Simulation depleted natural gas reservoirs for compressed air storage

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Abstract - One of the highly considered issues considered by engineers and designers in power networks is a lot of changes in the load chart during the day. Due to different cost of producing and selling electricity during different hours of the day, the idea of the storage of electrical energy in non-peak hours was introduced. There are many different ways in which electrical energy storage has a special importance in using the compressed air system. First, we study power generation way with compressed air energy, the background, methodology, framework, advantages and disadvantages. In addition, the main objective of this paper is to study and simulate the storage of compressed air in natural gas drainage wells. We have proposed suitable places for constructing compressed air energy storage power plants.

Keywords: Underground storage, EES, CAES, Natural gas reservoirs, Simulation

1. Introduction

In recent years, the lack of energy and air pollution from the use of fossil fuels has been raised as the world's biggest problem. To overcome these two major problems, the activities and budgets of governments and organizations are increased to conduct more studies, the development and delivery of renewable energy systems. Energy production systems have many limitations and high initial costs. It is vital to invent more efficient systems for the production, storage and recycling of energy. Electrical energy storage methods have been introduced as active, environmentally-safe and secure systems for energy storage and recycling.

According to the definition of electric power storage: "A physical system with energy capability for dispatcher and replacement of electricity at a later time". [1]

Such a process allows for the storage of electricity at low demand time, which produces low costs, and provides this energy at high demand at high production costs or when no other energy is available.

Advantages of Energy storage systems (EES) include reduced demand at peak times, deferred investment in the network and the development of transmission lines, frequency regulation, separation of production times from consumption times, optimal use of fossil fuel power plants and increasing their efficiency, and integrating renewable energy sources and helping to increase the output of distributed products. [2]

Energy storage can provide the flexibility needed to maintain a robust and stable electrical system. Various types of energy storage technology can be classified depending on their properties, applications or function. The most common way to classify energy storage depends on how energy is stored. It uses four methods of mechanical, electrical, thermal and chemical energy storage technology. Table 1 shows the classification of different methods of storing electrical energy.

However, only two types of EES technologies are valid for large-scale energy storage (over 100 megawatts), including PHS and CAES. Hydraulic Pump Storage (PHS) is widely used on a large scale for EES. PHS is a mature technology with a large volume, high storage time and high efficiency.

However, the shortage of sites available for two large reservoirs and one or two dams, a long time (typically ~ 10 years) and a high cost of construction (usually hundreds to thousands of dollars) and the environment (for example, removing trees and vegetation) are three other major barriers to the establishment of PHS. [3] and [4] These problems and limitations of PHS make CAES a good and attractive alternative case to large-scale energy storage. CAES is the only technology available on the market (in addition to PHS) that can transfer power storage (more than 100 MW) for large-scale storage. [5] and [6]

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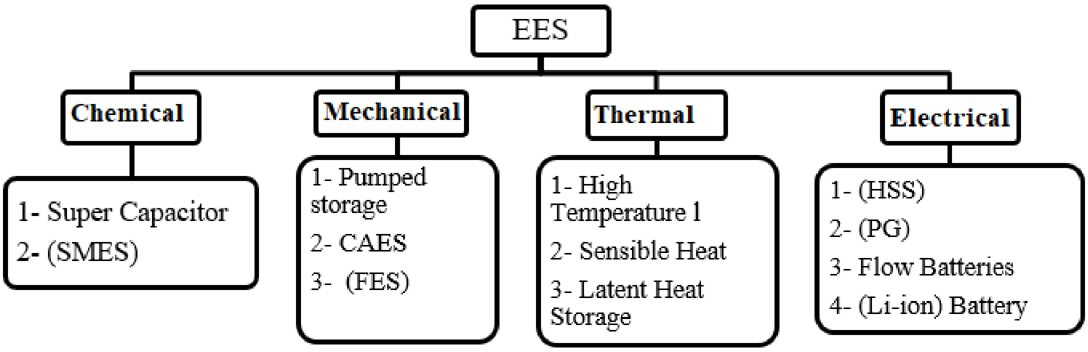
Table 1 Classification of electrical energy storage systems



Currently, at least 140 gigawatts of energy storage are installed on a large scale in electricity networks around the world. The vast majority (99%) of this capacity includes PSH technologies, which includes a combination of battery technology, CAES, flywheels and hydrogen storage. Figure 1 shows the worldwide storage capacity of electrical energy. [7]

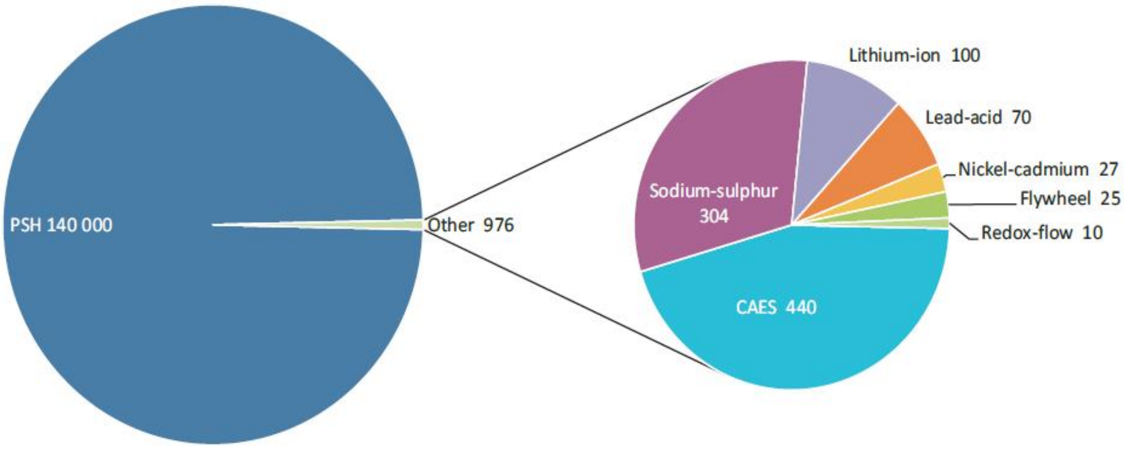


Figure 1 EES capacity installed in the world

The criteria for energy storage technologies are huge. But an appropriate system generally has the following features:

- High power capacity, both in terms of volume and mass;
- The ability to integrate and develop with renewable energy resources and current energy networks;
- Operational safety and high conversion efficiency;
- The ability to save energy in a high volume of power;
- Low installation cost and proper return after investment;
- Increase the power quality by reducing voltage waves, voltage drop and short-term power outages,
- Technical maturity
- Density of energy and strength
- Rapid response time
- The time of proper charging and discharging
- Has a high life cycle

Key applications for storage can be categorized as follows.

Seasonal storage - The ability to save energy for a day, week, month to compensate for the shortage of long-term power supply.

Arbitrage energy - Save electricity at low demand (non-peak time) and then sold at high demand (peak time);

Frequency Adjustment - Continuous balancing of supply and demand movement

Delaying investment in infrastructure

Time displacement - In order to integrate demand and supply of electrical energy, the demand time can be shifted;

Integrating system resources - Using EES to optimize system output;

In general, the advantages ofuse of EES systems is divided into three broad categories:

- power quality
- Improved reliability
- Application in the field of energy management [8]

1. Energy storage devices in the interval of one second or less, in order to correct the voltage. (Applications of this spectrum include capacitors, fluids, superconductors, which perform a charge and discharge operation in seconds).

2. In energy storage in a range of minute (includes storage applications for power grid stability).

3. Energy storage devices a range ursof ho(including energy management applications such as load curve leveling, and arbitrage).

In ,2figure the chart shows the electrical energy storage systems in terms of amount of power and storage (in MW) and the discharge time of each system (in terms of hours). [9]

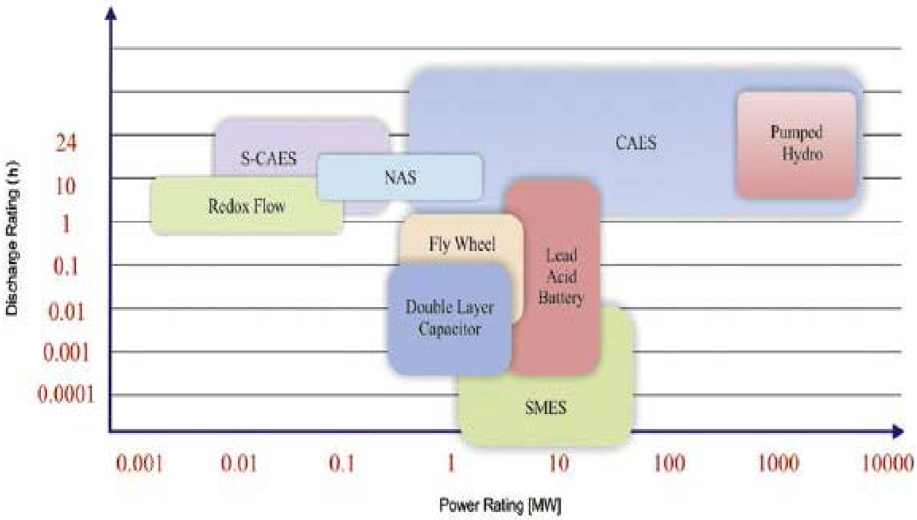


Figure 2 Comparison of different EESs in terms of storage time and storage capability

Based on the diagram shown in Figure 2, CAES system is in the highest power generation range and has the highest response time among different energy storage methods (EES).

The second part of this article reviews the compressed air storage system. In Section 3 and Section 4, which is the purpose of this study, we study the spatial and geomorphic features of CAES and simulate the location of CAES in natural gas drainage reservoirs. And in the last part, the summary of the research is presented.

2. Electrical energy storage with compressed air

2.1 Performance

A compressed air energy storage plant similarly operates with conventional gas turbine technology (GT) with compression and expansion stages that occur independently or simultaneously depending on the type of power plant. The CAES process can be divided into three main steps: compression, storage and expansion. Depending on the point of view and configuration of the system, thermal storage can also be considered as one step in the process, but note that it is not important for the process, but rather a factor for improving overall performance. At compression stage, an extra power or low-cost electricity is used to operate a chain of compressors that injects air into the tank. In the development phase, when the electricity is required, the air is released from the reservoir and is used to turn a gas turbine that generates electrical energy. Figure 3 shows the block diagram of a CAES. [10, 11]

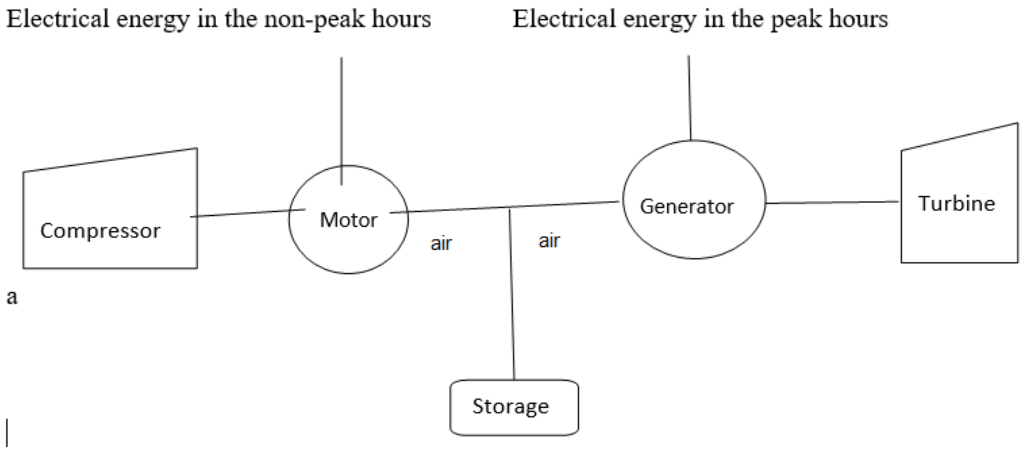


Figure 3 A simple plan of the CAES system

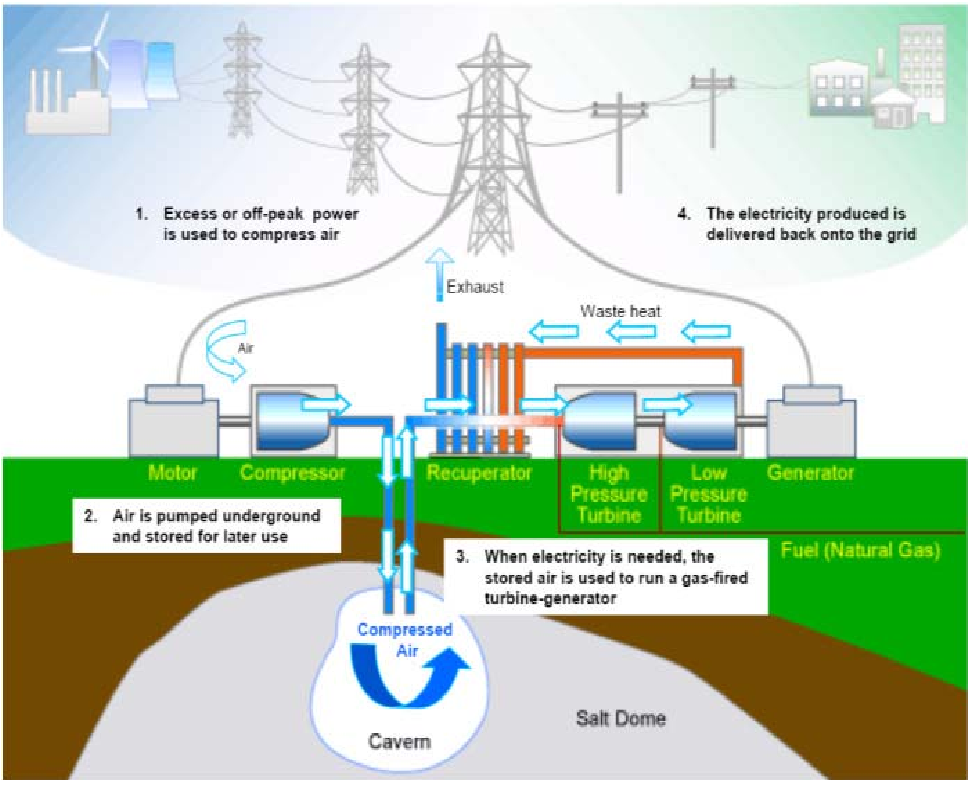


Figure 4 A simple schema of the CAES system

The compressed air energy supply is a relatively simple technology, which includes an air compressor, a high pressure turbine, an appropriate generator and reservoir or underground geological structure, as shown in Fig. 4 of these components. [12]

Compressors are driven by combustion engines with fossil fuels or by electric motors, whose primary purpose is to compress the air into the air cavity. Tanks are used to supply and store air, and due to its large size, it can cool the air better and remove some moisture from the air.

Filters prepare compressed air withabsorbing moisture, oil and dust for the operation of pneumatic tools and devices that require clean air without moisture. The pipes carry compressed air to the consumer equipment. Choosing, designing, repairing, optimizing each of these elements has an enormous impact on energy consumption. Energy management opportunities are linked to reducing the amount of work of compressing, thermal recovery, and reducing the potential energy loss of stored air. So, evaluation of the system and checking the status of system and comparing it to optimal situations is one of the tools rfo energy management.

2.2 advantages

Compressed air power plants have been considered increasingly among energy storage technologies due to low cost of capital and its scalability. This reliability and consistent effectiveness show up to 80%. Compressed air is used for its high security, flexibility and eco-friendliness in a variety of ways. CAES systems offer high scalability with low maintenance and low operating costs. As a result, CAES has the following benefits:

• Compressed air power plants have the ability to connect to various sources of renewable energy, especially wind power, which increases capacity.

• The standby power of CAES can be replaced with the typical battery system as a stand-by power;

• The compressed air system has a high lifecycle and low investment costs;

• Compressed air is a high level of security and security;

• Does not require high maintenance;

• Reduces greenhouse gas emissions in fossil fuels and reduces environmental pollution.

2.3 Disadvantages

Each technology has drawbacks and disadvantages and the CAES system is not an exception. It is necessary to mention some of them. One of the weaknesses is the geographic constraints that are the main obstacle to the implementation of this system. In addition, if CAES is used in its usual format, it needs to be connected to the gas turbine plant and fuel consumption and emissions. Also, when working, a lot of electrical energy is used to compress air and high thermal energy is wasted.

2.4 Establishment

The idea of storage based on new compressed air is not new. The concept of CAES technology is more than 40 years old, and the first research about their feasibility as a means to provide energy during peak demand and the time required for a power plant to reach the point started in 1970s. So far, there are two CAES commercial plants in the world: the world's first power plant, a 290 megawatt power plant owned by EN Kraftwerke, Huntorf, Germany, built in 1978 with a production capacity of 290 megawatts and 50 gigahertz, has a reservoir of two caves under the dome Salt and 600 meters underground with a total volume of 310000 square meters for operation at 48 to 66 barrels. The 110 MW plant from AEC (Alabama Electric Company) in McIntosh, Alabama, USA, which was built in 1991, has 110 MW power output and is powered by a salt dome that is about 450 m under the ground.The volume of 560000 square meters is made with a pressure of 7.5 mega-Pascal. In the United States, research on CAES is active and funds are available for studying technical and economic aspects as well as the so-called "advanced second-generation CAES". In Texas, with regard to increased wind penetration, the need for improved power transmission and the presence of salt domes, plans for the development of several CAES projects, including the 540-megawatt (4x135 megawatt) system in the city of Matjorda, have been announced. EPRI studies show that up to 80% of the United States has a geology that is suitable for a CAES underground reservoir; EPRI also believes that by 2020, 20 to 50 CAES power plants with different utility rates and support the US renewable energy market. In Europe, the idea of developing CAES is increasing due to the increased use of renewable sources of energy, and also in Israel and Russia, power plants have been proposed. [13]

3. Choosing the area for CAES system

3.1 Location

The first thing to do in an industrial project is to find a suitable place to build in that location. The best place to deploy storage technology depends on the capabilities expected of the energy system from supply to consumption. The CAES system, using economically viable natural reservoirs that is practical in comparison to the use of a compressor in a gas plant (more than half of the generation capacity of generators in power plants is used to rotate the compressor), led to the idea of building power plants CAES in areas where using underground reservoirs is available.

Different reservoirs are suitable for CAES applications and are formed by underground reservoirs and underground structures such as salt, hard rock, and porous rocks [3 and 4]. Two operating modes can be selected for tanks: constant volume and constant pressure. The most common condition is to operate the CAES in constant volume conditions that means the volume is constant and the reservoir operates within a specific pressure range. The characteristics of these reservoirs are different, but in general these reservoirs should have suitable conditions for the construction of the power plant.

A. Proximity to transmission lines

Due to the dependence of CAES on the power network, the more power plants are closer to the energy transmission lines, the load centers the closer they will be to.This issue is important for EES systems because there are losses in energy transmission in both storage and energy recovery situations. [3]

B. Access to natural gas

The installation of CAES power plants requires fossil fuels so the construction of the power plant should be selected wherever is close to natural gas sources and gas power plants. [4]

C. Noise

Due to the high noise of compressors and turbines at the CAES facility the construction of projects should be in a place where the sound from turbines and compressors does not adversely affect the equipment and the surrounding environment.

3.2 Types of underground storage tanks

3.2.1 Groundwater aquifers

These types of reservoirs include permeable, porous and underground rocky structures, and their geological characteristics are similar to oil and gas fields, but due to their lack of physical and geological characteristics, the potential and assessment of aquifer stability, high risk of geology, leakage and air storageproblems and also the lack of relevant infrastructurethese type of reservoirs , have higher development costs than gas or oil drainage reservoirs.

3.2.2 Salt caverns

These salt caverns, with tight and impenetrable walls, prevent the exhaust of injected air. The creation of this type of reservoirs is accomplished by the dissolution process, so that fresh water is injected through a well into a salt dome, and brine is discharged from it. One of the important points in creating air storage in salt caverns is access to required water, providing the necessary volume of water for solubilizing the salt and recycling the resulting ,es and alsobrinanother important parameter is the low volume of air storage for the power plant in salt caverns. In contrast, the injection rate and withdrawal rates are much higher than those of aquifers and reservoirs.

3.2. 3 Storage of compressed air in epletedd gas reservoirs

Usually the conversion of a depleted gas reservoir into a compressed air reservoir is simpler and cheaper than the other mentioned methods. The main advantages of these types of reservoirs are the complete recognition of the reservoir in terms of geology and reservoir (according to the data of drilling company), because there is a great certainty about the possibility of air storage in it. Also, near these types of reservoirs there are infrastructures and facilities that are already in the place to reduce the cost of implementing the project. These reservoirs should have the geophysical characteristics including pressure bearing capacity and the permeability of the reservoirs and the type of arch of the reservoirs.

A. No leakage: The reservoir must have the ability to withstand high pressure and no leakage in the reservoirs to store air. With new technologies, it is possible to scan the reservoir before the operation to ensure that there are no gaps and frail structures of reservoir.

B. Pressure bearing capacity: Due to the fact that compressed air storage systems operate to save more air and receive more energy and efficiency up to 80%, at high pressures (40 to 75 times), the drainage reservoirs must be able to bear these high pressures

C. Stone arches: The presence of U-shaped arches in the U-inverted form prevents the air from escaping and leaking from the upper layers. Therefore, before construction, geological conditions and reservoir arches should be examined and simulated.

Two important factors in the selection and advantage of depleted gas reservoirs are:

1 .Geographic proximity to the utilization centers and infrastructure of the transmission network and proximity to the power plants;

2 .Permeability and porosity above the reservoir rock.

Reservoir porosity is one of the factors that determines the volume of stored air in the reservoir. Permeability also determines the air flow velocity inside the reservoir, and ultimately determines the rate of input and output air. In Figure 5, the schematic shows a depleted reservoir , the various sections are numbered and they are:

1 .rock cover;

2. porous storage space;

3 .surface installations;

4. production units;

5, 6, 7. The observation wells are dug in the lower and upper water table. [15]

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The behavior of groundwater aquifers in storage operations depends entirely on the properties of the rocky layers. If the rocky layers are negligible in terms of ,geological permeability they have little effect on reservoir pressure during the injection and production intervals, but if the reservoir has a water table active, , the water level increases during the production and evacuation of the reservoir. [16]

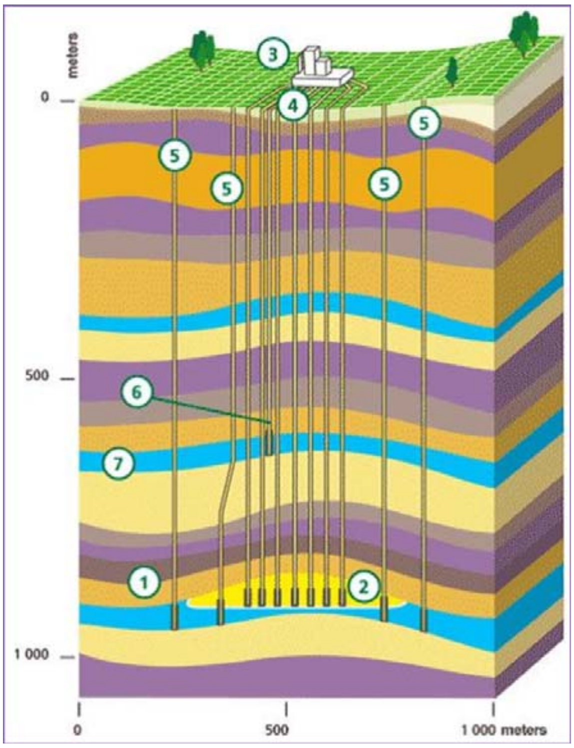

Figure 5 Overview of a underground depleted reservoirs

In the process of injection and production, in reservoirs containing active water aquifers, reservoir pressure is irreversibly increased and the volume of the reservoir decreases for storage of air, whereas the pressure increase in the reservoir without aquifers in the initial cycles was high and gradually decreased. In 6figure , the average pressure of the two reservoirs ,one with a water table and the other without a water table are shown. [17]

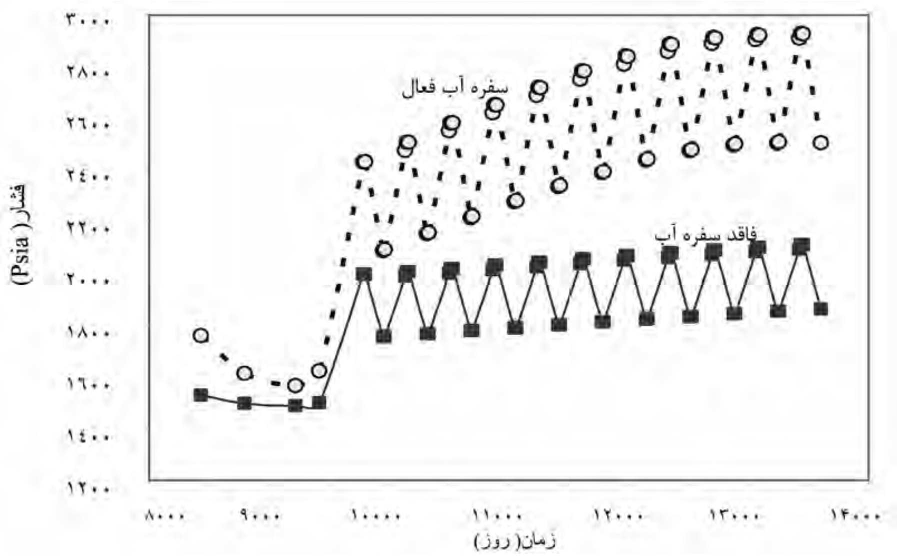

Figure 6 Pressure of the reservoir in the state of without water table and witha water table

4. Simulation of reservoirs

For UAS in depleted gas reservoirs, a proper simulation of the reservoir is needed that tostudy this ,subjectthe existence of a precision static model (geology) and precision dynamic (fluid motion) model are necessary.

A) Static model (geology)

For this kind of model, Petrel software, one of the most widely used software in the oil and gas industry, can be used. [17] The general process of constructing a static model of a reservoir is as follows:

1 .Entering the required software information, including the characteristics of the drainage wells, seismic data, and other information of wells that already exists in the drilling company's data;

2. Determine the scope and boundary of the project;

3. networking of the geology model of the wells;

4. stratigraphy and modeling;

5 .Modeling faults in the geology of the region;

6. modeling of petro-physical variables.

B) Required information

Input data including various maps and experiments at drilling time and new seismic data should be given to simulation software. These data are presented in two ways: 1. Fluid data including volumetric coefficients, fluid viscosity, studies of fluid flow in the reservoir, fluid tested models. 2. The rock data includes: permeability, reservoir thickness (geological maps at drilling time), reservoir height (graphing data and logs recorded at drilling time), capillary pressure, compressibility, measured pressure from the well at the time of drilling. [18 [and [19]

C) Innovations and possible outcomes

With the examination of technical specifications of underground storage ways of compressed air, the deficiencies and storage problems in the depleted gas reservoirs are determined. Technical contexts of storage are mentioned at the following paragraph.

1. compressed air volume
2. possible annual wheels
3. positions in today's trade
4. environmental problems
5. Recovery efficiency
6. Preparation time

With determination of the static and dynamic simulation, the results of underground storage of compressed air in depleted gas reservoirs can be obtained from the simulation model. Some of these results are included:

1 .predicts the future performance of the tank with production in different conditions

2. Determination of the injection site in the reservoir

3. Determination of the maximum storage capacity

4. Compare different strategies and determine the best method and scenario for injection and production

5. Investigating factors that have effects on the injection and production cycle

6 .Having the basic and final specifications and checking the status of the compressed air storage tank

5. Conclusion

Electric energy storage technologies are used to control and manage energy, improve power quality, or as an energy interface. In addition to the benefits that storage systems have from technical aspects, they can lead to economic profitability and the use of renewable energy. In this study, how to generate electricity with the help of compressed air energy, background, methodology, framework, advantages and disadvantages has been investigated. CAES is the only other commercial technology (in addition to PHS) that has the ability to store very high energy (more than 100MW). CAES reduces peak load, ,load levelingenergy management, use of renewable energy and standby power in energysystems power andtransmission.

In addition, in this study, the proper location of the CAES power plants has been investigated and different reservoirs has been examined and according to better characteristics and benefits of data of depleted gas resivours and simulated models, these reservoirs have better results than other reservoirs.

At the end, it is suggested that according to the importance of storage and the better results of ES in depleted natural gas reservoirs, the good potential of geological reservoirs inside the country and a considerable number of evacuated reservoirs in different regions of Iran, to conducted studies and to create more projects in this field within the country and further research in this field requires a proper, accurate and scientific method and a good simulation. With studying and performing static and dynamic simulations that are accurate and along with the history of the reservoir, the data of drilling and seismography and the initial experiments of the reservoir and the transfer of these data in accurate and appropriate software, an important step in the study of underground compressed air storage will be taken.

6. Abbreviations

EES: Electrical Energy Storage

CAES: Compressed air energy storage

ETS: Electrical Thermal Storage

PSH: Pumped storage

SMES: Superconducting magnetic energy storage

TEES: high temperature thermoelectric energy storage systems

TES: Thermal energy storage

HSS: Hydrogen Storage System

UAS: Underground Air Storage

DR: Depleted Reservoir

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