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The Nexus between Renewable Energy Sources and Electrical Distribution Systems

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Abstract*— The incorporation of sustainable energy sources holds significant significance in the economic, social, and environmental domains of any country because of the exhaustion of non-renewable energy resources and escalation of ecological degradation. This holds true irrespective of the country's geographical location. Owing to these two factors, the employment of this particular type of energy is emerging as a progressively noteworthy tactic. The present investigation involved the generation of power transmission network simulations using solar power plants. The network model was chosen as the preferred approach for a specific locality in Baghdad, Iraq, which is characterized by a noteworthy concentration of solar and wind energy generators. A numerical model was employed to construct a power transmission network model that integrated Renewable Energy Sources (RES). The Digsilent/Power Factory software has been utilized for the purpose of modeling the power transmission network that incorporates RES. The developed network model integrates several distinct case studies, each of which includes diverse links that exhibit varying levels of renewable energy sources (RES). As per the simulation findings, the 346 kV shared bus is linked to the 154 kV Iraqi transmission line via a 156/35.8 kV step-up transformer. The transmission system was represented by bus voltages of 156 and 290 kV. The permissible range of operational voltages for a transmission system should not deviate beyond 5% of the voltage level at the corresponding substations.

***Keywords*—**Power Transmission Network, Renewable Energy Sources, Voltage Profile.

1. Introduction

Renewable energy plays a significant role in the economic, social, and environmental activities of any country, as the depletion of fossil fuels and the rise in environmental pollution have raised the significance of utilizing this type of energy [1–5]. This has become an incentive for energy sector researchers and investors to be attracted to the knowledge and supply of energy from renewable sources [6–8]. The utilization of alternative energy sources is becoming increasingly imperative in the Persian Gulf region due to a variety of factors such as international sanctions, civil conflicts, and other energy crises. This highlights the need to shift away from traditional fossil fuels [9–11].

Although Iraq is one of the world's most oil-rich nations and has vast natural gas reserves, it may drastically reduce its consumption of fossil fuels by utilizing solar energy in many parts of the country because of its high radiation potential [12, 13]. The reasons for the need to use clean and renewable energy sources, especially wind and solar energy, in Iraq include the use of less complicated technology, the reduction of air and environmental pollution, and most importantly, the reduction of future fossil fuel consumption or the possibility of exporting and converting them into petrochemicals [14, 15]. With the rise in oil prices in recent years, industrialized nations have been compelled to focus on alternative energy sources [16]. Additionally, there has been an increase in Iraq over the past few decades. Iraq is one of the best countries in the world in terms of wind and solar energy potential, based on its geographic location. Because of the prevalence of rural areas in the country, wind and solar energy are among the most significant variables to consider [17].

In light of the fact that renewable energies do not affect the environment and have garnered a great deal of global attention, all nations, including Iraq, should prioritize the generation of power from all types of renewable energy sources. There are four techniques for boosting the output of power from renewable energy sources (solar, hydro, wind, and geothermal) [18–21]. One of the most crucial concerns in the field of policy formulation for the future of the Iraqi power industry is varied economic, social, political, technological, and environmental conditions [22]. Which form of energy has the largest impact on the country's electricity production and which of the analyzed power plants should serve as the foundation for the expansion of Iraq's electrical network?

In the context of investigating the effect of different types of renewable energy sources on electricity production, it can be stated that some people believe electricity can be produced from different

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Research Paper

types of renewable energy more than from other energies, and that experimental studies, such as (e.g. [23–26]) increase electricity production from different types of renewable energy sources in countries with these sources. They concluded significantly more than the other forces. While other studies have been conducted by economists, who believe that electricity production from renewable energies is not possible in some countries because there are more non-renewable resources than renewable resources in these countries, which includes greater economic savings, this study demonstrates that electricity production from renewable energies is feasible in all countries.

Lin and Chen [27] investigated the significance of electricity production as an innovation in China's Renewable Energy Sources (RES). Using the minimum and fully adjusted ordinary least squares methods, it was determined that the price of electricity from various sources - renewable energies–during the period 2006-2016 has long-term effects on electricity production, and a percentage increase in the variables of electricity prices and types of RES causes an increase in the amount of electricity production. The macroeconomic effect of RES on electricity production in Portugal over a 25-year period was investigated using a self-explanatory model [28]. Andini et al [28] determined that there is a positive and statistically significant correlation between the types of RES and the amount produced over the short and long term. Park and Kim [29] found a positive relationship between the types of RES and the amount of household electricity generation in their study on the effect of different types of RES on household electricity generation in the United States of America using panel data regression for monthly data from 2016 to 2013. They discovered that using renewable energy to generate electricity increased the amount of household electricity consumed by each household in the United States to approximately 16 million kWh. The study presented in [30] reports and analyzes an instance of voltage rise that is deemed unacceptable, particularly during noontime, when the photovoltaic (PV) penetration rate is at 50%. The issue of reverse power is being examined, with the assertion that a significant challenge arises for the network when the output power fails to align with the demand. This is due to the fact that all power transformers and protection components are engineered to accommodate unidirectional power flow [31]. The impact of photovoltaic penetration on the grid is analyzed and studied in the procedures outlined by Kharrazi et al. [32]. The proposed model by the authors takes into account the uncertainty of solar power generation and employs stochastic assessment methods to precisely evaluate the operational status of the network at varying levels of solar photovoltaic penetration. Nerkar et al. [33] involve an examination of the frequency response of a power system as the proportion of RES increases. The analysis is conducted using the 9-bus test system. Comprehending the reaction of RES in the generation mix is imperative in order to devise a suitable framework for regulating frequency.

As power systems evolve through the constant addition of new units to power systems and incremental operation under high-pressure conditions, various types of system instability and security have appeared in the past [34]. As a result, ensuring system stability, particularly static voltage stability analysis, is critical for maintaining system balance. Owing to its influence on the reliability and safety of the system, it is considered an important indicator. Alterations in the value of P and the voltages of all system buses can affect the reliability of the voltage [35]. Voltage stability can be defined as the power system's ability to maintain a stable state under certain conditions [36]. Voltage stability analysis can be used to determine whether the voltage level in all buses is appropriate because a specific beginning and after exposure to physical disturbance is considered [37]. current RES-based increases in distributed generation have an impact on networks [38]. Furthermore, because higher RES generation cannot be guaranteed compared to conventional energy sources, it is difficult to maintain system balance and sustainability.

Table 1. Specifications of RES

Wind farms ID	Turbines	Production capacity (kW)
1	28	68700
2	17	52800
3	54	110000
4	18	40000
5	45	43300
6	15	28000
7	20	10700
8	18	22200
9	17	15100
10	20	24300

This study developed a new Baghdad energy transmission network strategy using a numerical model. Power transmission network model system configurations were also discussed. The network model was built to compare the effects of RES on the power system based on case studies based on RES connection and energy demand. Modeling the power transmission network with RES uses Digsilent/Power Factory tool.

2. DIAGRAM OF THE MODELED POWER NETWORK

Fig. 1 depicts the streamlined transmission system that includes power plants that run on RES. We chose a section of the Baghdad region in the western Iraqi transmission system for this study because it has a relatively even distribution of load and production and a high concentration of power plants that are fueled by RES. The model that was developed includes seven power plants that are based on RES and are formed five times, each time with a different level of connectivity to the external network. The power ratings of generators that have been installed are shown in Table 1. The double-feed induction generators (DFIG) that are based on wind turbine generators are connected to the 336 kV common bus by means of a step-up generator transformer that operates at 0.8/35.8 kV. Connecting the 346 kV common bus to the 154 kV transmission system in Turkey is a step-up transformer with a voltage rating of 156/35.8 kV. Both 156 and 290 kilovolts are present at the bus voltage levels in the modeled transmission system. Within a transmission system's substations, the maximum and minimum operational voltage restrictions are required to be within a 5% tolerance of each other. In addition, base values are usually utilized instead of the real values associated with system components like voltage, current, as well as active and reactive powers. This is because base values are easier to calculate than actual values. This is due to the fact that calculating base values is more simpler than calculating real values. As a direct consequence of this, the analyses carried out in this work made use of the base voltage values of 156 and 385 kV respectively. The modeled transmission network includes a total of 12 substations and transmission lines connecting each of these substations (Fig. 1). As a direct consequence of this, the voltage range is 0.93 to 1.4 pu, and bus load voltage range is 0.96 to 1.09 pu.

In this section, voltage changes in bus loads have been simulated and examined in different case studies that were created according to RES values of energy demand. The offending scenarios in case studies are as follows.

- Scenario 1: The amount of production of farms is minimum and energy demand is minimum
- Scenario 2: The amount of production of farms is maximum and energy demand is minimum

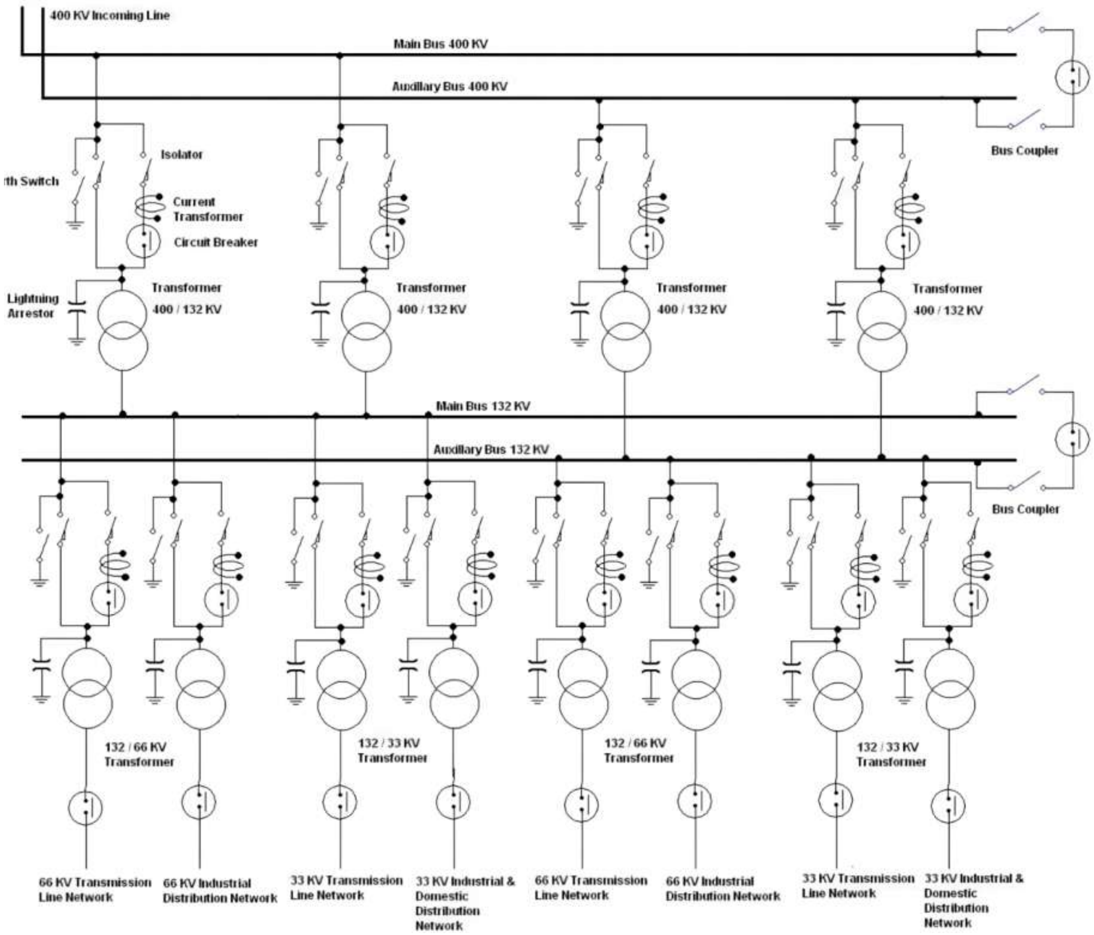

Fig. 1. Single line diagram of power transmission system

- Scenario 3: The amount of production of farms is minimum one line cut and energy demand is maximum

3. RESULTS AND DISCUSSION

3.1. Scenario 1

The demand for matching bus loads is at its lowest in Scenario 1, which is based on wind generation. In this scenario, production is based on the minimum amount of wind that can blow, and the bus's need is frequently met by the external network. Fig. 2 presents the values of the voltage and phase angle in the bus loads for this scenario. Even though the involvement of wind power plants and demand in the respective bus loads is limited, the role of the external network and reactive power, as well as the values of voltage and phase angle in the bus loads, are presented. Wind power plants and demand play limited roles in the respective bus loads. This production exceeds the demand in terms of bus loads because of the lengthy lines currently in operation. Because of the imbalance between the amount of power generated and the amount of power demanded by the bus load, the voltage levels in the bus load increased to levels that exceeded the bus load voltage limitations. However, the Bass values were almost always within the acceptable range of the operating voltage.

Adjusting the reactive power may be more difficult when there is minimal active power, which is why renewable energy generation ceases. These conditions necessitate the use of a WF alongside a reactive power supply and voltage regulation. Therefore, it is essential to consider the reactive load conditions of the network when planning investments, and links should be mentioned.

3.2. Scenario 2

This is repeated multiple times in Scenario 2, with the maximum wind-based output and minimum bass demand. As shown in Fig. 2, the voltage values on the bus are frequently within the working voltage range. As shown in Fig. 2, the network profile voltage is greater in Scenario 2 than in Scenario 1. Even though the demand in the respective bus loads is minimal and the function of the external grid is reduced in Scenario 1, wind-based generation is also at its maximum because of the low inductance of power plant ID 3. The reactive power of the system was absorbed. Consequently, the bus load voltages decreased, and the voltage regulators were close to their nominal values. In scenario 2, while the voltages of buses 1, 2, and 3 decrease, the voltages of the other buses increase. In addition, the phase angles of all buses were altered relative to Scenario 1, as the active power of the wind farm was directed to high-consumption areas. Because the bus loads in the power plant ID 2, 3, 4, 5, and 6 are unloaded, the entire amount of energy generated is transferred.

3.3. Scenario 3

In Scenario 3, this is determined to be a 390 kV line that has been severed. In addition, the demand for bus loads peaked. The profile voltage networks in this scenario are shown in Figure 3. In addition, all bus voltages and phase angles are listed in Table 6 as a result of the analysis. Clearly, bus loads 1, 2, and 3 are disconnected from the network owing to a 390 kV line failure. The voltage values in the loads became the most nominal of the three things as a result of a decrease in voltage because

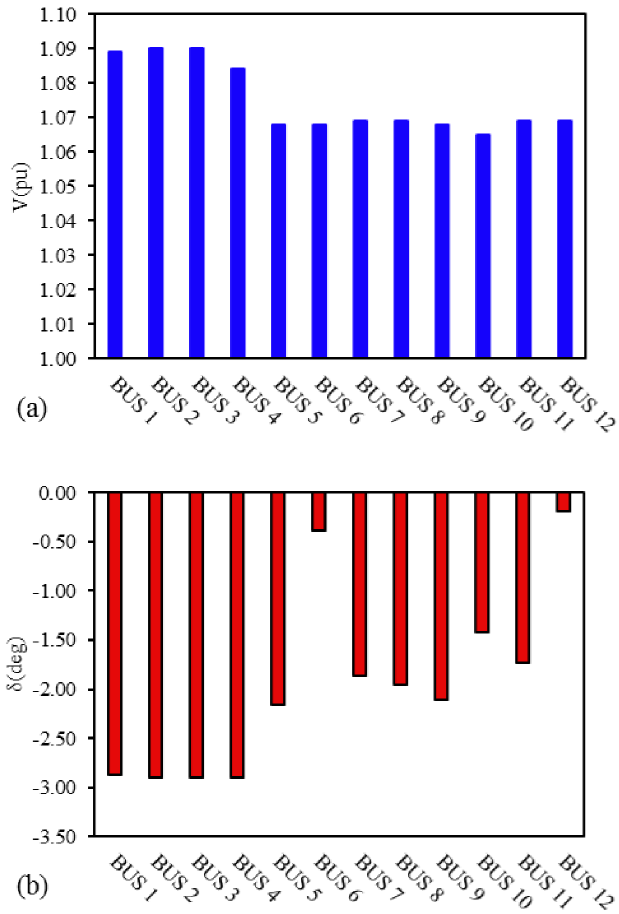

Fig. 2. Voltage and phase angle in the bus loads for scenario 1

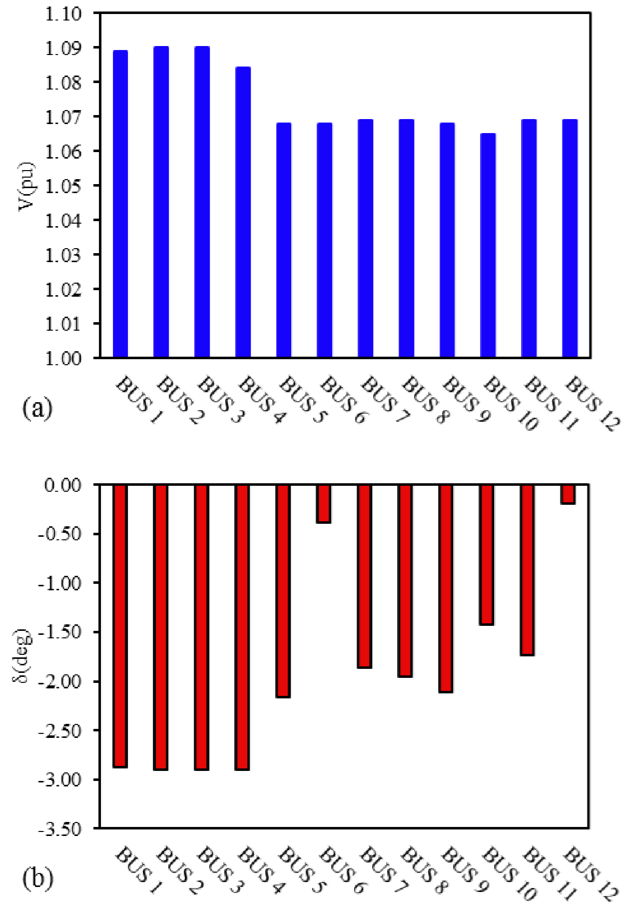

Fig. 3. Voltage and phase angle in the bus loads for scenario 2

the demand associated with the loads was the greatest and wind turbine involvement in the system was minimal.

By comparing Scenarios 1 and 3, despite the fact that wind power plants play the same function in both circumstances, the voltage values in the bus loads are larger in Scenario 1 than in Scenario 3. This is because the reactive power of lines plays an important role. The transmission is operational and the disparity between supply and demand is modest during peak hours.

3.4. Result comparison

This section examines the practice of comparing the outcomes of hypothetical situations with the findings of previous studies. The results of the three voltage tests performed with Monga [39] data are displayed in Table 2. Monga [39] has evaluated the results in 11 BUS. Comparing the results of these simulations with those of other studies demonstrates their validity.

Table 2. Voltage results comparison

BUS number	V(pu)			
	Scenario 1	Scenario 2	Scenario 3	Monga [39]
BUS 1	1.089	1.075	–	0.977
BUS 2	1.09	1.075	–	1.012
BUS 3	1.09	1.075	–	1.045
BUS 4	1.084	1.075	1.05	1.045
BUS 5	1.068	1.075	1.059	1.043
BUS 6	1.068	1.068	1.054	1.043
BUS 7	1.069	1.074	1.06	1.087
BUS 8	1.069	1.075	1.06	1.075
BUS 9	1.068	1.075	1.059	1.076
BUS 10	1.065	1.069	1.06	1.075
BUS 11	1.069	1.071	1.06	1.075
BUS 12	1.069	1.067	1.066	–

4. CONCLUSION

The ever-increasing global awareness of environmental issues has resulted in an increase in the utilization of sustainable forms of energy. The generation of electricity from RES is a viable alternative that can be put to productive use in the fight against rising energy concerns worldwide. However, the incorporation of RES has resulted in a negative impact on the operation of electricity systems. This article explores not only the advantages but also the disadvantages that RES has brought to the electrical system. This study used Case studies were conducted to evaluate

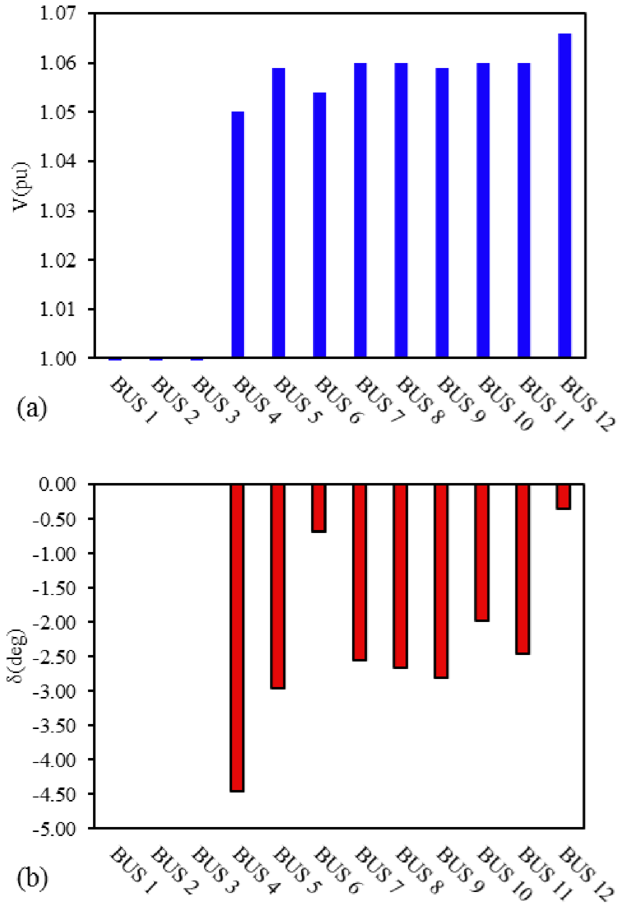

Fig. 4. Voltage and phase angle in the bus loads for scenario 3

the effects of RES on the system voltage profile. These case studies were based on the number of RES that were connected to the system and the amount of energy required by the network model. The number of linked RES was used as the primary variable in each case study. The conclusions and suggestions are summarized as follows:

- The application of this research revealed that linking wind farms to the network increased the voltage profile of the system.
- In power systems, a modest mismatch between production and demand results in a minor variance in the bus voltage.
- Bus voltages of 156 kV and 290 kV were used to represent the transmission system. The acceptable operational voltage range of a transmission system must not exceed 5% deviation from the voltage level at the corresponding substations.
- Reduce reliance on non-native energy sources by hastening the construction of solar, geothermal, and wind power facilities and elevating the percentage of total electricity production from RES.
- Wind turbines that have recently been installed and comply with the regulations of the electricity market must be placed in the frequency and voltage control of the receiver.

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