Water, gravel, pebble, soil, etc.	Organics, inorganics	Metal chlorides, metal hydrides, etc.
Type	Water, rock, and ground-based system	Active and passive storage	Thermal sorption and chemical reaction
Advantage	Environmentally friendly, cheap material, relatively simple system, easily control, and reliable	Higher energy density Than sensible heat storage, and provide thermal energy at a constant temperature	Highest energy density, compact system, and negligible heat losses
Disadvantage	Low energy density, huge volumes required, self-discharge and heat losses problem, high cost of site construction, and geological requirements	Lack of thermal stability, crystallization corrosion, and high cost of storage material	Inadequate heat and mass transfer property under high-density condition, uncertain cyclability, and high cost of storage material
Present status	Large-scale demonstration projects	Laboratory-scale prototypes	Laboratory-scale prototypes
	Optimization of a control strategy to advance the solar fraction and reduce the power consumption, optimization of storage temperature to reduce heat losses, and simulation of ground-based system with the consideration of affecting factors	Researching for better phase change material materials with higher heat of fusion, an optimal study on store process and concept, and further thermodynamic and kinetic study, noble reaction cycle	Optimization for particle size reaction bed structure to get constant heat output, optimization of temperature level during the charging/discharging process, screening for more suitable and economical materials, and further thermodynamic and kinetic study, noble reaction cycle

3.2. Electric Heat Storage

Electric Heat Storage (ETS) is an electric heating system that uses heat-insulated refractory bricks for later use [58] and is available for residential and commercial applications [59].]. With ETS, heat energy can be converted from electricity and used to meet the heat demand [60]. In the ETS model, which shows the charge energy of P (ETS) il, k and ETS that are sent to electric heating at a time and step k and with η (ETS) and Ets illustrate the efficiency, the corresponding thermal energy of the current P (ETS), k = η (ETS) P (ETS) u, k. Given the rate of discharge of ETS L (ETS) k, and heat demand P (d) seventh, k where ETS serves at time k, the energy stored in k + 1 consecutive time in ETS as [60] It states:

$$E_{k+1}^{ETS} = E_k^{ETS} + \left(P_{th,k}^{ETS} - P_{th,k}^{d}\right)\Delta t_k - L_{th,k}^{ETS} \quad (11)$$

ETS [61] is included in resource optimization with wind and inland water resources, including the

Mart network, to make more use of RES and to limit the limitation of RES generation. ETS modules are an essential asset for end-user applications in cold weather. The heat storage capacity of ETS units is more significant in volume than the temperature-controlled loads (such as water heaters or air conditioners), and ETS units are cheaper than batteries. Direct control of the ETS allows it to be controlled by dynamic charging, given that the thermal time constant is much higher than the electric constants. The advanced energy management developed in [60], using the MPC-based approach, considers the deviation in expected values of renewable energy generation and demand.

3.3. The exploitation of TES with Variable Renewable Energy Sources

Renewable energy (RES) sources such as geothermal, marine, solar, and wind energy are naturally variable and provide clean and sustainable electricity. Due to climate change, the RES process is highly studied with storage. Particular focus is on variable renewable energy sources (VRES). VRES is an irreplaceable RES (that is, it cannot be controlled to track the variable demand for electricity). Due to the variable nature, VRES cannot act as a controlled reference, such as a power plant or biomass, or to some extent as a geothermal energy source. VRES generation systems such as solar energy (photovoltaic solar, solar heating, CSP concentrated solar energy) and wind energy (land and sea) have variable energy due to their alternating nature [12]. The power of this VRES is uncertain and dependent on weather conditions compared to conventional removable power plants whose outputs are concerning market conditions and energy balances. For concentrated PV and solar systems, VRES-based power generation varies depending on the presence of clouds but also on the effect of temporary shading (which should be avoided as far as possible by design). Besides, faulty units may need storage outside the normal operating range to compensate for lost power. Besides, the VRES site depends on the availability of the energy source and generally does not correspond to the location of the loading centers [62]. Besides, VRES requires energy storage to make seasonal and daily changes and ensure continuous performance across systems. VRES is used almost continuously to reduce VRES output fluctuations. TEES, shown in Fig. 3 [63], can be used during peak demand for additional electricity, heat conversion and heat storage for use in a secondary thermodynamic cycle with a steam turbine for an electrical generation used in the grid during peak periods of electric charge (Fig. 4).

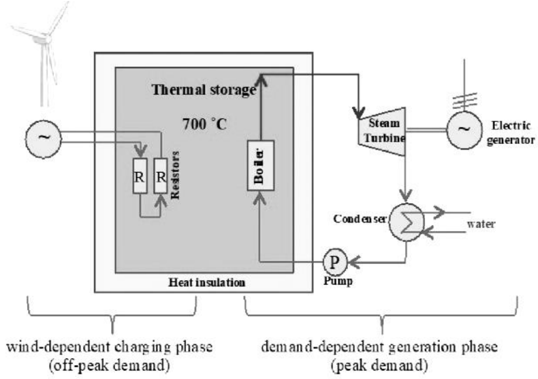

Figure 4. Thermoelectrical energy storage (TEES)

TES, along with VRES can be either Thermal Heat Energy Storage (HTES) or Cold Heat Energy Storage (CTES) [64]. In both cases, when the storage system is combined with a central heating system or a local cooling system, the effect of TES is more excellent.

A centralized solar system uses solar thermal energy for thermal motor power (for example, a steam turbine, Fig. 4 [65]). As such, it is easy to replace CSP with TES, using heat exchangers to transfer heat energy between the heat transfer fluid used in the CSP and the storage system [66].

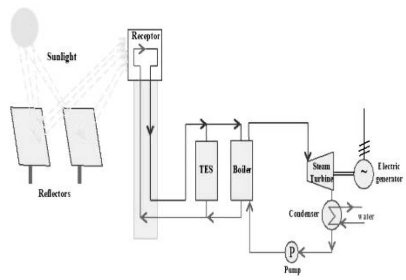

Figure 5. Concentrated power field-TES

Liquids used in storage systems are usually molten salt. CSP heat that is not sent to the heat engine is stored for later use. This fact is crucial for converting benefits by converting energy into grids from periods of low energy prices to periods of higher energy prices. Besides, the presence of TES may be an advantage to increase the size of the CSP system relative to the capacity of the transmission line, whenever the CSP output exceeds the capacity of the line, causing heat storage and heat stored in the thermal engine at a concentrated solar output less than line capacity (Fig. 5).

Various sources indicate that the presence of the TES system increases the value of the CSP system [65]. The program described in [67] refers to the CSP system in addition to the TES in the system connected to the power grid. The existence of a storage system allows to reduce the additional burden on the components and thus reduces the need for further investment. Therefore, the added value provided by TES results in significant cost savings in terms of CSP use alone. The value of TES in optimal conditions for charging and discharging storage is determined by reducing production costs while taking into account requirements for standby, needs balancing, availability, and factory performance. The study in [66] refers to a centralized solar system consisting of parabolic troughs, electric towers, or linear sections. As the size of CES-TES grows, the CSP-TES system becomes more unique in converting power injected into the grid (and selling it on the market) to periods of higher electricity prices. Besides, as TES volume increases, more energy is stored and used, which reduces unused generation. The presented results show that breakeven cost (i.e., the maximum cost of capital that can be provided by expected earnings) for using the CSP-TES system in different locations concerning the energy market, as well as by adding ancillary services market. The trade-off between cost and income of a CSP plant with TES has been examined using scenario-based analysis in [68], looking at the uncertainties of renewable energy production. The CSP-TES solution is coated in [69] by adding an electric heater that converts electricity from other sources (e.g., mains or other outputs of other RES systems) to heat to increase efficiency. The study program includes CSP-TES and the wind energy system and considers the uncertainty of RES in the random unit commitment and the model of industrial transmission with energy and reserves, using scenario analysis.

Wind energy Thermal storage energy systems can be considered as an efficient and useful solution in systems with high wind generation that necessitate wind reduction and occur during warming [70]. In this case, the problem is analyzed in a multipurpose framework, where objective functions are reduced, conventional production fuel costs and wind reduction, and the size of the heat storage system varies. On the other hand, TES can be used to save the extra energy provided by wind systems if proper energy is transmitted. As such, it may be prevented from building a new thermal power plant, as in [71] concerning wind energy and the possibility of storing heat (e.g., for space heating) or cooling energy (through electric coolers). The debate is on. According to the TEES principle, some sources suggest the possibility of generating heat directly above the wind tower, where there is a heat generator. In this structure, there is no electric line inside the wind tower. The heat generated by the heat generator is transmitted to the TES system using the heat transfer fluid (HTF). A secondary circuit containing a steam turbine (connected to a synchronous generator for power generation and connection), a capacitor and a circular pump It is provided by a heat exchanger. In the solution presented in [72] (Fig. 5), called Wind Thermal Energy System (WTES), TES acts as a heat source, and the electricity generated by the synchronous generator depends on demand. This solution is more expensive than using the wind system with battery storage. Another feature is the ability to share some plant parts with CSP-based or biomass-based plants using TES. The same concepts are used in [73] to use WTES by directly converting rotational energy to heat, including on-site electricity stocks and heat generation (Fig. 6).

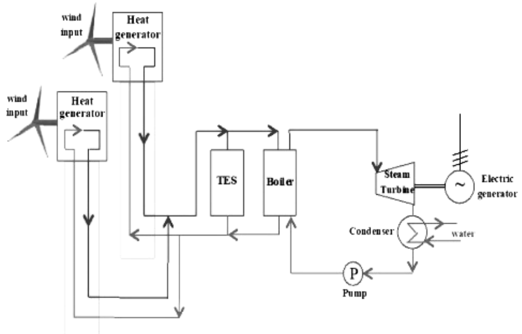

Figure 6. Wind power field-TES

In other words, negative heat storage, which consists of storing heat in a building, is considered when permitting indoor temperature changes. This solution is more suitable than using heat storage tanks to promote better integration of wind energy with the installation of heat pumps [74]. Similarly, heat storage is evaluated by buildings where heat pumps are installed [75] in systems with high wind energy penetration. In the application described in [76], there is a positive aspect of the relationship between wind energy and energy demand for the heating season in seasons. In this case, heat storage from water tanks is sufficient to compensate for the deviation of wind energy concerning space heating needs. The feasibility and efficiency of using thermal storage with electric boilers to reduce wind power at wind penetration levels are reduced following the weaknesses of wind energy investments [77]. If there is a negative correlation between the availability of different VRES systems, the benefits may stem from the frequent misuse of different VRES systems. This can create a range factor (that is, the ratio between average production with maximum output, where maximum output is expressed incapacity, and average power for a specific period) that makes the combined plant more efficient. Adding TES may improve u situation. In the example shown in [78], wind and CSP are in the same location, and the other benefits are the use of low-cost, high-efficiency TES in CSP.

4. Results and Discussion

TES systems for TES systems may be of practical importance for smaller power systems, such as distributed energy source microgrid (DER) programs, as well as in isolated systems. Mathematical models of optimal energy flow and unit commitment have been formulated to describe energy management strategies in the high-impact microgrid. In these embodiments, TES systems are designed in specific ways, taking into account their features and limitations. Operation of a microgrid that features multiple systems with improved electrical and thermal loads, renewable energy generation, cooling stations, combined heat energy and heat storage units, optimized and integrated electricity with the primary grid (including answering services On-demand) also manages [79]. The contribution of ETS systems, including heat dissipation for power management in the microgrid in [60], along with other DER units, is designed with consideration of network constraints and reactive power support control. [80] The thermal ice storage system is used to construct energy models to help control voltage and reduce frequency fluctuations in weak electrical networks.

Multifunctional Networks and Resilient Aspects of Multiple Power Systems (MES) [81], as the evolution of multi-generation distributed systems [82], adds more dimensions and opportunities to energy management in local electricity networks. Also, through the interaction of different energy carriers. In particular, MES has been able to deploy multi-network services [83], in which a combination of RES, CHP, boilers, batteries, and TES offers broad prospects for energy conversion and multi-force induction. [85]. The MES also incorporates the integration of various power grids into power centers, taking into account district heating and cooling (DHC) systems. TES has many advantages over other storage systems when it comes to DHC systems. An in-depth discussion of these potential advantages and disadvantages is provided in [54]. For example, to reduce RES fluctuations, shaving heat or fascia can affect the electrical grid as well as the energy utilization for heat (P2H) solutions where electric boilers are used instead of heat pumps. Energy cost optimization with electricity, heat and gas networks and various types of storage (including slope constraints) is formulated in [39], and additional services are provided by heat pumps alongside TES in the combined RES system. Covered in [87]. At MES, one of the critical aspects of improvement is the ability to improve system performance and opportunities to provide energy services. Many of the applied definitions of electrical systems have referred to the availability of a "generic set of generator sets to respond to variance and uncertainty in net load" or "ability to quickly balance changes in renewable energy generation and expected errors" in the energy system. In this context, the TES system can be integrated either on the women's side or the net load side. A talent that can be provided by residential TES for load transfer, arbitrage electricity, and emergency supplies is discussed in [90]. Multiple energy storage is included among the various accessibility options designed in [83]. Electric boilers and heating cabinets are intended to improve their availability in [40]. Heat storage tanks are effective throughout the energy system to save energy. In [91], TES with housing is used in the optimization process to provide demand response concerning thermal comfort. The possibility of using electricity for heating, called P2H, along with heat storage, has become more interesting [92.93]. Depending on the TES size, the potentials of P2H depending on the size of the TES can be significantly increased, as explained in [94] for central heating applications where electric boilers are used for P2H.

The central aspect focuses on current trends in multi-power system performance. In this context, numerous resources are available to provide demand response capability, which can be reduced or increased from the grid (at the request of a specific program) by considering the switching of power between different power vectors. TES is part of smart heating and cooling strategies that can make short-term availability options available at a relatively low cost [95]. Aspects of demand response have been combined with ETS to provide more shave and enable RES at 61 degrees as a Smart Electric Heat Storage (SETS). This study was conducted theoretically and experimentally in 1996 with a detailed analysis of the aspects of heat transfer. TES Residential is an example of demand-side resources that can be used for energy judgment, reducing net load instability, and securing reserves. In the United States, the Advanced Energy Research Projects Agency (ARPA-E) is implementing a program called "Adding Time to Power Storage (DAYS)" to develop storage systems with a 10 to 100-hour timeframe [97]. About half of the projects funded use some kind of TES. Besides, ARPA-E runs an Advanced High Energy Thermal Storage Program (HEATS), to create a revolutionary, cost-effective TES in three specific regions of a high-temperature solar TES, and sunlight Convert heat to synthetic fuel production and use TES to enable thermal management of internal combustion engine vehicles and to increase the range of driving of electric vehicles. The potential of adopting TES solutions is also changing from developing materials to advanced properties, including some of the solutions investigated include nanostructured heat storage materials, mineral hydride storage, supercritical thermal energy storage systems, batteries Thermal, and new thermoelectric materials by increasing the direct conversion efficiency for heat to electricity. A detailed evaluation of the critical aspects of obtaining highly efficient TES is presented in [48]. These aspects include high energy density of storage materials, low internal waste and possibly high-temperature operation; high heat transfer between HTF and storage materials, also due to heat exchanger performance; load-cycle reflection and discharge, mechanical and chemical stability of materials Rotary storage, and a TES fusion device and control over the entire power system.

One of the critical drivers of future developments in feasibility assessment is the potential for TES integration into different energy systems targeting smart cities and energy communities [39]. Attention has been limited to the implementation of TES in communities [2,38] but is now increasing [83]. It has been mentioned in community energy storage [98] that only conventional heat storage with water tanks is generally economically viable. In the future, more integration is expected between different carriers. The added power of the multipurpose system may be to integrate TES with P2G and battery storage, to increase storage capacity for electricity and heat and to provide better network services. In this regard, P2G can be suitable for relatively long-term storage, while battery storage can cover short-term performance, and TES can be a complementary option to enhance the effectiveness of mid-range operating strategies. Be it. Besides, TES mobile systems have been studied and tested. The system is portable using trucks to make the heat source accessible to remote areas of the thermal power grid. In particular, latent heat or chemical TES is portable due to its relatively small size relative to the appropriate TES temperature [54]. More broadly, TES is attractive for improving the efficiency of CAES technology and leads to the development of advanced CAI Adiabatic Solutions (AACAES) [8]. These systems use TES to store heat from the compression process. The stored heat is then used to warm the air during the expansion phase. Beyond increased productivity, AACAES technology is promising and operational on-site due to its minimal environmental impact and relatively low costs. Experimental experiments were performed with combined physical temperature/potential, and their results provide a promising prospect for further analysis [101]. Including great solutions for TES, compressed heat energy storage, or compressed thermal energy storage [102] is another attractive solution because it only applies to geographical constraints (as is the case for PHS or CAES) or It is not limited to a short life span.

5. Conclusions

The use of TES technologies may increase in future grid applications. These technologies contribute to reducing the peak demand for electricity, alleviating the fluctuations caused by the uncertain generation of renewable energy sources, and increasing the efficiency of energy systems, providing additional network services for distribution networks, micro-networks, or multi-energy systems. These aspects are also aimed at achieving the primary goals of strategic plans to promote "clean energy" projects, by reducing greenhouse gas emissions and empowering consumers in a way that raises awareness of local consumer groups-creating local energy communities and markets. By using TES, the energy transfer between multiple energy carriers can increase the ability to use integrated energy systems using integrated energy systems, which reduces the need for heat discharge to the environment. Besides, TES systems require limited maintenance. For these reasons, the adoption of appropriate applications that exploit TES systems is generally high. Today, despite increasing access to tools that are capable of analyzing energy systems such as TES and estimating the potential benefits in recent times, low awareness of technologies and their potential arises. In specific applications (for example, for cooling storage), it may be harmful to use toxic or hazardous liquids, although the replacement of these liquids with "green" options is underway. Besides, aspects of thermal capacity limit the significant availability of TES systems and their direct involvement in providing fast network services. At the same time, heat capacity can create some degree of "thermal defect" that can be beneficial because of rapid temperature changes in energy processes. Other aspects related to the use of electrical energy storage and the combination of TES in heat energy applications have been explored to show their features that may lead to new opportunities for grid applications. Many positive trends for TES deployment are emerging in current and future energy systems. TES continues to play a unique role in cross-cutting frameworks, including principles of clean and clean energy, resource sustainability, and consumer awareness, and can be more critical in terms of improving material efficiency and identifying new forms of energy integration.

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Conflicts of Interest

The authors declare no conflict of interest.

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