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Multi criteria site selection model for wind-compressed air energy storage power plants in Iran

Mohammad Satkin [a], Younes Noorollahi [b,*], Majid Abbaspour [c], Hossein Yousefi [b]

[a] Faculty of Energy and Environmental, Science and Research Branch, Islamic Azad University, Tehran, Iran
[b] Department of Renewable Energies and Environmental Engineering, Faculty of New Sciences and Technologies, University of Tehran, Tehran, Iran
[c] School of Mechanical Engineering, Sharif University of Technology (SUT), Tehran, Iran

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A B S T R A C T

In this research, a site selection method for wind-compressed air energy storage (wind-CAES) power plants was developed and Iran was selected as a case study for modeling. The parameters delineated criteria for potential wind development localities for wind-CAES power plant sites. One important consequence of this research was the identification of the wind energy potential for wind-CAES sites. The theoretical wind energy potential of Iran of greater than 50 W/m^2 was identified from a wind atlas of Iran. The model produced factor maps by considering the boundary conditions of the input data and created geo-databases from the outputs maps. The main factor maps were electrical grids and substations, gas transmission lines, a wind energy atlas, thermal power plants (location and capacity), salt dome locations and extends (for compressed air reservation), slope data, a digital elevation model, cities and residential areas, water bodies and access roads. For every data layer, criteria where developed from existing laws, regulations and scientific studies and normalized for Iran. In the final step of analysis and modeling, the factor maps were integrated by coding using ArcGIS software and the wind-CAES power plants sites were selected. This research showed that 30 sites in 5 major zones have the capability to support installation of wind-CASE power plants in Iran.

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1. Introduction

Energy is a driving force for global social, economic and technological development. Fossil fuels are the dominant available global resource and play a crucial role in supplying mankind's increasing demand for energy. Fossil fuel reserves are limited, however, and their use has negative environmental impacts. The present rate of energy consumption of energy is high and fossil-based resources cannot continue to provide energy at their current rate; these resources will be used up in the relatively near future. Renewable energy is expected to play an important role in handling the demand for energy and reducing environmental pollution [1].

Since the first oil crisis, renewable energy sources have been discussed as renewable, sustainable, and environmentally friendly

* Corresponding author. Tel.: +98 912 213 2885; fax: +98 218 861 7087.
E-mail address: Noorollahi@ut.ac.ir (Y. Noorollahi).

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forms of energy. Geothermal, solar and wind-based renewable energy sources have the potential to reduce dependence on fossil fuels for electricity and reduce greenhouse gas emissions [2]. The role of renewable energy sources for electricity has improved and they are considered alternatives for replacing fossil fuels for power production because of increased public awareness of the negative environmental impacts of conventional power-generating methods, such as coal- and oil-fired plants.

Wind energy is a reliable and promising form of renewable energy. It is currently a significant, fast growing, commonly-used and commercially attractive resource. It has become more attractive as a clean renewable energy resource because of the maturation and cost-effectiveness of energy conversation technology. The installed capacity of electricity generation from wind energy is rapidly increasing in countries that are implementing a variety of incentive policies and, thus, the importance of wind energy is expected to increase in the coming decades [3]. The cost of electricity generation from wind energy has become competitive with that of electricity from fossil fuel power plants. This makes wind power a popular and safe form of renewable energy that can be economically viable, does not produce significant environmental pollution, and can contribute significantly to the reduction of CO_2, NO_x and SO_x.

Novan measured the decrease in CO_2, NO_x, and SO_2 production from electricity supplied by wind turbines in the Texas electricity market. He found clear evidence that renewable generation in the region offset significant amounts of each of the pollutants examined. The average pollution offset by a MWh of renewable electricity is 0.54 to 0.93 t of CO_2, 0.88 to 1.92 lb of NO_x, and 0.97 to 4.30 lb of SO_2 [4].

The wind energy is expected to play a major role in fulfilling the recent targets set by national policy in Iran. This energy is attractive for planners and developers because of its lower energy, environmental and social costs that minimize the dependency on fossil fuels and improve the economy and lifestyles of remote areas. Because wind energy is a clean and renewable energy source, in the global context of increased social concerns about climate change and energy supplies, it has experienced strong and stable levels of public support.

Despite the advantages, the intermittent nature of wind energy remains a challenge and efforts are ongoing to find a solution. One solution is the storage of electricity from wind turbines as compressed air in underground caverns. In this technique, off-peak electricity produced by wind turbines is used to run air compressors used to fill underground mines, abandoned oil and gas wells or salt domes with compressed air. In the absence of wind or at peak times, the compressed air is released to a gas turbine that produces electricity with higher efficiency to meet grid demand.

Identifying suitable areas for such underground structures to store compressed air in areas with adequate wind resources and other criteria is a complex task. Location-based decision-making by integration of the results of surveys and studies is a procedure subject to human error. Geographical information systems (GIS) can be used as digital location-based computation tools to minimize errors by identifying prospective areas using digital thematic maps [5] and conceptual models for data integration [6].

The focus of this paper is to find the most suitable locations for wind-CAES development as a peak-shaving tool in Iran. Wind-CAES site selection is an innovative method of applying technology to wind energy; the method locates suitable locales with suitable geology and reservoirs available to hold air at pressures of less than 90 bars [7] to operate CAES-powered gas power plants. The practicality of the issue in this context is one of economic viability.

A utility company would only build a wind-CAES plant in Iran if all requirements could be easily obtained and utilized. Wind-CAES makes economic sense over other options to mitigate problems associated with intermittent wind. This paper examines how to use GIS integration models for a wind farm and CAES plant site selection.

2. Wind compressed air energy storage

Management of the energy supply using renewable energy generators can be achieved by energy storage. Despite the lack of significant new construction, interest in energy storage did not completely cease when the cost of fossil fuel dipped. Research and development has continued, along with an increasing number of proposed projects [1]. Recent renewed interest in energy storage has been motivated by at least five factors:

- Advances in storage technology.
- An increase in fossil fuel prices.
- The development of deregulated energy markets, including those for high-value ancillary services.
- Challenges to siting new transmission and distribution facilities.
- The perceived need and opportunities for storage using variable renewable generators [1,8].

Energy storage increases the technical reliability of the power supply, stabilizes the cost of electricity and helps to reduce greenhouse gas emissions, but electrical energy storage presents difficult engineering and scientific obstacles that have not been fully overcome. Consumers are still waiting for batteries that last longer and utilities have been searching for affordable large-scale storage that will allow them to run generators at a constant rate rather than ramping up and down with demand. The increased use of intermittent renewable resources (wind and solar) adds another level of complexity for utility companies [9].

Storing large amounts of electrical energy in a cost effective and efficient method remains a difficult challenge. The advent of modern renewable energy sources improves the ability to collect or harvest energy, but not to store what is gathered. Modern renewable energy sources intensify the search for robust, cost-effective means to store energy. Intermittent energy sources such as solar panels or wind turbines require energy storage capacity if they are to provide consistent, on-demand power to the user and be able to replace traditional fossil-fuelled systems [10].

The major options for utility-scale energy storage are CAES, pumped hydroelectric energy storage, different types of batteries, flywheels, superconducting magnetic energy storage (SMES), and ultracapacitors [10]. The technology chosen is generally a function of the duration of storage, as indicated below:

- Long duration storage (>10 h): pumped hydro.
- Intermediate duration storage (4–10 h): compressed air.
- Short duration storage (<3 h): batteries, SMES, and flywheels [10,11].

Large scale energy storage systems are one solution. One of the most promising forms of large scale storage is CAES, which is an inexpensive way to store massive amounts of energy for long periods of time. Aside from pumped hydro storage, compressing air when power is inexpensive and plentiful and then using it to boost natural gas-fired power turbines during peak demand is the only way to shift hundreds of megawatts of load from 1 hour to the next [11–13]. CAES plants save a region's abundant wind power for later use, when demand is high and power supplies are more costly.

CAES is designed to store off-peak energy for use during peak demand periods. During off-peak periods, a motor operates on excess power to compress and store air in subsurface formations.

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