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Multi-criteria evaluation and priority analysis of different types of existing power plants in Iran: An optimized energy planning system

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ABSTRACT

The energy assurance and electricity supply are significant factors for progress and development of all countries. Low investment costs, reducing greenhouse emission, and high output efficiency for good performance of power plants are key factors in evaluating energy parameters for governments. This study is intended on determining and proving the compatibility of existing power plants in the country of Iran by applying observational data through the application of Multi-Criteria Decision-Making Analysis (MCDA). The obtained compromise solutions applied through a MATLAB code that helped in specifying which power plants are particularly suitable for establishment in the future work. Furthermore, it supports the generalization and validation of applying VIKOR method for thorough evaluation of power systems by comparing the results with real condition. The different types of power plants have been considered as alternatives. Multi-criteria evaluations of these diverse power plants were also carried out with respect to the environmental, technological, and economic criteria. It was concluded that hydropower plant is the best possible case for establishment, and the VIKOR method is a reliable technique for evaluating energy systems which can help to rank alternatives and determines the solution named compromise that is the closest to the ideal case.

1. Introduction

To address the concerns about the accelerated trend of demand for energy supply, there are different approaches which are being investigated and employed. These concerns cover diverse aspects of environment consequences, depletion of fossil fuels, and necessity of developing alternative energy sources for its efficient economic development and simple survival in the future [1,2]. Developing Renewable Energy Sources (RES) is a widely-accepted policy. It has affected most research interests and consequently resulted in more efficient power plants that mitigate their environmental impact through improved energy efficiency and development and deployment of low-carbon technologies [3]. As a result of extensive research in this filed, various approaches have been documented in the pertinent literature emphasizing the optimizing methods for energy generation [4]. Power plants are deemed as the heart of electricity generation industry in all countries having non-stop diurnal activities. It is believed that they have a critical and determining role in the survival of industry and economy. The necessity for supplying energy and its growing demand are directly proportional to considerations involved in constructing more power plants. Therefore, they are definitely one of the most important essentials of development in a country [5].

One of the well-cited methods for evaluation of power plants is employing Multi-Criteria Decision Making (MCDM) techniques. The application areas of MCDM in energy planning have been widely used to take care of multiple, conflicting criteria to arrive at better solutions for energy management [6–8]. In 2001, Afgan et al. have presented selection of criteria for the renewable energy sources in order to assess which method could meet the sustainability criterion, and concluded that this method is of the great interest for evaluation of power plants [9]. To evaluate power plants in Turkey, in 2012, a research was conducted in which Analytic Network Process (ANP) method was employed for MCDM procedure. The well-thought-out criteria included technology, sustainability, economy, life quality, and socioeconomic impacts. The results showed that nuclear power plant has the best-case plan for Turkey [10]. In another research in Turkey, Kabak investigated about the prioritization of renewable energy sources through MCDM methodology. The results supported the conclusion that

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hydropower is the best alternative for the country [11]. The methodology has also been applied in wind industry for the site selection and offshore wind farms [12,13]. Furthermore, there have been several attempts to evaluate energy resources of manufacturing industry through MCDM approaches [14].

Matteson presented a review for multi-criteria assessment of power plants accompanied by proposing a new techniques for normalization and rankings which eliminates the negative effects of system comparison [15]. Multi-Criteria Decision Analysis (MCDA) has also been employed for evaluation of future possible scenarios for electricity generation in Portuguese and showed different ranks which is not unexpected [16].

In another study MCDM has been employed for evaluation the sustainability of a city and it is claimed to be a practical application [17].

In this paper, the evaluation of five established power plants in Iran has been conducted through Multi-Criteria Decision Analysis in order to find optimum case based on the careful selection of criteria. In pertinent literature the fundamentals and priorities for cleaner production in industries has been conducted [18,19]. Yet energy generation is an important resource to be considered. We also investigate the validation of applied MCDM method for evaluation of power plants by comparing the real condition. These power plants are located in different parts of Iran that have diverse climatic conditions. At these locations, there are different type power plants, including combined cycle power plant, gas power plant, hydropower, wind farm and combined Heat and Power (CHP). The Input data, which is based on their real performance, have been obtained from the published reports. The selected criteria that are considered in this study consist of technology, economics and environmental impacts which includes assessment of specific effects as well as carbon dioxide (CO_2) emission, efficiency, and land use.

To assess and compare the cases, VIKOR (Vlse Kriterijumsk Optimizacija Kompromisno Resenje) method, which is a Multi-Criteria Decision Making (MCDM) procedure, has been employed. The VIKOR method is used to solve decision problems with conflicting (e.g., different units) criteria, assuming that the decision maker would like to obtain a solution that is the closest to the ideal case. Furthermore, the alternatives are evaluated according to all established criteria. VIKOR ranks alternatives and determines the solution named compromise that is the closest to the ideal case [20,21]. Additionally, the criteria have been weighted through Entropy-Shannon algorithm. The obtained results have been analyzed and discussed for the specified situations in Iran in order to verify the overall assessment of presented Multi-Criteria Decision Analysis.

2. Background of Iran

Iran is a country located in middle-east of Asia. Eastern Iran is dominated by a high plateau, with large salt flats and vast sand deserts. The plateau is surrounded by even higher mountains, including Zagros in west and Elburz in the north. Farming and settlement are largely concentrated in the narrow plains or valleys in the west or north, where there is more rainfall; hence, it has more diverse climatic conditions in different part of the country. Iran's largest oil reserves lie in the southwest, along the Persian Gulf [22]. When looking at the most easily accessible reserves, Iran fall right behind Venezuela and the Kingdom of Saudi Arabia. Iranian oil is found in close to 150 hydrocarbon fields, many of which have both petroleum crude oil and natural gas.

Iran has the second largest gas reserves in the world after Russia, with 33.6 trillion cubic meters [23], and third largest natural gas production in the world after Indonesia, and Russia. It also ranks fourth in oil reserves with an estimated 153,600 million barrels [24,25]. It is OPEC's second largest oil exporter and is an energy superpower for feeding the power plants [26,27]. Oil industry output averaged 4 million barrels per day in 2005, compared with the peak of six million barrels per day reached in 1974. The employed sources of energy for generation of electricity contains, about 75% based on natural gas, 18% on oil, and 7% on hydroelectric power. Currently, hydropower is the country's largest renewable resource by generational capacity, and Iranian companies have considerable experience in hydropower development. They are also increasingly active on the international stage. The 1040 MW Siah Bishe pumped-storage plant, which commissioned its first 260 MW generating turbine in 2013, entered in its full commercial operation in September 2015, when the fourth and final pump-turbine was commissioned as well. This station generates electricity during periods of high energy demand and consumes 940 MW of electrical power for pumping operation during periods of low demand. It is intended to meet peak electricity demand in the capital city, Tehran, which is 125 km to the south. There are also a number of small and medium-sized projects at various stages of development in the country. Fourteen small and medium-sized projects are complete for investment, representing a total of 430 MW in capacity [28]. In Iranian northwestern cities of Tabriz and Ardabil mean annual wind energy output is about 1100 MWh [93–95]. However mean annual wind power density in Bushehr province is 150 W/m^2 [96] and in Sistan and Balpuchestan provinceis about 280 W/m^2 for Zabol and Zahak cities and 140 W/m^2 for Zahedan and Mirjaveh cities [97].

In 2004, Iran established its first wind-powered and geothermal plants, and the first solar thermal plant has become online in 2009 [29]. Demographic trends and intensified industrialization have caused electric power demand to grow by 8% per year. The government's goal of 53,000 MW of installed capacity has been reached by bringing on line new gas-fired plants and by adding hydroelectric, and nuclear power generating capacity [30,31].

Iran comprising a land area of 1,648,195 km^2, it is the second-largest country in the Middle East and the 18th-largest in the world, with 78.4 million inhabitants. Iran is also the world's 17th-most-populous country [32,33]. It is the only country that has both a Caspian Sea and an Indian Ocean coastline. Iran's climate ranges from arid or semiarid, to subtropical along the Caspian coast and the northern forests. In the northern part of the country (the Caspian coastal plain) temperatures rarely fall below freezing and the area remains humid for the rest of the year. Summer temperatures rarely exceed 29 °C (84.2 °F) [34,35]. Annual precipitation is 680 mm in the eastern part of the plain and more than 1700 mm in the western part. In west, settlements in Zagros basin experience lower temperatures, severe winters with below zero average daily temperatures and heavy snowfall. The eastern and central basins are arid, with less than 200 mm of rain, and have occasional deserts [36]. Average summer temperatures rarely exceed 38 °C (100.4 °F). The coastal plains of Persian Gulf and Gulf of Oman in southern Iran have mild winters, and very humid and hot summers. The annual precipitation ranges from 135 to 355 mm [37]. This different climate conditions in Iran is illustrated in Fig. 1.

As illustrated in Fig. 2, by considering the above mentioned specifics climatic conditions, we selected five power plants cases that are more appropriate in five different places of Iran with those diverse weather conditions.

3. Methodology

3.1. Criteria selection

There are different criteria to demonstrate the implementation of power plants; however, we need to establish thresholds and to