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# Assessment of renewable energy generation in terms of small signals stability

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**Abstract:** All countries of the world tend to use Renewable Energy Source (RES) more broadly as countries are shifting to cleaner forms of energy. The Egyptian Electricity Holding Company (EEHC) is interest in increasing electricity production from the RES, which requires many studies to keep the energy system safe and stable. In this paper, a framework is propos to examine renewable energy generation scenarios to confirm stability of power system network. The scenario screening framework relies on sensitivity of the system Eigen values with respect to penetration of renewable energy into the energy system grid. The model created by DigSILENT software.
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**Keywords:** Dig SILENT, modelling, simulation.

## 1. Introduction

As the safe global warming limit has changed from 2 to 1.5 °C above pre-industrial levels [1], tightened policies and procedures from governments around the world are expect to be passed to eradicate $CO_2$ emissions and to shift fully to RES [2]. Because of the heightened interest in integrating RES such as wind and solar energy in the power system, the need for integration studies of these RES also increases. This is because of the intermittent nature associated with RES. A secure power system should be able to maintain stability. Even with fluctuating RES output and be able to withstand the resulting contingencies or disruptions.

EEHC aims at increasing electricity production from RES in a wider range. Available renewable sources of energy have been study and used in future plans of the company. The future plan of EEHC proposes an increase in RES to 20% in 2022 [3-9]. The increase of RES represents a major challenge for the Egyptian energy system. The thermal stations are replacing to RES. It is through different operating scenarios, while total generation power of the network is constant. This replacement increases the frequency deviation of the system. It also exposes the network to instability [10].

In order to describe the small-signal stability of the power system for RES generation scenarios, eigenvalues of the power system must be checked. If an eigenvalue is found at the right-half of the complex plane, the system is unstable [11–13]. Different methods used to simulate the power station scheduling for representing and studying the frequency deviation [14–20].

Wind stations were built in zones away from the loading center (400-600 km). The network must be upgraded to improve its electrical behavior [21, 22]. The new transformers and transmission lines must be installed to transfer the energy from wind stations to the load areas [23].

This paper presents a framework for screening of RES generation scenarios in terms of the frequency deviation and small-signal stability of the Egyptian network. It based on eigenvalue sensitivity with respect to RES generation. This is through three scenarios are increasing RES percentage to 10 %, 15% and 20 % at 2019, 2020 and 2022 respectively. It provides proposals for upgrading the network to improve the electrical behavior with connect RES [24].

## 2. Overview of the Egyptian network system

The Egyptian network has many areas according to the geographical location, as shown in Fig. 1. Each area has generation stations, transmission lines (500kv, 220kv and 132kv) and transformers substation (500/220kv, 500/132kv and 220/132kv) [5, 6]. The thermal stations occupy the first space in power generation of the Egyptian network, as they represent 90% of the generated energy. Fig. 2 shows the power generation rates of the Egyptian network [5].

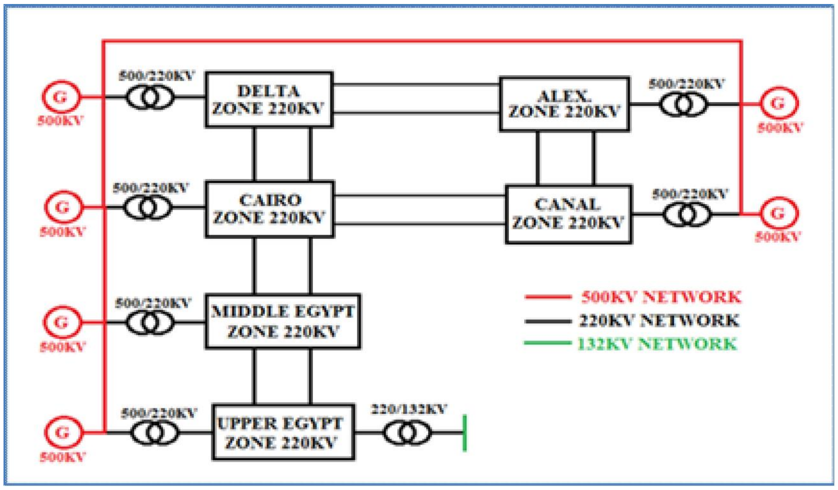



Fig. 1. Egypt Network (500kv, 220kv and 132kv)

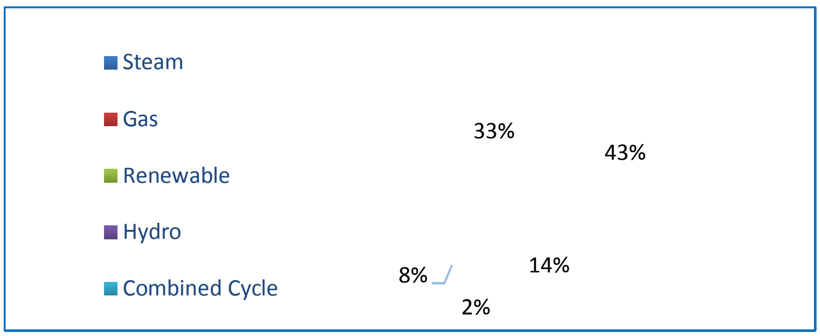



Fig. 2. Generation Rates of Egypt Network

The EEHC strategy based on the diversification of energy sources and increasing electricity production from RES. The renewable energy production reached 750 MW in 2016. The future plan of EEHC is build the renewable power generation at the Suez Gulf, Menia and Beni Suef. The wind power plant (WP) full capacity will be 12% (7200 MW) in 2022 [25]. The photovoltaic power plant (PV) full capacity will be 3500 MW in 2027 [4-8]. The RES full capacity in the network will reach 10 Gw at the end of 2022 [5]. Fig. 3 shows the production plan of RES.

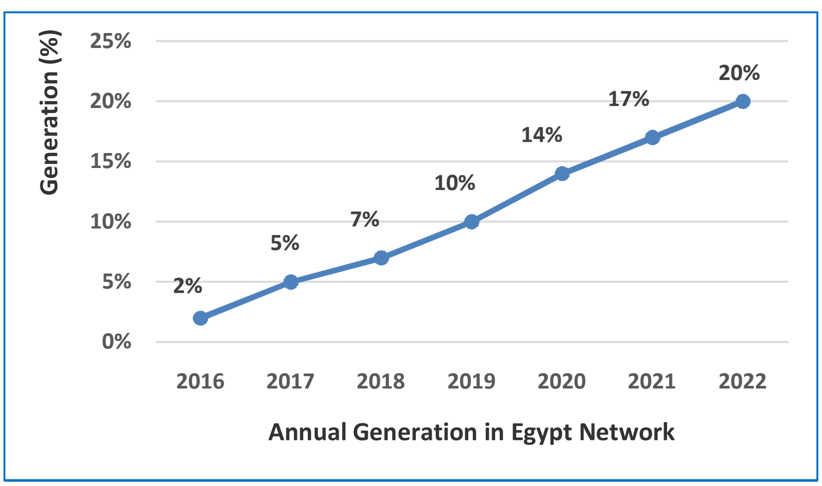



Fig. 3. The Production Strategy of RES in Egypt

## 3. Detailed View of the Egyptian Network Model

The model created by the DigSILENT software [26]. It consists of generators, loads, transmission lines and transformers for (500kv, 220kv) Egyptian network system. Each generation station represented by a model frame (composite model). Fig. 4 shown composite model block diagram, it includes excitation, governor, turbine and in/out signals [27].

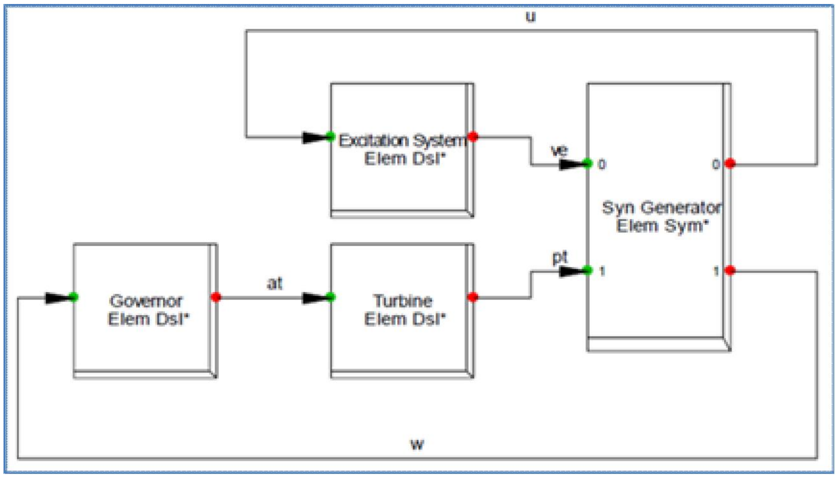



Fig. 4. Block Diagram of Composite Model

The power balance block diagram of Egyptian network shown in Fig. 5. It consists of all power plants (gas power plants (GPP), steam power plant (SPP), combined cycle power plant (CCPP), hydropower plants (HPP) and renewable energy (PV and WP)) [28- 34].

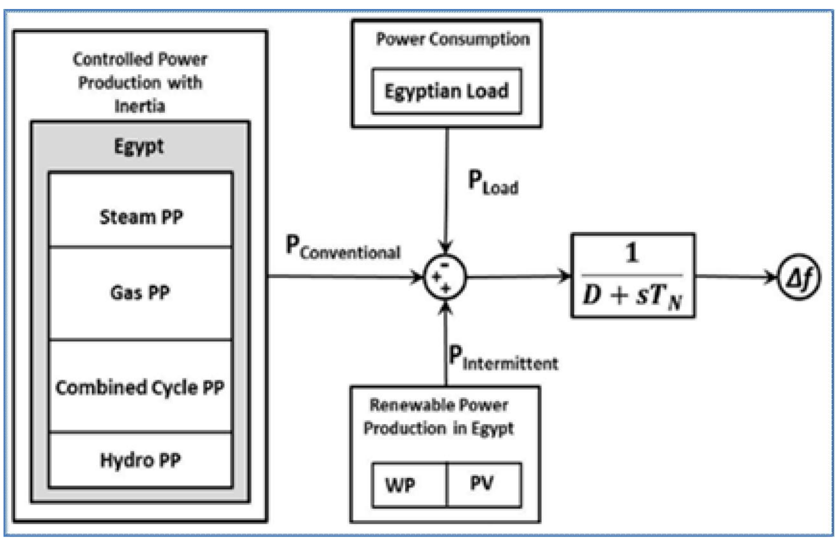



Fig. 5. Block Diagram of Power Balance for Egyptian Network

The frequency deviation Δf depends on load damping constant (D) and acceleration time constant (TN) of the network [27, 28]. The inertia is very important in electrical energy system, since it is responsible for stabilizing the system frequency within the first moment after disturbance [35]. The total inertia can be calculated as follows;

$$T_N = \frac{\sum_{i=1}^{n} T_{G_i} P_{G_i}}{\sum_{i=1}^{n} P_{G_i} + P_{RES}} \quad (1)$$

$$T_{G_i} = \frac{J\Omega_N^2}{P_{G_i}} \quad (2)$$

Where;

Δf Frequency Deviation

| | |
|---|---|
| $P_{Load}$ | Power of Load |
| $P_{conventional}$ | Power of Conventional Plants |
| $P_{intermittent}$ | Power of RES Plants (WP and PV) |
| $T_{Gi}$ | Acceleration Time Constant of Each Generation Unit |
| $P_{Gi}$ | Power of Each Generation Unit |
| J | Moment of Inertia |
| $\Omega_N$ | Angular Velocity |

The wind turbine in the Egyptian wind farms is doubly fed induction machine (DFIM) as shown in Fig. 6 [36]. All data of DFIM is related to actual turbine in network. The type of turbine is (G80-2 MW) [5, 37].

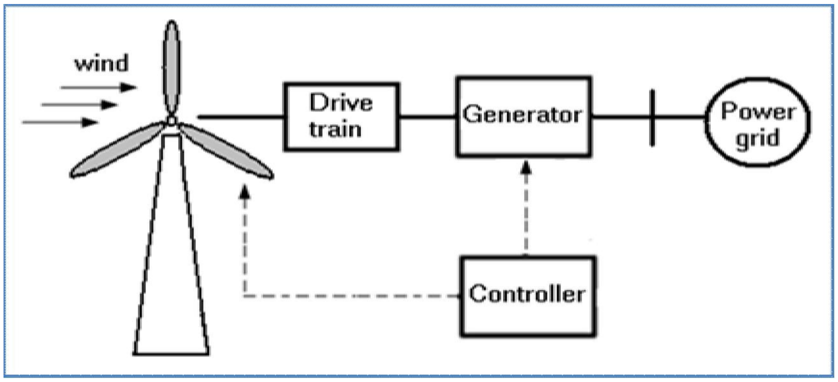



Fig. 6. Block Diagram of (DFIM) Wind Turbine

Fig. 7 shows how to use the eigenvalue sensitivity for check RES scenarios. The blue circles represent places of critical eigenvalues. The critical eigenvalues expressed by eigenvalues with the lowest damping ratios or eigenvalues with the largest real parts. The dashed line determines the margin of the damping ratio, so the values after it represent critical eigenvalues. While applying many scenarios to the system, some eigenvalues may exceed the imaginary axis. If the eigenvalues are found on the right side of the complex plane, the system is unstable for that scenario [38].

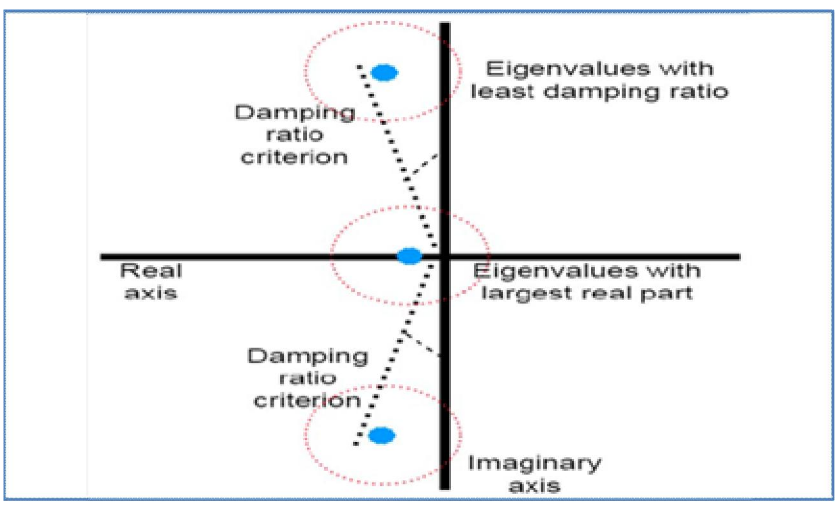



Fig. 7. Scenario screening framework based on eigenvalue sensitivity

## 4. Simulation Results and Analysis

The study is based on replacing the thermal stations with RES through three scenarios. The result of each scenario compared with the basic case of network (2015 - Egyptian network). Scenarios will be presented as shown in Fig. 8 [4].

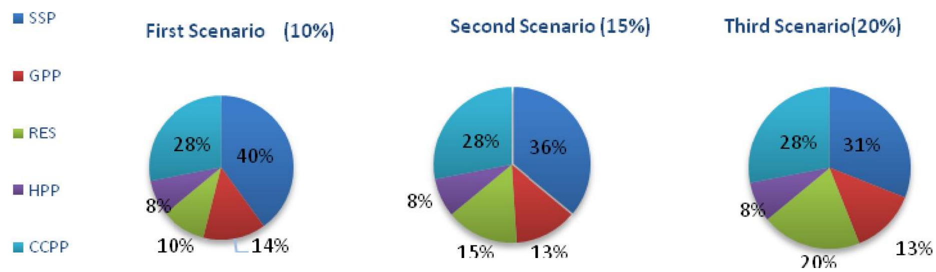



Fig. 8. Operation Scenario

Simulation of three scenarios applied on the Egyptian network at 2015. Selection of separating thermal stations depends on the life and the dilapidated stations. Table No. 1 shows the thermal plants stopped and replaced by RES. The total capacity is 4271 MW of the separation thermal plants.

Table 1 Separation thermal Power Plants

| **Gen. No.** | **Gen. Name** | **Cap. (MW)** | **V (KV)** | **Zone** |
|---|---|---|---|---|
| G117,118 | WALIDIA | 406 | 220 | Upper & Middle Egypt |
| G209:212 | SHOB-KH | 800 | 220 | Cairo |
| G220:224 | CAIRO-S | 180 | 220 | Cairo |
| G305 | SIDI KRIR | 221 | 220 | Alexandria |
| G309:313 | A-KIR | 583 | 220 | Alexandria |
| G314 | MATROUH | 43 | 220 | Alexandria |
| G401:404 | K-DAWAR | 432 | 220 | Delta |
| G406:408 | DAMANHOUR | 174 | 220 | Delta |
| G411:415 | DAMANH-W | 134 | 220 | Delta |
| G423:434 | TALKHA | 266 | 220 | Delta |
| G442:449 | MAHMUDIYAH | 224 | 220 | Delta |
| G515,516 | A-SULTAN | 240 | 220 | Canal |
| G519,520 | ATAKA-GEN | 202 | 220 | Canal |
| G525,526 | PORSAID BOOT | 366 | 220 | Canal |

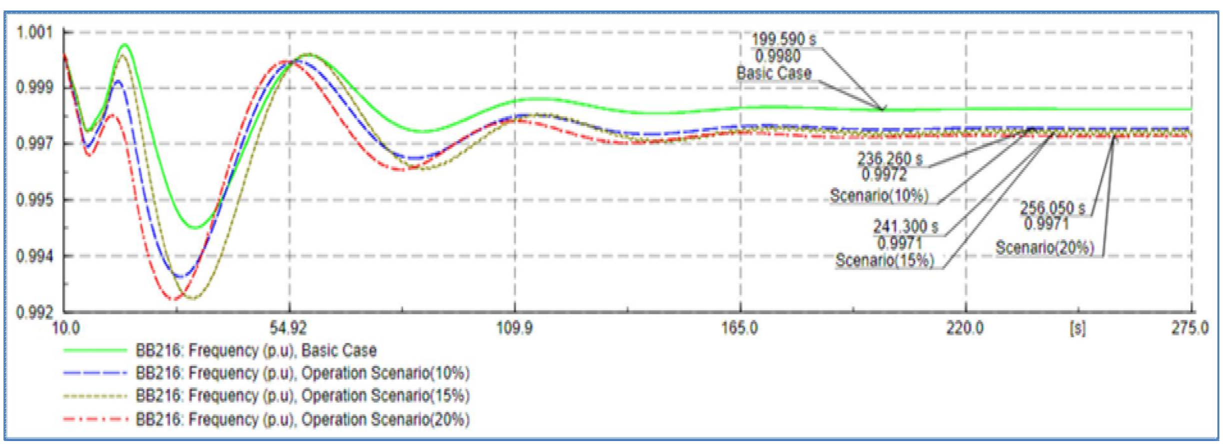



Fig. 9. Frequency of Three Scenarios

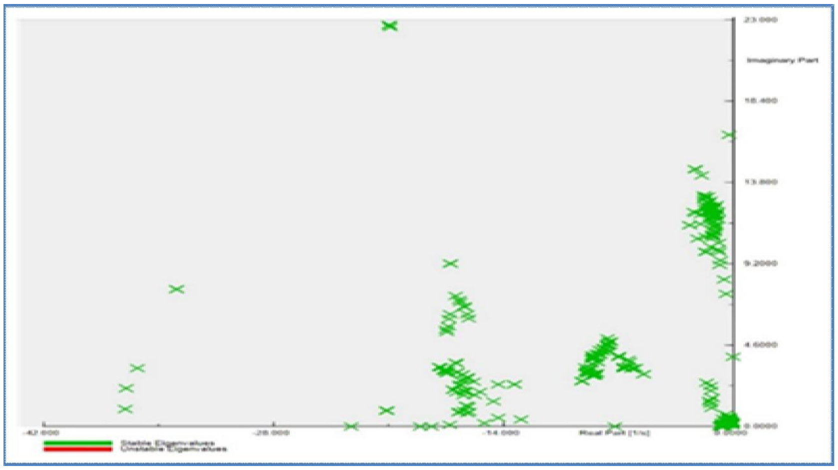
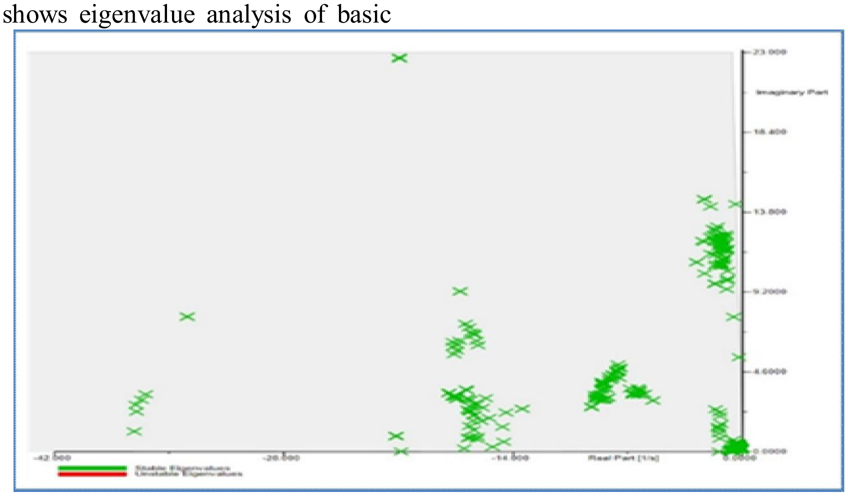
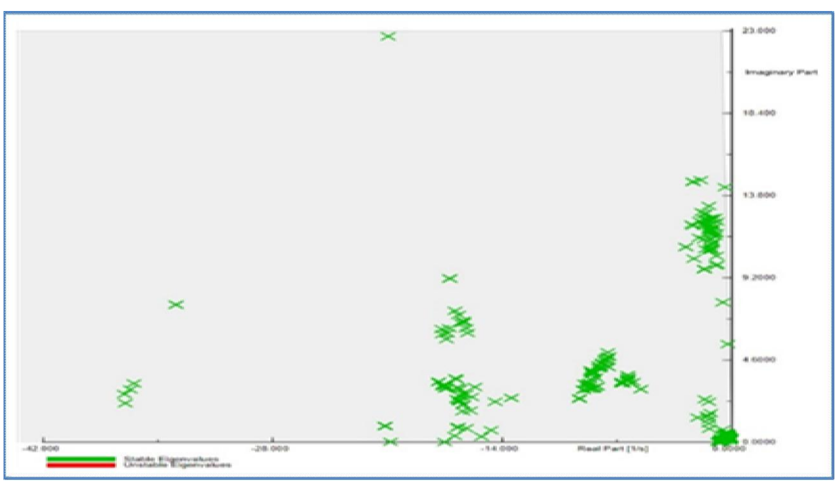



Fig. 10. Eigenvalue analysis of basic case

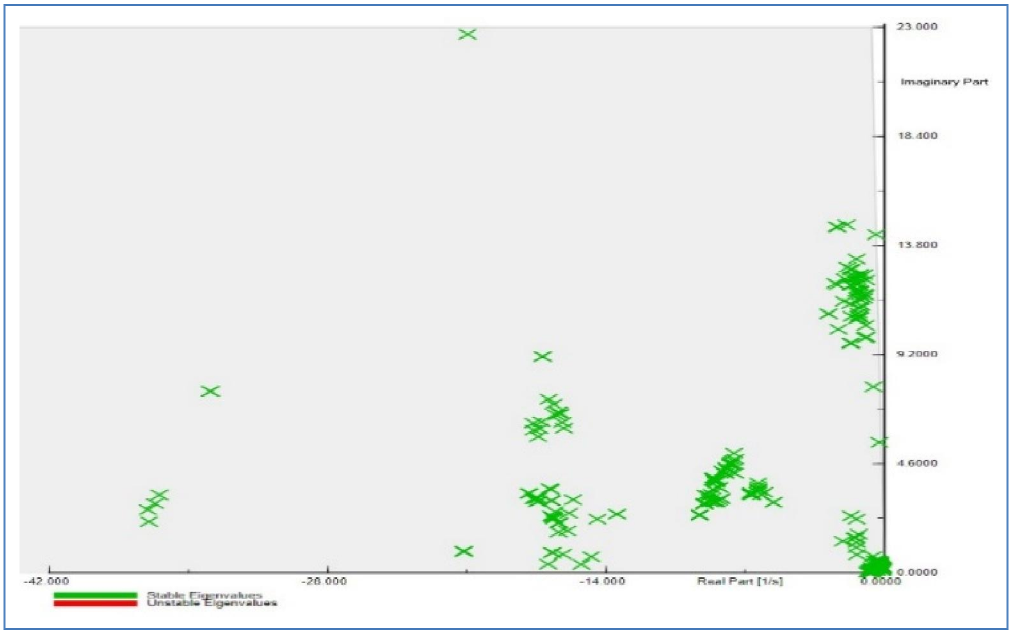
Fig. 9 shows comparison between the frequency (p.u.) of the basic case (0.998 p.u.) and first (0.9972 p.u.), second (0.9971 p.u.) and third (0.9971 p.u.) scenarios. Fig.10 shows eigenvalue analysis of basic case, the system had 4062 eigenvalues. Real eigenvalues were 2822 and the other 1240 were complex eigenvalues (620 complex eigenvalue pairs).




(a) First Scenario




(b) Second Scenario




(c) Third Scenario

Fig. 11. Eigenvalue Analysis of Three Scenarios

Table 2 Description of Egyptian Network Upgrade

| Description | Location |
|---|---|
| Add new transformers substations (500/220 KV) | Cairo, Delta and Canal zones, |
| Add new transformer substations (22/220 KV) | Suez Gulf, Gabal Elzeit, Menia and Beniswif areas |
| Increase the number of overhead transmission lines (500KV, 220 KV) | Assyut, Sikr-Kor, Tibben, Suez Boot, Sokhna, Nobaria, Wadi-H, Bassos, Heliopolis and Domiat |

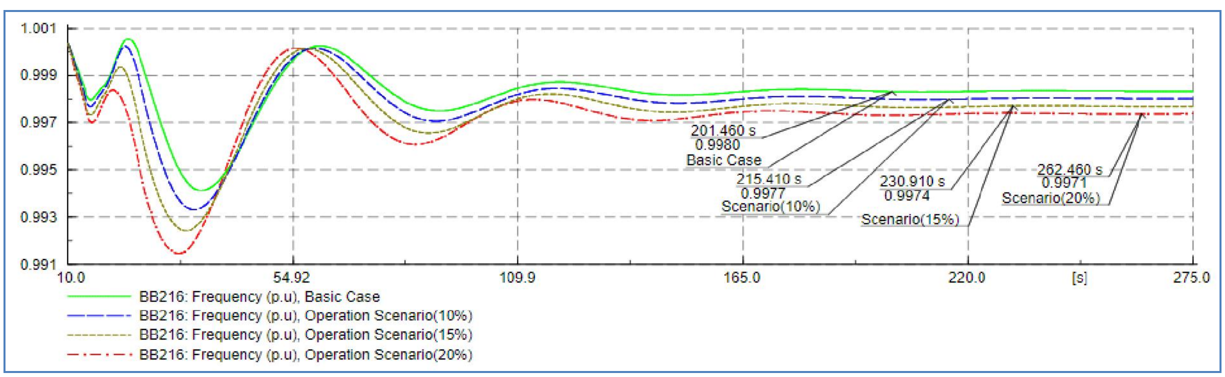
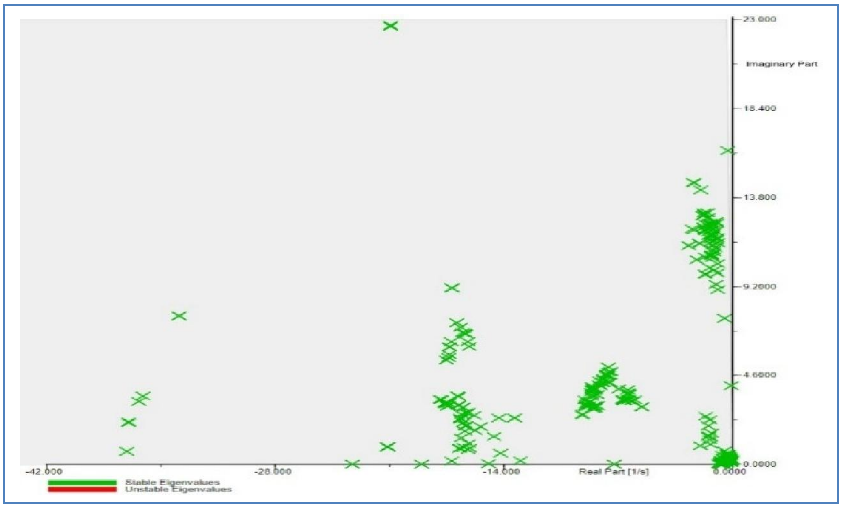


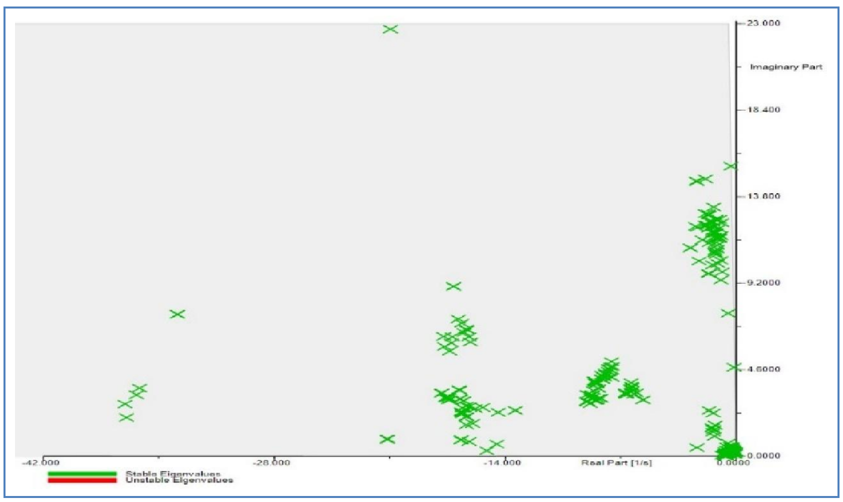

Fig. 12. Frequency of Three Scenarios After Upgrade Network

Table 3 comparison of the frequency deviation before and after the upgrade

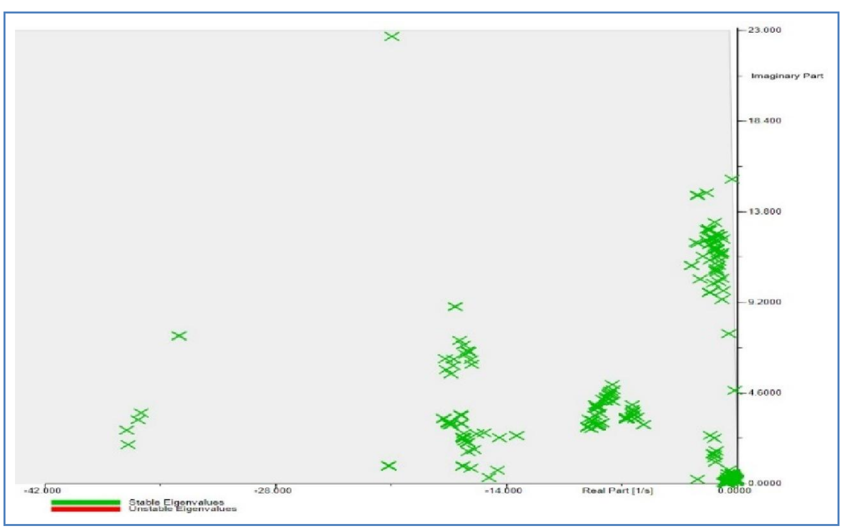
| Operation Case | | 1st- Scen. | 2nd- Scen. | 3rd- Scen. |
|---|---|---|---|---|
| Before upgrade | Freq. (p.u.) | 0.9972 | 0.9971 | 0.9971 |
| | Freq. Dev. (p.u.) | 0.0008 | 0.0009 | 0.0009 |
| After upgrade | Freq. (p.u.) | 0.9977 | 0.9974 | 0.9971 |
| | Freq. Dev. (p.u.) | 0.0003 | 0.0006 | 0.0009 |




(A) First Scenario




(B) Second Scenario




(C) Third Scenario

Fig. 13. Eigenvalue analysis of Three Scenarios After Upgrade Network

Fig.13 shows eigenvalue of three scenarios after upgrading the Egyptian network. The lowest damping ratio criterion, used to classify eigenvalues that are critical. If the damping ratio is less than or equal to 0.1 or 10% for complex eigenvalue, then the eigenvalue is critical. the real parts criterion, eigenvalues with real part greater than -0.10 considered critical eigenvalues. Table 4 is a comparison of the critical eigenvalue before and after the upgrade of Egyptian network.

After the network is upgraded, the frequency deviation for the first (10%) and second (15%) scenarios are reduced to 0.0006 p.u. and 0.0003 p.u. respectively. But there is no change in the third scenario (0.0009 p.u.). All scenarios were stable scenarios. The number of critical eigenvalue of first (10%), second (15%) and third (20%) scenarios are reduced by 11%, 9% and 11% respectively.

Table 4 comparison of the eigenvalue before and after the upgrade

| **Operation Case** | | **1st- Scen.** | **2nd- Scen.** | **3rd- Scen.** |
|---|---|---|---|---|
| Before upgrade | check the stability | stable | stable | stable |
| | no. of all eigenvalue | 3577 | 3198 | 3048 |
| | no. of critical real eigenvalue | 64 | 56 | 53 |
| | no. of critical complex eigenvalue | 52 | 32 | 30 |
| After upgrade | check the stability | stable | stable | stable |
| | no. of all eigenvalue | 3577 | 3198 | 3048 |
| | no. of critical real eigenvalue | 57 | 50 | 46 |
| | no. of critical complex eigenvalue | 36 | 30 | 28 |

## 5. Conclusions

This paper presents examination of RES scenarios in terms of small signal stability and frequency deviation. The EEHC plan increases the RES ratio to 20% at 2022 by replacing the conventional station with RES, so that the total capacity reaches 4271 MW.

The plan applies during three scenarios. These scenarios increase the RES by 10%, 15% and 20% in 2019, 2020 and 2022, respectively. DIgSILENT used to prepare the Egyptian network model.

While applying the scenarios on the Egyptian network. The following elements are observing that the frequency deviation does not change, the network is stable at each scenario, and increasing the load ratio of network components. So, it should be upgraded the network, to improve all previous elements.

The network upgrade led to the frequency deviation is less, the network is more stable. The number of critical eigenvalues is reducing to 11%, 9% and 11%. for first, second and third scenarios respectively. It is recommended to increase the RES to 20%, the networked should be upgraded to keep the frequency deviation and stability of network.

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