



e-ISSN: 2319-8753 | p-ISSN: 2320-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 5, May 2021

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 7.512

9940 572 462

6381 907 438

ijirset@gmail.com

www.ijirset.com



Transmission Network Study Using GIS in Wind Farm Injection Planning

Amany B. Mohamed¹, Walid El khatam², Hisham Temraz³

P.G. Student, Dept. of Electrical Power and Machine, Faculty of Engineering, ASU, Cairo, Egypt¹

Professor, Dept. of Electrical Power and Machine, Faculty of Engineering, Ain Shams University, Cairo, Egypt^{2,3}

ABSTRACT: This paper presents an application of the Geographic Information Systems (GIS) to the site selection of wind farms. The proposed methodology exploits the extensive capabilities of GIS technology in analyzing several forms databases especially maps. Throughout this work, the data collection process has spanned several data sources including maps, the Egyptian wind atlas, the unified transmission grid data, etc. The constraints applied in wind farm planning have been presented in the form of GIS layers and a sequential filtering procedure has been utilized to clip out the unsuitable sites. The main constraints for wind farm site selection applied to this work are wind speed, distance to national electricity grid and main roads, land height, adjacent urban areas and airport locations, historical places, ports, water network, and oil pipelines and liquid fuel tanks. In addition, to using GIS for site selection, the effect of a proposed wind farm connection to the unified grid has been studied using ETAP software regarding load flow and short circuit level. For these studies, the Canal Zone and red seashore area have been modelled. The existing and proposed wind farms have been presented at a plant level model.

KEYWORDS: geographic information system, renewable energy, wind farms, planning, site selection.

I. INTRODUCTION

Climate change has encouraged many countries to turn to renewable energy as an effective measure to reduce greenhouse gas emissions. Wind farms are an important source of green energy that are being used to replace electricity derived from fossil fuels. While the environmental benefits of replacing fossil fuel-derived energy with wind energy are vast, there can be some environmental concerns with the installation of wind farms in certain areas of ecological importance. For instance, the construction of wind farms requires access for large construction equipment and may have some temporary but significant impact on the environment. Noise should be measured to assess its effect on the nearby inhabitants. To minimize such effect, Geographic Information System GIS is used for site selection of wind farms.

Paper is organized as follows. Section II describes world wind power market and the wind power status in Egypt, connected component analysis and set of selection or rejection criteria. The flow diagram represents the step of the algorithm. Wind farms development including the site selection technique that is given in Section III. Section IV presents Geographic Information System GIS model for wind potential analysis showing results of output maps. An ETAP model created to evaluate Power Flow study and Fault study in Section V. Finally, Section VI presents conclusion.

II. WIND POWER STATUS

The world market for renewable energy is expanding at an increasing pace, the real interest in wind power generation marked its start with the oil crisis at the beginning of the 1970s. As a result, financial support for research and development of wind energy gained momentum and the wind energy technology improved gradually.

a. WORLD WIND POWER MARKET

It was not until the 1980s that large utility scale wind farms were constructed. During the 1990s, wind power took off and grew into a multibillion-dollar industry. At the end of 2017, the installed capacity of wind-powered generators reached 539 GW. Several countries have achieved relatively high levels of wind energy penetration in their electricity grids. On a global basis, wind energy's contribution is estimated at approximately 5%. [1][2].

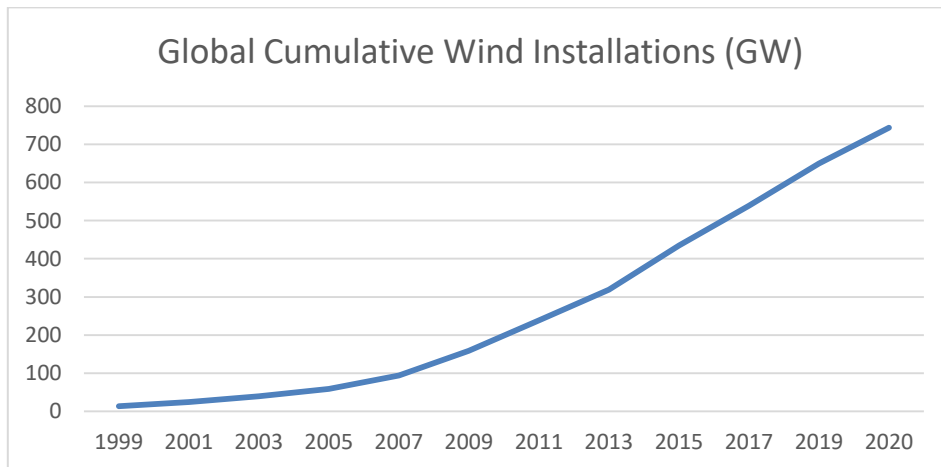


Fig. 1. Wind power capacity installations worldwide from 1999 to 2020 [3]

Over the years, the size of wind turbines increased from around 75 kW in the 1980s, to 300-750 kW in the 1990s and 1.5-2.0 MW in the 2000s. Today, the largest wind turbines on the market are the 9.5 MW [Vestas V164](#).

World wind generation capacity increased more than 4 times between 2009 and 2019 and the global investment in wind power in 2019 totaled 142.7 USD billion [4].

In February 2018, the Global Wind Energy Council GWEC released its annual market statistics and stated that "wind is the most competitively priced technology in many if not most markets. The emergence of wind/solar hybrids, sophisticated grid management systems and affordable energy storage technologies began to paint a picture of a fully commercial fossil-free power sector"

b. WIND POWER STATUS IN EGYPT

Egypt is a strong candidate to become a renewable energy-dependent country since it has an abundance of land, sunny weather, and high wind speeds. Egypt has excellent wind sites on the Gulf of Suez with an average wind speed of 10.5 m/sec. Generally, wind speed in summer is higher than in winter. The Egyptian climate makes it the most prominent for developing wind power and has generous abilities to become a major player in renewable energy.

Egypt has built a 545 MW wind farm near the city of Zafarana; this plant is connected to the transmission network and has produced 931GW in 2009.

South of Zafarana at Gabal Al-Zeit, an area of 700 square kilometers has been earmarked to house wind energy projects, mostly planned to be funded by private investments. Currently two wind farms joined commercial operation in that location, the first has a nominal capacity of 240MW and was funded by the European Investment Bank (EIB), the second wind farm was funded by the Japanese International Cooperation Agency (JICA) and has a nominal installed capacity of 220MW.

Wind farms can also be housed in the Gulf of Suez, Faiyoum, Beni sweif, Minya and Kharga oasis. Egypt currently has approximately 1,005 MW of wind farms and 1,070 MW under implementation and development. Egypt intends to supply 20 percent of its generated electricity through renewable energy sources by 2022, with 12 percent from wind.

Nowadays two wind farm projects are under construction: 120MW Gulf of El Zayt3 and 250MW Gulf of Suez under a Build Own Operate (BOO) scheme [5].

III. WIND FARMS

When a good wind site is located, wind turbines are installed to form a wind farm or a wind park. Obvious advantages result from clustering wind turbines together at a windy site, namely:

- Reduce site development costs.
- Simplify connections to transmission lines.
- Centralized access for operation and maintenance.

Wind turbines located too close together will result in upwind turbines interfering with the wind received by those located downwind. Recommended spacing is 3 to 5 rotor diameters separating towers within a row and 5 to 9 diameters between rows [6]. More conservative approaches suggest that the optimum spacing shall be 8 to 12 rotor diameters apart in the wind direction, [7]. The offsetting, or staggering, of one row of towers behind another, is also common [8],[9].



The power output, P, from a wind turbine is given by the well-known expression:

$$P = \frac{1}{2} C_p \rho A V^3 \tag{1}$$

C_p is the power coefficient of the turbine, ρ is the density of air (1.225 kg/m^3), A is the rotor swept area and V is the wind speed.

This equation shows that doubling of the rotor diameter leads to four times increase in power output, while doubling the wind speed leads to an eight-fold increase in power. Thus, wind farms are developed in areas of the highest wind speeds furthermore, extremely high towers are being used (more than 60–80 m) to take advantage of the increase of wind speed with height [10].

The average power in the wind is given by:

$$P_{avg} = \left(\frac{1}{2} \rho A v^3 \right)_{avg} = \frac{1}{2} \rho A (v^3)_{avg} \tag{2}$$

The average wind speed can be given by:

$$v_{avg} = \sum_i [v_i \cdot \text{probability}(v = v_i)] \tag{3}$$

Similarly,

$$(v^3)_{avg} = \sum_i [v_i^3 \cdot \text{probability}(v = v_i)] \tag{4}$$

It's a common procedure to measure values of average wind speed using an anemometer located 10 m above the ground are used to estimate average wind speed and wind power density (W/m^2) at a height 50 m above the ground.

If measured site wind speed data is available, then the energy yield of a wind turbine can be estimated by combining the wind speed distribution with the power curve:

$$E = \sum_{i=1}^n P(V_i) H(V_i) \tag{5}$$

$P(V_i)$ is the power output of the wind turbine at wind speed V_i , $H(V_i)$ is the number of hours in wind speed bin V_i and there are n wind bins. $P(V_i)$ is obtained from the power curve of the turbine which is a plot of the output power from the turbine versus the wind speed. Power curves are provided by turbine manufacturers.

a. DEVELOPMENT OF WIND FARMS

The development of wind farm has many cost factors such as site preparation, access roads, connection to electric grid, etc., the most expensive element is the wind turbines themselves, which is mostly more than 50% of the project cost. It is preferable to construct a large wind farm to spread the fixed costs such as, electrical network connection and project development, over a bigger investment. The main elements of wind farm development are the technical and commercial issues, environment considerations and consultation. *The phases of a Wind farm project include:*

- 1- Initial site selection
- 2- Project feasibility assessment
- 3- Preparation and planning application
- 4- Construction
- 5- Operation
- 6- Decommissioning and land reinstatement

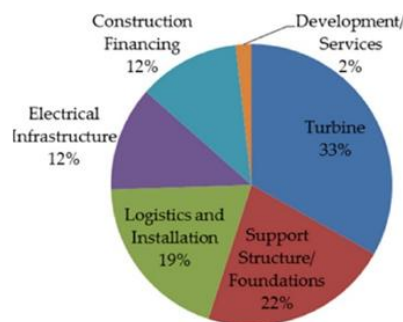


Fig.2. Wind farm plant capital cost breakdown [11]



b. WIND FARM SITE SELECTION

Wind generators are feasible if wind speed is 4.5 m/s or greater. An ideal location would have a near constant flow of non-turbulent wind throughout the year with a minimum likelihood of sudden powerful bursts of wind. Usually, sites are preselected on basis of wind measurement. It is also necessary to confirm that access roads are available or can be developed at reasonable cost to allow for the transportation of the turbines, blades and other equipment such as the main transformer which is the heaviest piece of equipment in large wind farm.

Another important factor affecting the location of wind farms is the accessibility to local demand and/or transmission networks. The ground conditions at the site also need to be investigated to ensure that the turbine foundations, access roads and other structures can be provided and maintained at reasonable cost. Other considerations on wind farm site selection include visual and landscape assessment, noise assessment, interference with telecommunication systems and radars, and ecological assessment [12]

IV. GEOGRAPHIC INFORMATION SYSTEMS GIS

A geographic information system GIS is a method for gathering geographical context and process relevant data into layers. These information layers reveal patterns and relations between all types of used data. GIS integrates hardware, software, and data to capture, manage, analyze, and display all forms of geographically referenced information [13]. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, reports, and charts.

GIS technology can be integrated into any enterprise information system framework. GIS is a powerful tool to help in the deployment of wind energy projects due to its complex spatial analysis which is useful for determining renewable energy potential, studying environmental impact, and site feasibility [14].

GIS convert the wind data into NetCDF (network Common Data Form) file format for storing multidimensional scientific data (variables) such as temperature, humidity, pressure, wind speed, and direction. Each of these variables can be displayed through a dimension (such as time or distance) in ArcGIS by creating a layer or table view from the NetCDF file.

a. GIS FOR WIND POTENTIAL ANALYSIS

GIS software is utilized to import and display wind resource data, which indicates optimum wind availability in the area of interest. GIS can clearly display property ownership, public land, community boundaries, transmission line availability and capacity for power transmission and distribution planning. After a wind farm has been constructed, GIS can provide project managers with infrastructure monitoring and transmission line connection status.

A topographic map and 3-D terrain model will quickly highlight the optimal site for turbine placement and help expose obstructions to the prevailing wind. Wind power can be classified into wind power density classes ranging from poor to excellent.

Environmental compliance is critical for wind energy project development. Developers must take into account aviation and bird migratory patterns, wetland or other environmentally vulnerable areas, cumulative turbine noise potential and visual impact. GIS can display and present these data layers for public review and community outreach. [15].

The life of a wind farm project starts with a look at potential plots of land. Most developers require land within a prescribed distance of a transmission line to tie in power to the grid. If the wind is strong and steady, developers may decide to build their own transmission line. By loading utility data into the GIS, researchers can quickly see existing transmission routes and estimate the benefits of accessing existing electric lines.

Another important consideration for developers is land ownership. State and county land-use data in the GIS identifies areas under development restrictions from the Land Management Authority and those requiring right-of-way grants. If land is privately owned, developers will have to obtain consent from individual landowners.

A layer of constraints is added, marking areas that are environmentally protected for migratory flight paths or another animal activity. Other site restrictions are military bases and airports where developers must consider radar interference and Aviation Administration regulations.

Wind data is essential to researchers, who add a resource layer to GIS detailing wind speed and reliability. In addition to site research, meteorologists use wind data stored in GIS Server to help design the layout of a wind farm by identifying wind direction, strength, and location.



b. DEVELOPMENT OF GIS MODEL

A detailed wind atlas for the Gulf of Suez region was issued in 2003 with the aid of Denmark. In 2006, the wind atlas of Egypt was issued. It was found that about 20 GW of wind farms can be housed in the Gulf of Suez area, which is comparable to the most favorable regions in northwestern Europe.

Wind resource maps for any area in Egypt can be established using the regional wind climate statistics from the numerical wind atlas [16].

In this paper, the used Scales of digital maps are: 250k and the 50k. The 250k is used to cover the Nile River, Towns, Major electricity, Major roads, Contour lines, Governorates, and Wind speed. While the 50k is used to have more details for Main roads, Cities, and Urban areas.

A map projection is an essential component of any GIS which is a mathematical function transforming coordinates from a curved surface to a plane map. Since the Earth is roughly the shape of an oblate spheroid, map projections are necessary for creating maps of the Earth or parts of the Earth that are represented on a plane such as a piece of paper or a computer screen [17].

There are an infinite number of possible map projections, A fundamental projection classification is based on the type of projection surface onto which the globe is conceptually projected. These surfaces are cylindrical (e.g. Mercator), conic (e.g., Albers), or azimuthal or plane (e.g. stereographic).

Two coordinates' systems (projections) are used in the Wind Atlas: the usual geographic coordinates (latitude, longitude) and the Cartesian Universal Transverse Mercator (UTM) system. Both systems are referenced to the World Geodetic System 1984 (WGS 84) datum.

The work presented in this paper makes use of the following layers:

- 1- Wind speed
- 2- National electricity grid
- 3- Main roads
- 4- Land height
- 5- Urban areas
- 6- Airport locations
- 7- Historical places
- 8- Shore line
- 9- Nile river
- 10- Ports
- 11- Water network
- 12- Oil line
- 13- Petrol Tanks

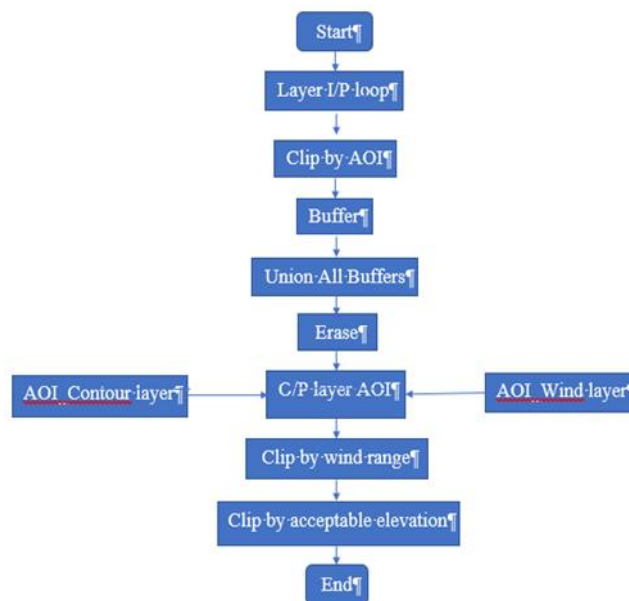


Figure (4): Flowchart of GIS work



c. PROCESSING GIS LAYERS

At first, Projection was made to give all layers the same geographic coordinate system, and the same projection type. in this study, the Mercator projection was utilized. A unified layer comprising the mosque layer, church layer, historical monuments layer, and landmarks layer was created and labeled as the Historical Places.

In this study, it was obvious that the Gulf of Suez area has the highest wind speed in Egypt. It was labeled “the area of interest (AOI)” and the AOI layer is created to clip all other layers of interest to optimize the processing time needed for running the script.

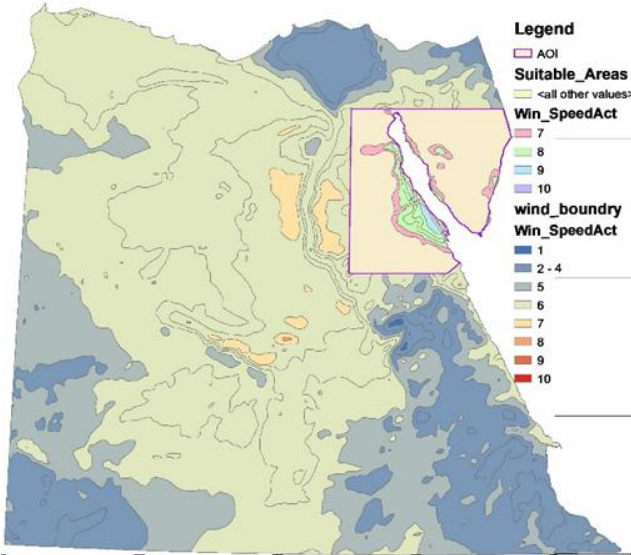


Figure (5): selecting the Area of Interest (AOI) layers.

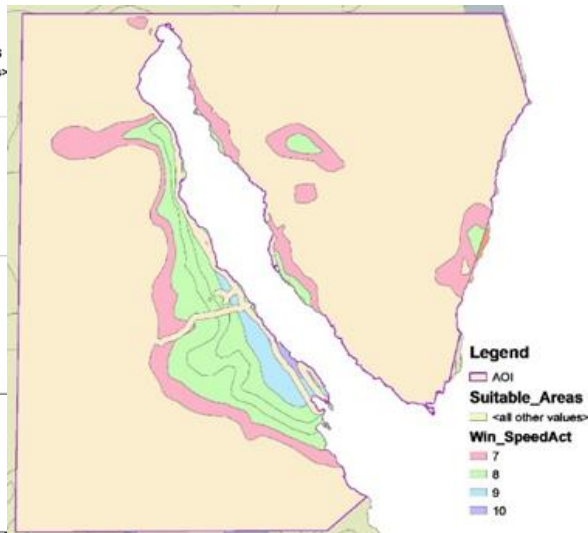


Figure (6): clipping the Area of Interest (AOI).

Buffering is creating of a zone of a specified width around a specific GIS object such as a point or a line or a polygon area. The buffer operation takes two parameters: a buffer distance and the object around which the buffer is to be created. The buffer distance changes for each layer, for example the buffer around the historical places is different from the buffer around the shoreline and so on.

For example, the proposed model has been set to preserve a buffer distance of 2000 m around oil pipeline objects and a buffer distance of 1000 m around: cities, liquid fuel tanks, airports, ports and historical Monuments.

all these buffers are then united to build a new layer named “All buffers layer” which is then subtracted from the AOI layer, to obtain the feasible areas for wind farm construction.



Figure (7): suitable sites in case of wind speed ≥ 7 m/s



Then the elimination sequence starts and proceeds as follows:

- 1- Selecting the sites at which the wind speed is appropriate for wind farms construction (wind speed \geq specific value).
- 2- Selecting the sites closer to the transmission network or load centers, ...
- 3- Selecting land plots where the height above mean sea level is between, e.g.;50 and 500 meters.
- 4- Saving the selected areas in a new layer (outputfeature class layer).
- 5- Rank the selected areas according to their fitness to the specified criteria.

V. ETAP MODEL CREATION

In addition of using GIS for wind farm site selection, the effect of a proposed wind farm connection to the unified grid has been studied using ETAP software regarding load flow and short circuit. ETAP is a convenient tool that can support engineers in monitoring power, managing energy, optimizing a system or automating certain processes.

ETAP offers a large array of tools for power system design. The designed project can be studied by performing load flow analysis, short-circuit analysis, harmonic analysis, transient stability analysis and others.

The model in the ETAP software was made for the eastern part of Egypt. In this model two wind farms were modeled to the electric network grid at Gabl Elzeit and Ras Ghareb wind farm. Each wind farm has 90 wind turbines, each turbine is rated 2 MW at 0.69 KV. A transformer steps up the output of each wind turbine to 220 KV. The total power in each wind farm is 180 MW.

The collection system is made up of 22 KV cables and connects a group of 30 turbines to a 75 MVA, 22/220 KV step up transformer. Each wind farm comprises 3 identical 75 MVA, 22/220 KV step up transformers.

Several static and dynamic power system studies need to be carried out to evaluate the impacts of new wind farms on the overall performance of the power system. This paper had addressed load flow and short circuit studies only as examples of power system studies related to wind farm planning.

The Egyptian unified is relatively complicated, thus a model was built for the Suez Canal zone only. The existing wind farms in ZAFARANA and the two proposed wind farms have been included to the model at machine level details.

a. POWER FLOW STUDY:

An analysis of the performance of power systems both in normal operating conditions and under fault (short-circuit) condition has been carried out before and after the addition of the proposed wind farms. A power flow study was made to the system before adding the wind farms, and the results is listed in table (1)

This study shows that an improvement must be made in Safaga and Hurgada voltages. Two wind farms added in Ras Ghareb and Gabl Elzeit and the power flow study was repeated, and the results is listed in table (2).

BUS ID	Voltage	Generated Power	
	U (KV)	P (MW)	Q (MVAr)
Zafrana1	227.425	184	-39.5
Zafrana2	227.35	130	-48.1
Safaga	204.829	60.2	-32.5
Hurgada	201.556	145.7	-86.5

Table (1): power flow without wind farm

BUS ID	Voltage	Generated Power	
	U (KV)	P (MW)	Q (MVAr)
Zafrana1	225.845	188	-39
Zafrana2	227.35	130	-47.4
Safaga	214.597	61.7	-33.3
Hurgada	213.571	150.4	-89.3
Gabl Elzeit	219.41	179.1	-9.9
Ras Gharib	221.975	179.1	-9.6

Table (2) : power flow with wind farm



It was noticeable that the cities of (Safaga and Hurgada) benefited from the added wind farms in terms of voltage drop improvement. Hurgada and Safaga had normal operation voltage drops of 7%, 8.6% respectively. Introducing the proposed wind farms resulted in a considerable enhancement to a 4.5% normal operation voltage drop in both cities.

b. FAULT STUDY:

A short circuit study is required to ensure personnel and equipment are protected by establishing proper interrupting ratings. When an electrical fault exceeds the interruption rating of the protective device, the consequences can be devastating, including injury, damaged electrical equipment, and costly downtime.

Wind farms connected to the transmission network must ride through three-phase as well as unbalanced short-circuit faults and local wind turbines connected to the distribution networks which could disconnect in case of a grid fault.

A fault study was made to measure the short circuit current in case of a duty fault without adding the wind farms. The observations of this study declared that:

S.C current is 21.7 KA at Zafarana1, 20.2 KA at Zafarana2, 7 KA at Safaga, and 6 KA at Hurgada. All of these values are within the breaking capacity of installed C.B (25KA)

The study was repeated with added wind farms to decide if there is a need for circuit breaker replacement. The new study results was:

S.C current at Zafarana1 is 24.5 KA, at Zafarana2 is 23.2 KA, at Safaga 9.6 KA, Hurgada 9.6 KA, Gabl Elzeit 10.2 KA, and 10.8 KA at Ras Gharib. all the system values are within the breaking capacity of installed circuit breakers (25KA). Although the short circuit level had slightly increased at nearby substations after adding the wind farms but still no need to carry out any circuit breaker replacements at the substations.

VI. CONCLUSION

Egypt has the opportunity to step up to the future by using wind, solar and nuclear energy. Egypt has already issued the national wind atlas. Locating the right site for constructing a wind farm can be done quickly and accurately with publicly available data and GIS technology. Geographic information systems (GIS) provide a quantum leap in efficiency organize and analyze data to ascertain the answers needed for informed decision making and comprehensive research. GIS enables wind farm planners to reach the goal of finding the best wind areas while causing as little impact as possible to wildlife and environment.

Similar to any other power plant, power system studies are carried out to evaluate the impacts of new wind farms on the overall performance of the power system. This paper has addressed load flow and short circuit studies only as examples of power system studies related to wind farm planning. ETAP model was built for the Suez Canal zone transmission network. ArcView GIS has been applied successfully to identify suitable wind farm locations. ETAP has been applied to verify the connectivity of wind farms to power system through power flow and short circuit studies.

REFERENCES

- [1] <https://wwindea.org/wind-power-capacity-worldwide-reaches-600-gw-539-gw-added-in-2018>, World Wind Energy Association WWEA, "2019 report", Germany, 2019
- [2] Wiser R., Bolinger M., Berkeley L., U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy EERE, "2017 wind technologies market report", 2018
- [3] <https://wwindea.org/worldwide-wind-capacity-reaches-744-gigawatts/>, WWEA World Wind Energy Association, "Worldwide Wind Capacity Reaches 744 Gigawatts – An Unprecedented 93 Gigawatts added in 2020", Germany, 2021
- [4] Renewable Now REN21, "Renewables 2020 Global Status Report GSR", France, ISBN 978-3-948393-00-7, 2020
- [5] National Renewable Energy Authority, "NREA Annual Report", Egypt, 2018
- [6] Patel, Mukund R., "Wind and Solar Power Systems Design, Analysis, and Operation", Taylor & Francis, 3rd edition, ISBN-10: 0367476932, ISBN-13: 978-0367476939, 2021
- [7] Masters, Gilbert M., "Renewable and Efficient Electric Power Systems", John Wiley & Sons, Inc., Hoboken, New Jersey, 2nd edition, ISBN-13: 978-1118140628, 2013
- [8] Milborrow, D. J. and Surman, "Status of wake and array loss research", P. L. Palm Springs, CA, AWEA Windpower 91 Conference, 1987
- [9] Grubb, M. J. and Meyer, N. I., "Wind Energy Resources, Systems, and Regional Strategies", Washington, D.C., Island Press, 1993
- [10] Tony Burton, Nick Jenkins, David Sharpe and Ervin Bossanyi, "WIND ENERGY HANDBOOK", 2nd Edition,



John Wiley & Sons, Ltd, United Kingdom, ISBN: 978-0-470-69975-1, 2011

- [11] Dang Ahn, Sung-chu shin, Soo-young Kim, Hicham Kharoufi, Hyun-cheol Kim, “Comparative evaluation of different offshore wind turbine installation vessels for Korean west–south wind farm”, International Journal of Naval Architecture and Ocean Engineering, vol. 9, no. 1, pp. 45-54, 2017
- [12] Tetra Tech EC Inc., Nixon Preabody LLP, “Wind Energy Sitting Handbook”, American wind energy association (AWEA), 2008
- [13] A. M. Bazzi and D. A. Fares, “GIS-based wind farm site selection in Lebanon”, 2008 IEEE International Conference on Electro/Information Technology, pp. 201-204, doi: 10.1109/EIT.2008.4554296, 2008
- [14] Almoataz Y. Abdelaziz, Said F. Mekhamer, Amany B. Mohamed, “Geographic Information Systems (GIS) Application in Wind Farm Planning”, The Online Journal on Power and Energy Engineering (OJPEE), Vol. (3) – No. (2), Reference Number: W11-0105,2012
- [15] D. L. Elliott, “Assessing the Worlds Wind Resources”, IEEE Power Engineering Review, Vol. 22, No. 9, pp. 4-9, 2002.
- [16] Egyptian New and Renewable Energy Authority NREA, Egyptian Meteorological Authority EMA, Risø National Laboratory, “Wind Atlas of Egypt”, ISBN 87-550-3493-4, 2006
- [17] Environmental Systems Research Institute ESRI, “ArcGIS – Using ArcGIS Desktop”, ESRI, 2020



INNO  **SPACE**
SJIF Scientific Journal Impact Factor

Impact Factor:
7.512

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 **9940 572 462**  **6381 907 438**  **ijirset@gmail.com**



www.ijirset.com

Scan to save the contact details