Renewable Energy Technologies as Distribution Generation and its Effect on Electrical Distribution System in a Semi Desert Area

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Abstract. This paper focuses on renewable energy generated generation (DG) systems that will satisfy the operational requirement in different cases. The global need for a sustainable energy system is becoming very important over the next few years due to the recent attention on conventional energy resources such as fossil fuels which have effects on the environment. The renewable energy technologies such as solar energy systems are becoming more critical energy technology of the generation system. However, selecting optimal sites for DG systems depends on the local conditions and potential of renewable energy. In this work, a semi-desert area network of Libyan electrical distribution systems has been chosen as a case study. The objectives of this work are to observe the effects of DG systems in an electrical distribution system and also to present its different performance levels. Furthermore, this paper presents the implementation of a Newton Raphson method using NEPLAN software to analyze the transition and the use of sub-transmission networks, interconnecting the DG units for a semi-desert area in Libya. The simulation results are analyzed and discussed to make a suggestion for adapting this method in using the sub-transmission networks to interconnect the DG systems.

Keywords: Renewable Energy Systems (RES), Distributed Generation (DG), Electrical Distribution System, Libya, Semi Desert Area, Solar Energy, Photovoltaic (PV).

1 Introduction

Nowadays, the evolution of the electric power industry undergoes indispensable changes and challenges throughout the world. Significant carbon emission increase in the atmosphere due to high demand of generated energy by fossil fuel resources (e.g. natural gas and crude oil) which cause environmental concern such as the global warming is resulting to the significant increase of the carbon emission to the atmosphere. According to prediction, the energy consumption will increase throughout the world rising to 37 kilo-terawatt hours in 2030 [1]. As a result, many countries have accepted based on the Kyoto protocol to reduce 50% of the greenhouse emission by 2050. Furthermore, high world economic development and exponential population growth cause a high increase in demand for energy which leads to the shortage of energy and increase the greenhouse gas emission in the atmosphere [2]. Achieving solution for the mentioned problems that presently the energy sector over the world needs long term planning actions for shifting the power generation sector and electric power system for more sustainable system by increasing the generation from renewable energy sources (RESs) such as photovoltaic (PV) systems and wind in the form of distributed generations (DGs) [3]. Distributed generation (DG) is an important system in the electric power system infrastructure and market. It is an electrical power source that is linked right to the distribution network or customer on-site. Also according to [4], DG is simply defined as a small-scale electricity generation. Furthermore, different agencies define the DG system differently. But according to the International energy agency (IEA) distributed generation is a generation plant that supplies power to customers' premises or to the grid at the distribution level [5]. International council on the large electric system (ICLE) defines DG as an electric power generation that is less than 100 MW in which the system is not planned to be centralled or dispatched, but is simply linked to the distribution network or customers on-site. However, the electric power research institute (EPRI) looked at it the other way round as electric power generation ranging from few kilowatts to 50 MW [6]. There are several types of DG systems available in the market such as photovoltaic, wind turbines, internal combustion engines, combustion turbines, microturbines, and fuel cells, among others [7].

Distributed generation (DG) may encounter technical and safety problems during integration into other distribution networks. The system is sensitive to increase fault currents, cause voltage oscillations, interfere with voltage-control processes, diminish or increase losses depending on the site location [8]. However, according to [9], there are limitations in determining the DG location. Studies have shown base on the existing index that DG can be more useful for the distribution networks. DG can also be allocated in the best optimum way to reduce power losses, improve reliability, power quality and the voltage profile the chances of connecting more distribution networks will increase [8]. As previously mentioned, the main limitations of DG during integration are the operational constraints such as thermal constraints and voltage constraints. The conventional “fit-and-forget” principle only accepts DG where there is no constraint violation under the worst-case condition which causes limitation in connecting the DG to the network as they are no longer passive[10]. The smart grid technology such as active network management (ANM) scheme can be developed to explore DG benefits which can address the weaknesses caused by the “fit-and-forget” principle. It is important to reshape the operation and planning strategies of the electricity distribution system to benefit from the potentials of the DG system. It has been indicated, in the future that a high increase in customer demands led may allow ANM to effectively and efficiently connect small and medium scale electric power sources. The distributed generation (DG) is commonly used as back-up power to improve network reliability. It can also be a means of put back investment in transmission and distribution networks, nullifies network charges, decreases line losses, delays construction of extensive generation facilities, replaces costly grid-supplied power, makes provision for alternative sources of supply in markets and provides environmental benefits [11].

In the Distribution Generation (DG) research, several critical features are left unsearched and unexplored which these areas require more specific study, even though, the DG system is presently assumed to be well researched. However, in this research, it was believed to be worthy to widely investigate the electrical distribution system in order to identify and discuss its reactivities. It is believed that this could result in achieving an optimum electrical distribution system. In this research, analysis and discussion of sub-transmission networks with the interconnection of DG units for a semi-desert area in Libya will be considered.

2 Solar Nature

Solar power can be a further form of renewable energy that agrees to the stochastic nature of solar irradiance. It is similar to wind energy, in which the only dissimilarity is that the generating systems absorb heat from the sun as a changeable resource to produce electrical energy for the grid. As it is important to understand the nature of solar power generation, it is equally essential to understand the characteristics of solar irradiance. The sun is defined as a spherical-shaped object that holds hot gaseous matter. To describe the properties of the sun, it has a diameter of 1.39 .109 mm and located at an average distance from the earth at 1.5 .1011 mm. Observing from the point of the earth of view, the rotation of the sun on its axis occurs once every four weeks, whereas observing from the equator and Polar Regions can take between 27 to 30 days for each rotation [12]. According to the properties of the sun, the body temperature can reach off to 5777 KK, while the inner core temperature is estimated at 8.106 KK to 40.106 KK, and have a density of 100 times to that of water [12]. It can be understood that the sun is specifically an energy source where the radiant energy is emitted by the process of fusion which occurs between hydrogen to form helium. The hydrogen contains four protons and one helium nucleus. Since mass is less than the four protons, it becomes lost in the reaction process leaving only energy behind [12]. This energy is generated from the internal area of the sun where the temperature differs to a large extent which is transmitted to the surface of the earth. The transfer of energy from the sun's core to the surface of the earth is called solar irradiance. It is also important to consider the location of the sun, time and day characteristics which described the relationship with the earth as to how much solar irradiance is transferred. This is to say, while the solar radiation is directly incident upon the equator of the earth, then the intensity of solar is high compared to the poles.

Solar irradiance defined solar energy transmitted from the sun core as the amount of electromagnetic radiation to the surface of the earth. In addition, the radiation is merely an interaction between complex energies of the sun reflecting upon the surface of the earth as well as the atmosphere surroundings. In another term, solar irradiance can be defined as the amount of heat intensity incident on the surface of the earth, whilst taking into account the spatial area and the time interval in which the heat intensity is incident upon. The reflected radiation is described as the sunlight that has been reflected off from the surface of the earth and into the atmosphere. The global radiation is also referred to as the total radiation combined with direct, diffuse and reflected components added together [13]. Solar irradiance is usually measured in [$W/m2$] or [k /$m2$]. The peak value of solar irradiance is the standard 1000 [$W/m2$] and solar constant is the average value of solar irradiance outside the earth’s atmosphere with a value of 1366 [$W/m2$] [14]. However, this means that solar irradiance is not always available from the sun as it differs significantly with respect to location, atmospheric conditions, time of day, etc. [15]. These factors could hinder or change the pattern of solar irradiance if they continue to occur at random. It is difficult to analyze the amount of solar radiance received by the earth's surface due to these factors. However, accurate estimation models have been predicted by three components to estimate the solar irradiance. These components are direct radiation, diffuse radiation, reflected radiation and global radiation. Direct radiation is defined as a straight beam of radiation reaching the earth's surface without any disturbances. Diffuse radiation is the scattering of molecules and particles due to the sunlight, which separates into the atmosphere but in time reaches back to the surface [13].

3 Photo-Voltaic Generators

PV (Photo-Voltaic) generators receive and store solar radiation from the sun as a variable resource. The solar energy coming from the sun are usually photons that energies electrons in the semiconductor device. This energizing effect creates a flow of electrical current that travels through a conductive medium and produces a voltage, putting into consideration the resistance levels [16]. Power generation utilizes solar flat plate panels composed of various cells due to the presence of the photo-voltaic to harvest the solar radiation and finally convert it to electrical energy. The cell types can use variations of solar panels such as Mono-crystalline solar panels, Polycrystalline solar panels and Amorphous solar panels [17]. The panels are different with respect to their efficiency, cost, and arrangement. Since solar energy is an important resource like wind energy, the amount of solar radiation received on a clear sunny day receives maximum power generation. On the other hand, receive no energy when there is the interference of rain or interruption of the cloud during the process of heat absorption. One of the main characteristics of solar PV technology that differ from the wind turbine generators is that PV generators having a higher longevity period around 25 years [16]. They have less maintenance and installation costs which make them an attractively ideal source of renewable energy systems. Figure 1 below shows the grid-connected PV system showing all the supportive components involved in the process. It is interesting to know how the configuration of solar panels can create a change within the system by introducing either series or parallel connected PV cells. However, the solar flat plate panels can normally produce as much as 12 to 24 volts [17].

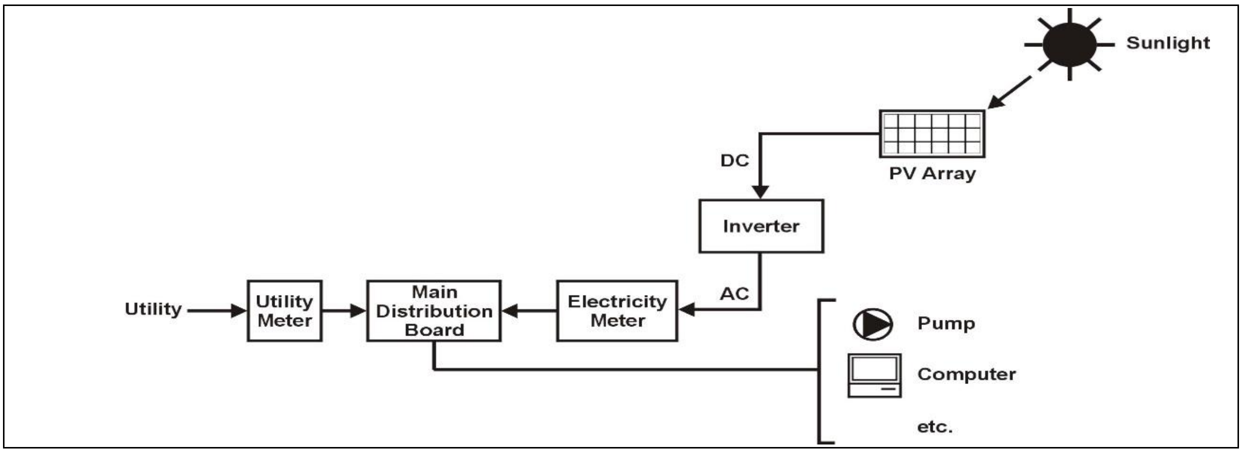

Figure 1: the grid-connected PV system [12][15]

4 Solar Power Curve and Energy Calculation

There is a need for understanding the characteristic curves in the design and implementation of PV modules. From the characteristics point of view, one can predict how much power can be provided by a PV module, specify the solar irradiance, approximate temperature of the PV panel as well as establishing maximum power operating point of the PV module [12]. Figure 2. below shows the P-V curve characteristics with the solar radiation at which the PV module operates.

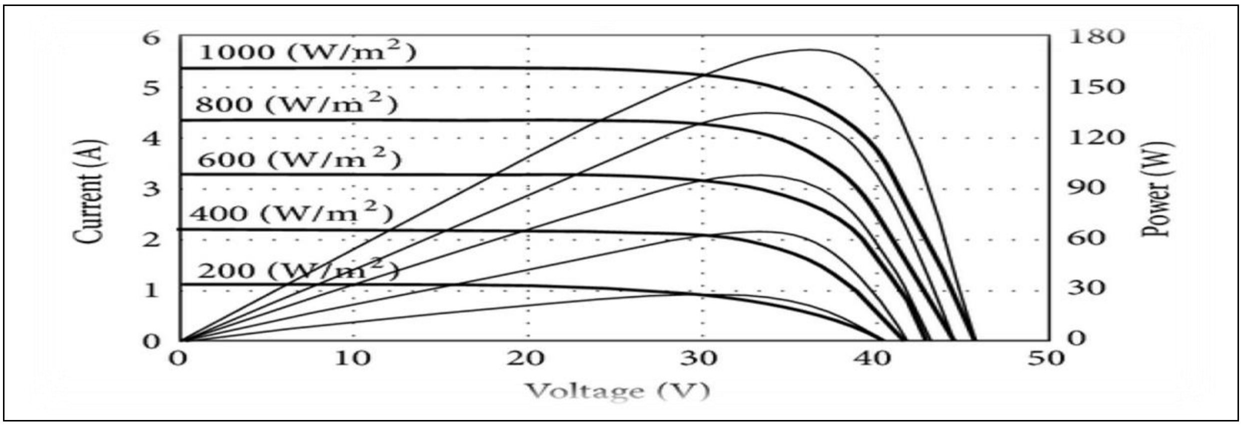

Figure 2: P-V curve characteristics with the solar radiation

5 Case study

The main idea behind this study is to use a renewable energy source, especially photovoltaic as the distribution generation (DG) in the southern area of Libya. The south area of Libya is a semi-desert area and the irradiation was in large where Samno or Samnu network is located. To show the effects and the impacts of applying DG systems to the semi-desert area of southern Libya, Samno 220/66 KV substation is considered. The DG units are also considered to be a renewable energy source such that solar radiation is very high. The sub-station of Samno (220/66) KV is fed from the Libyan local grid and suffers low voltage profile during the peak period and high radiation of reactive power as a result of high reactive loads in the area. Figure 3 shows the 66kv network that feeds from 220KV bus through three (220/66) KV transformers of 63 MVA size each. The main busbar of Samno 66 KV feeds 10 busbars through the 66KV transmission system, as indicated on the network design. This network will be analyzed using power flowing (PF) and optimal power flow program (OPF) using different operation scenarios at peak loading time and at different PVDG penetration ratios. Finally, in this work, the case study will be analyzed, simulated and discusse the network in normal operation, optimal operation, Samno connected together and Samno optimal isolated. Then Irradiation Curve with the daily load curve will also be presented in detail. Samno Location, as shown in Figure 8, Samno is a town located in a Saharan oasis, where the Tamanhint Airport is nearest Libyan airport. It is located about 800 km southwest of Tripoli in the desert region, its geographical coordinates are: 27 16' 00" latitude north and 14 54' 00" longitude east. Note, some online websites translate Samno world from Arabic to other languages as Samnu, which ends by U latter. And please keep in mind that the busbars are with red color instead of green color that will be shown in the figures mean that the voltages at the load end are still low.

5.1 Normal Operation:

In this case, the network is operating as a steady-state, and there is a Ten Distribution Substation connecting to the Samno network 220KV. These substations are (Samno, Temenhent A, Temenhent B, Temenhent City, Alshareet, New Sabha, Samno City, Aledaha, North Sabha 1, Alhejara), as shown in Figure 3 below.

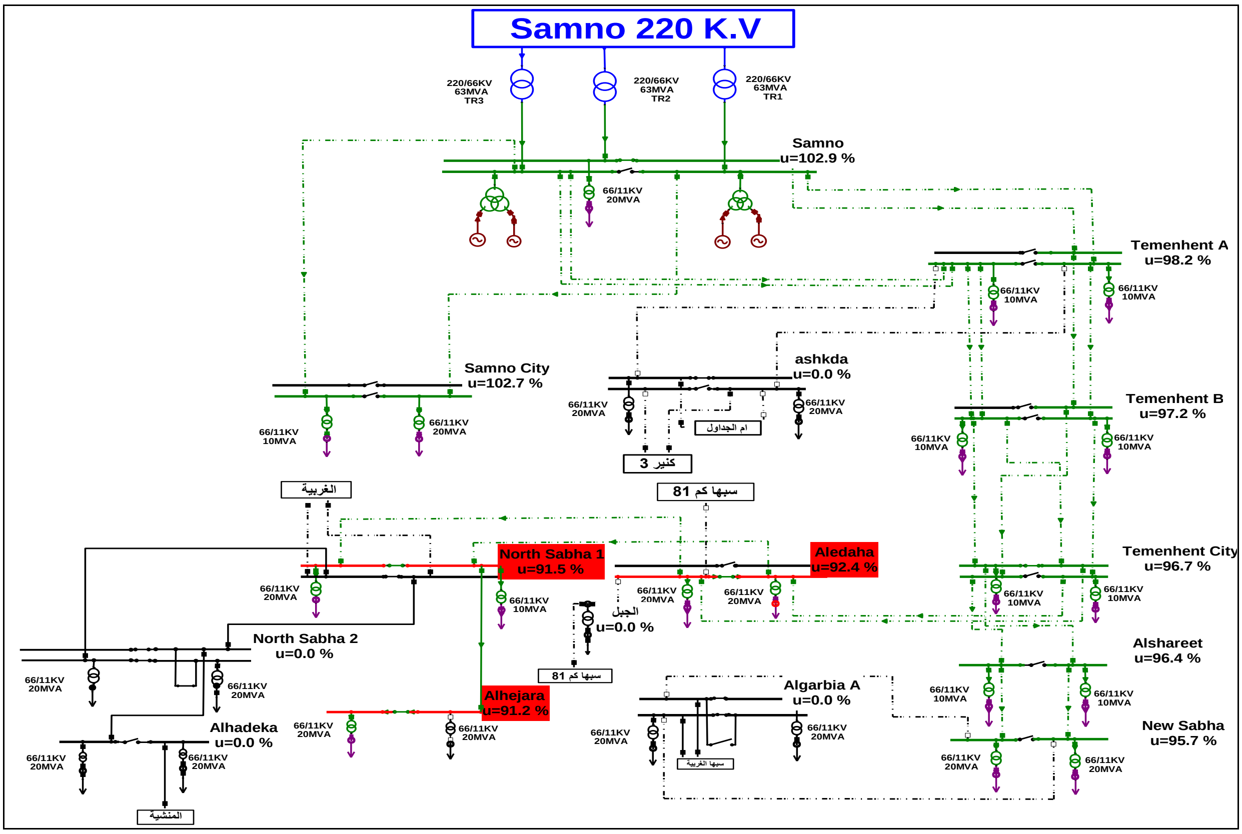

Figure 3: A semi-desert area network (Normal Operation).

The total load for this network is (P_{load} = 76.6MW), and power losses are (P_{Loss} =4.085MW), and the power generation is (P_G = 80.637MW). And there are three distribution substations (See busbars are with red color) have voltages less than 95%, at (Aledaha, North Sabha 1, Alhejara). As shown in Table 1 and Figure 4.

Table 1 Voltage value in distribution substations

Locations	V %
Samno	103
Temenhent A	98.2
Temenhent B	97.2
Temenhent City	96.7
Alshareet	96.4
New Sabha	95.7
Samno city	103
Aledaha	92.4
North Sabha 1	91.5
Alhejara	91.2

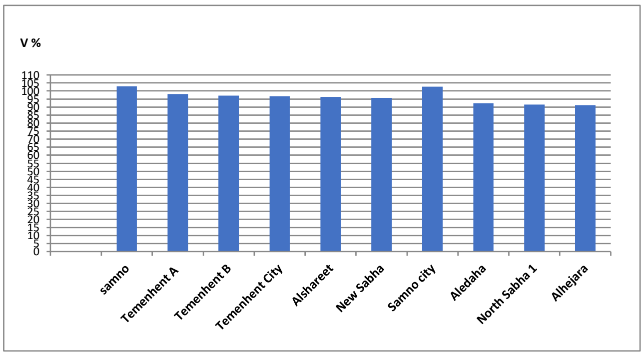

Figure 4: Three distribution substations voltages less than 95%

5.2 Optimal Operation

In this case, there is a distribution generation connecting to the Network, and we should find the best location at the distribution substations when the losses is minimum, and the voltages at all buss are acceptable (±5%), after many steps, the best location is founded at (North Sabha 1) as shown in figure 5, and the capacity of the D.G is (P= 22MW) and the reactive power needed is (Q= 33.84 MVAR).

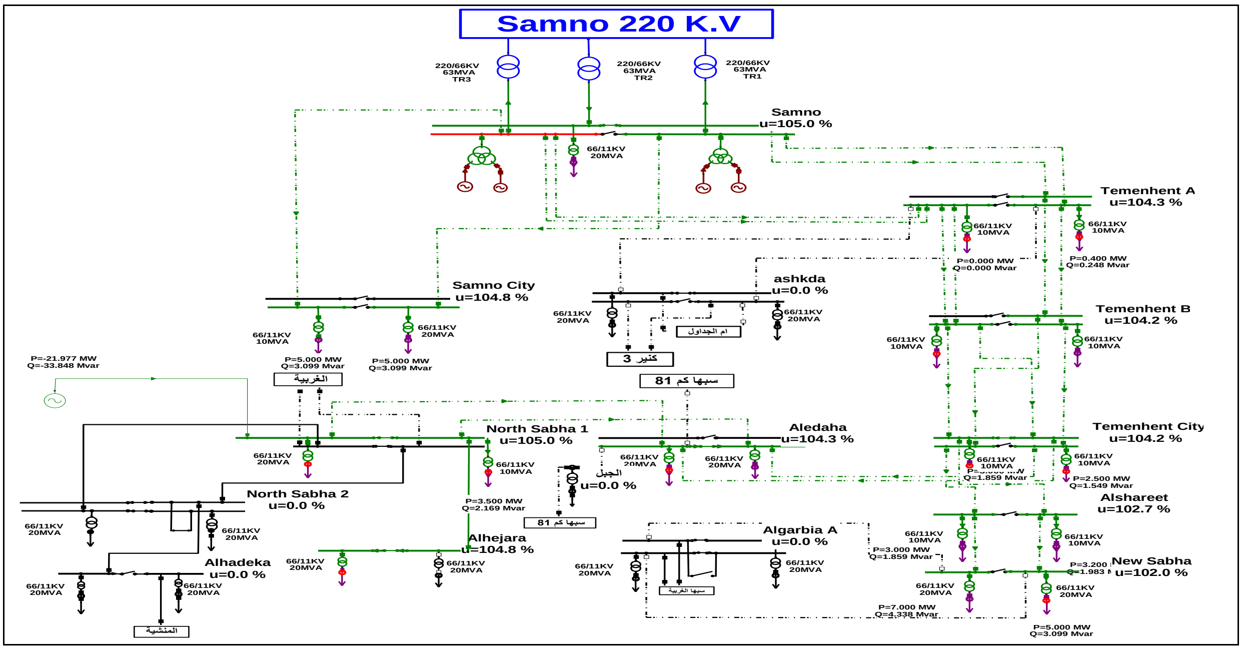

Figure 5: Optimal operation case (DG connected to the network at North Sabha 1)

Figure 6 illustrates that the power losses result is reduced from (P losses = 4.085 M.W) to (P losses = 1.376 MW). And also the magnitude of the voltages has been improved as shown in Table 2 and figure 7 below.

Table 2 Voltage value in distribution substations

Locations	V %
Samno	105
Temenhent A	104.3
Temenhent B	104.2
Temenhent City	104.2
Alshareet	102.7
New Sabha	102
Samno city	104.8
Aledaha	104.3
North Sabha 1	105
Alhejara	104.8

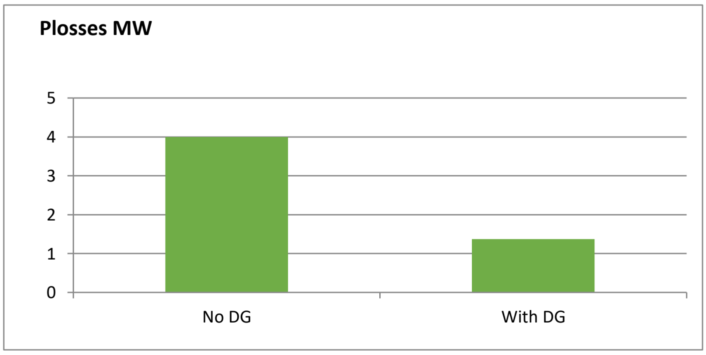

Figure 6: The power losses result

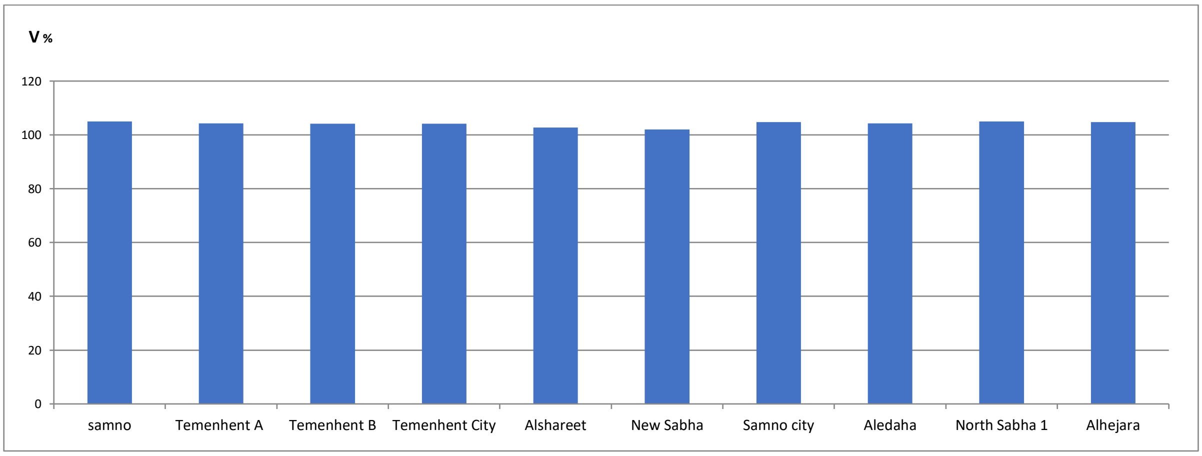

Figure 7: Distribution substations voltages more than 95%

5.3 Samno Network Connected Together

In this case, it was supposed that all distribution substations are connected to Samno network 220K.V, there are Five added to Ten distribution substations connected to the Samno network (Ashkda , Algarbia A, Aljabal, North Sabha 2, Alhadeka). As shown in figure 8. From the results, the voltages at buss are very low, and One of the Third transformers is overloaded, and the losses in transmission lines are high due to voltage collapse,(PG=150.92MW, PL=132.91MW, Plosses=17.68MW).

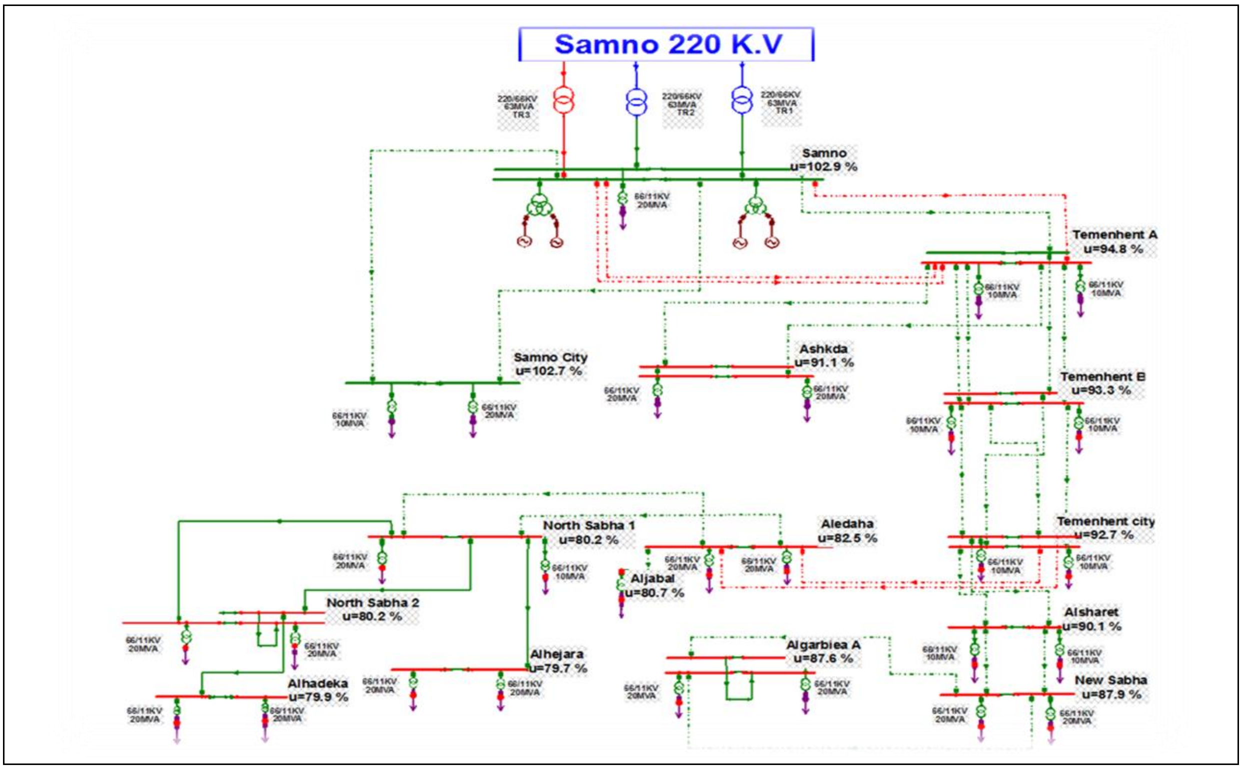

Figure 8: Samno network connected together.

Table 3, and figure 9 explain the magnitude of voltage value at all buss.

Table 3 Voltage in distribution substations

Locations	V %
Samno	102.9
Temenhent A	94.8
Temenhent B	93.3
Temenhent City	92.7
Alshareet	90.1
New Sabha	87.9
Samno city	102.7
Aledaha	82.5
North Sabha 1	80.2
Alhejara	79.7
Ashkda	91.1
Algarbiea A	87.6
Aljabal	80.7

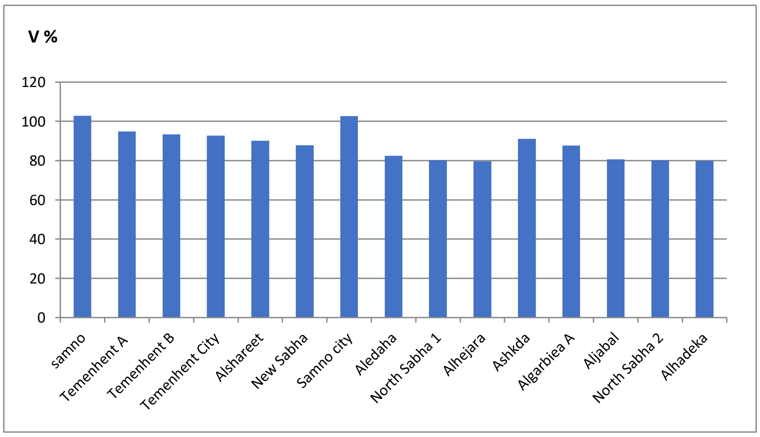

Figure 9: Some distribution substations voltages less than 95%

5.4 Samno Optimal Isolated:

This case explains how to evaluate the capacity of the DG, and it is the position when the power losses in the network are minimum, and the voltages at the buss are within limits (± 5%) from the rated value, as shown in figure 10. After several simulations, the rating of the distributed generation is founded as [P=100MW, Q=85Mvar]. And the sitting of this D.G at North Sabha 2. Therefore, the power losses in the network are reduced to 3.897MW.

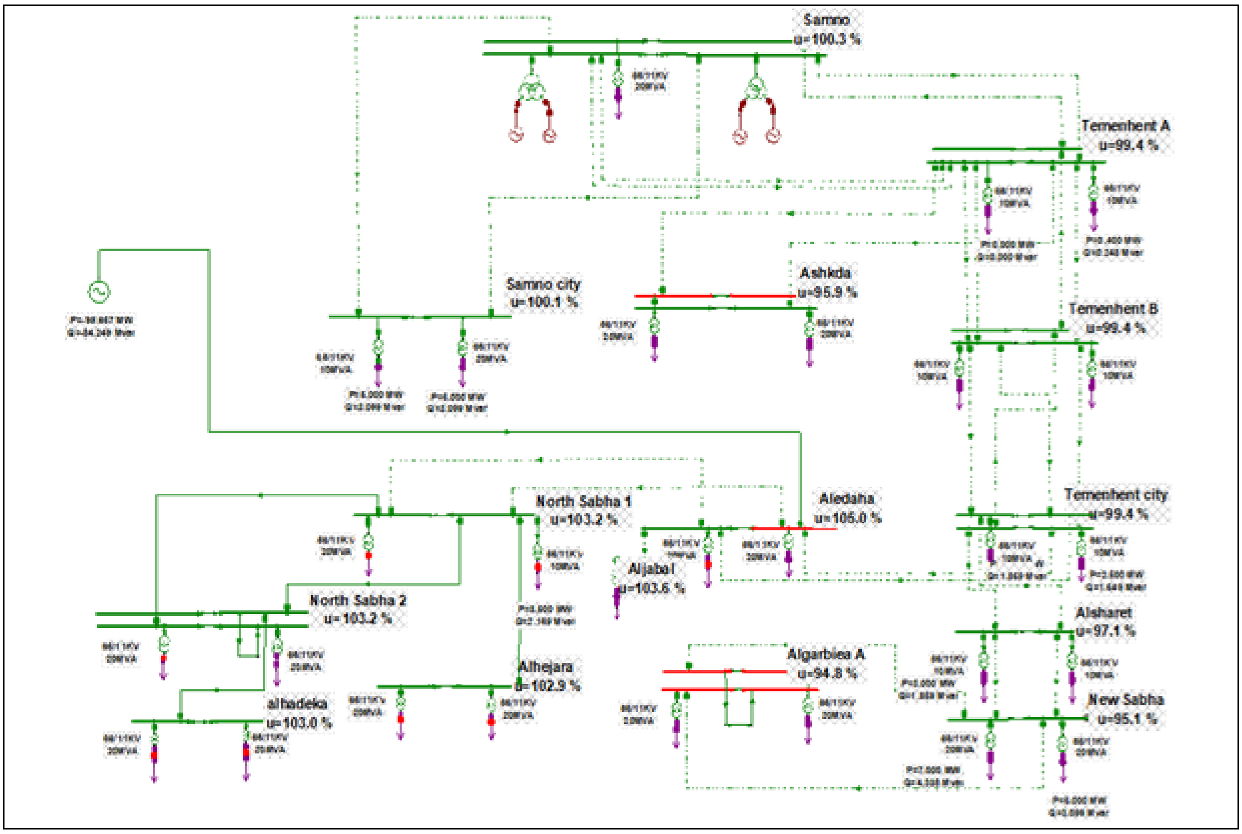

Figure 10: Samno Optimal Isolated Network

The power losses in the network are reduced from [17.68 MW to 3.897MW] after DG connected. see the next Table 4 and figure 11.

Table 4 Power losses

Case	P_{losses} MW
No DG	17.68.3
With DG	3.897

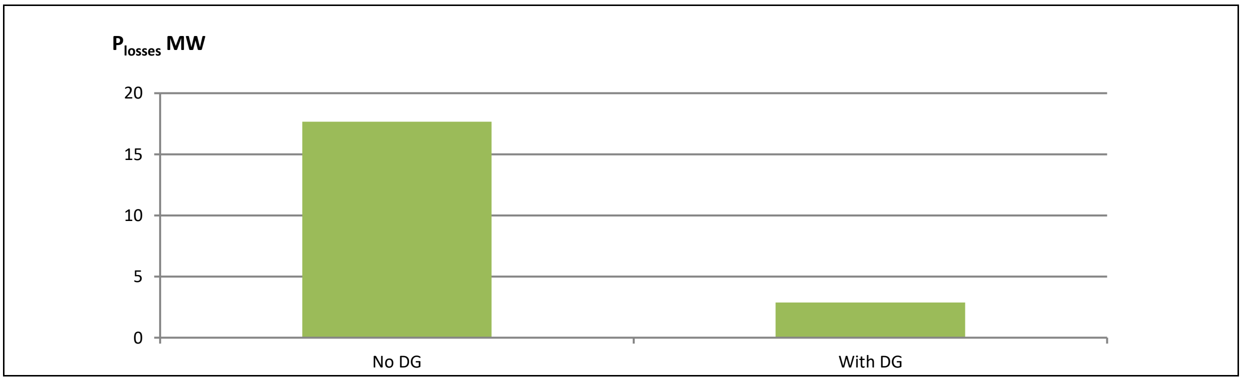

Figure 11: Power lossesThe voltages magnitude at buss were improved when connecting DG. from the results, as shown in Table 5 and Figure 12.

Table 5 Voltage in distribution substations

Locations	V %
Samno	100.3
Temenhent A	99.4
Temenhent B	99.4
Temenhent City	99.4
Alshareet	97.1
New Sabha	95.1
Samno city	100.1
Aledaha	105
North Sabha 1	103.2
Alhejara	102.9
Ashkda	95.9
Algarbiea A	94.8
Aljabal	103.6
North Sabha 2	103.2
Alhadeka	103

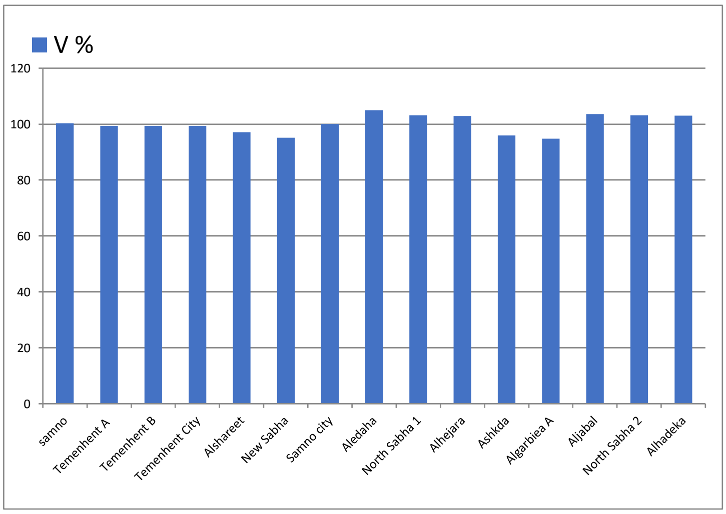

Figure 12: all distribution substations voltages appr. up 95%

6 Irradiation Curve:

As a known, the photovoltaic as D.G is depending on the irradiation, so when irradiation abounds, there is a power, when NO irradiation, there is NO power. And the global radiation on a horizontal surface is shown in table 6, and these measurements are obtained from the Energy Research Center (ERC). And Figure 13 shows the daily irradiation-curve for a summer day,

Table 6 The Global Irradiation (W/m²) in 24 hours

Time(hours)	Radiation(W/m²)	Time(hours)	Radiation(W/m²)
1	0	13	990
2	0	14	917
3	0	15	780
4	0	16	585
5	30	17	375
6	140	18	154
7	343	19	20
8	532	20	0
9	747	21	0
10	910	22	0
11	1019	23	0
12	1062	24	0

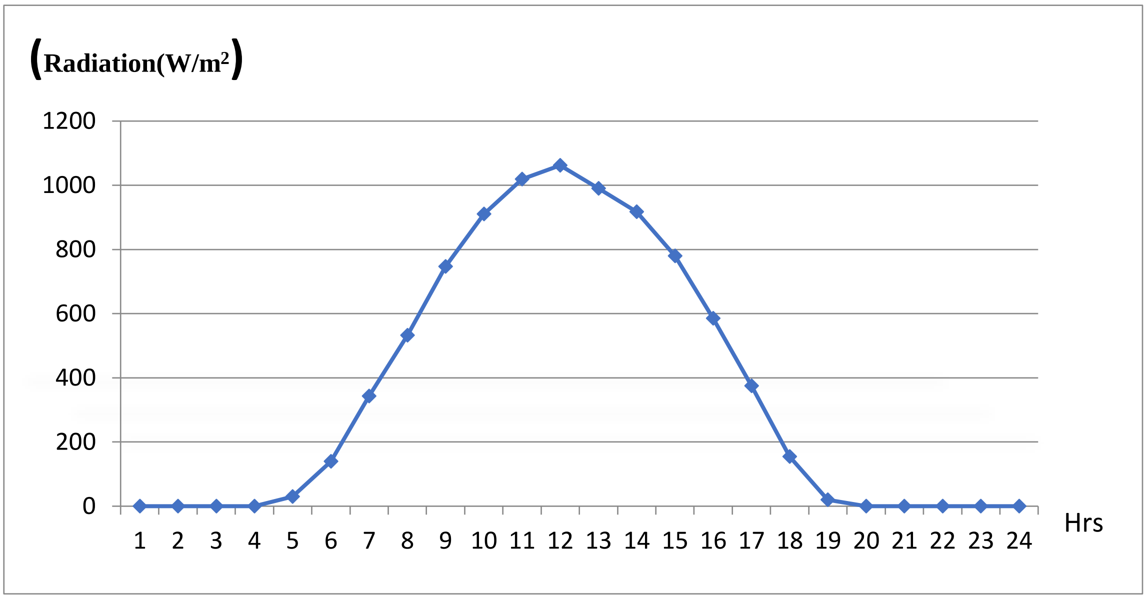

Figure 13: The daily irradiation-curve for a summer day

6.1 Operating the network depends on the daily load curve:

From the date was taken from the General Electricity Company of Libya (GECOL), the daily load curve starts growing at the morning, after sunrise when the irradiation is a pounded, and when plotted the daily load curve data, we noted the daily load curve is matched the irradiation curve, this means that the maximum load occurred when there are irradiation. Table 7 explains the daily load curve.

Table 7 The daily load curve

	Real	Approximated
	65	65
2	56	56
3	56	56
4	56	56
5	56	56
6	56	56
7	56	56
8	56	56
9	56	69
10	78	82
11	88.5	92
12	97	102
13	106	112
14	112.1	122
15	115	132
16	118	142
17	132.7	142
18	132.7	142
19	121	129
20	103	116
21	94	103
22	80	90
23	74	77
24	65	65

The daily load curve can be approximated to geometrical figures because it is easy to calculate the area under the curve . as shown in figure 14.

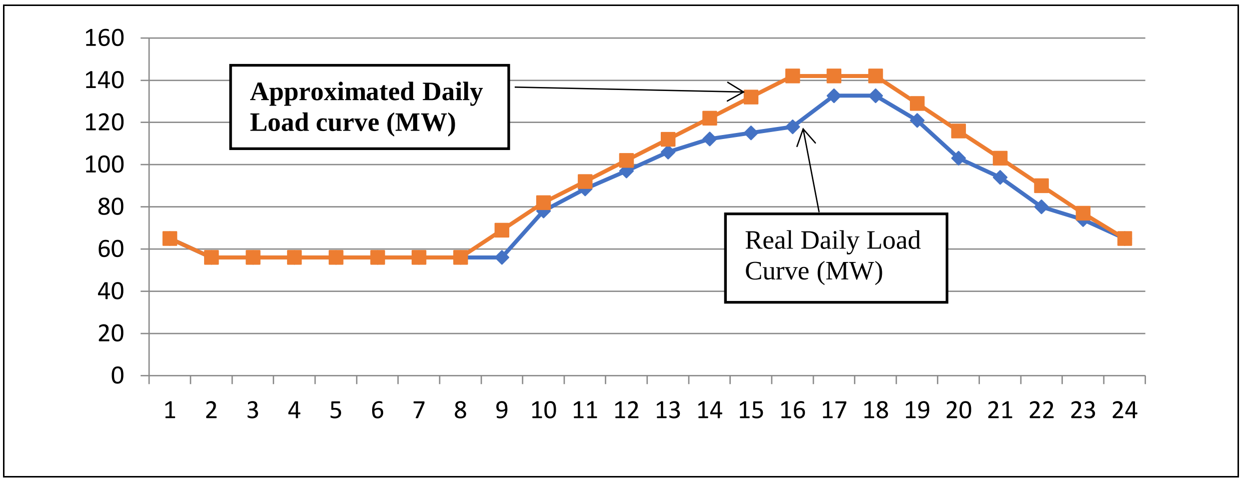

Figure 14: The daily load curve

The area under the curve represents the energy that consumed in One day (24 hours), from the figure we note the base load is 56 MW. so the assumption, in this case, is the baseload is feeding from the generators at Samno (4*20MW = 80MW), and the other power is feeding on photovoltaic PV and the batteries E.S.S (Energy Storage System).
If the Network operating depending on a daily load curve, the size of PV is equal (PDG =142 – 56 = 86 MW).
From the approximate daily load curve, see figure 15, we can compute the rating of the batteries that needed for this case.

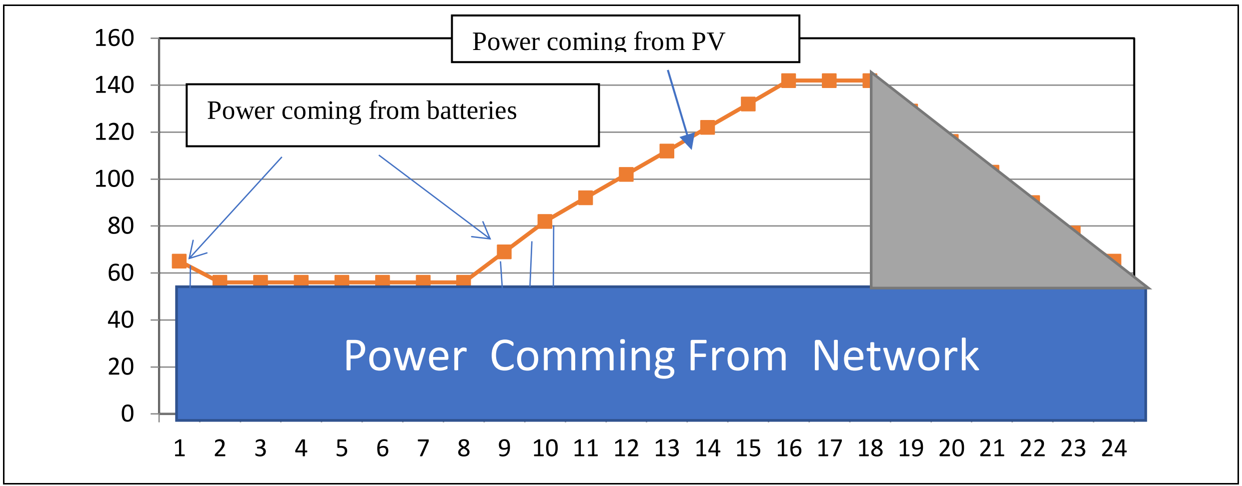

Figure 15: approximate daily load curve

Batteries or charging system has been analyzed and calculated to be applied at the morning time of the day (1 to 2 & 8 to 10) as illustrated in the above figure. Also, the batteries system will be used at the evening time (18 to 24). The rating of the batteries is:
1) From (1am- 2am) :
A= 0.5 * 1h * (65 – 56) MW = **4.5 MWh**.
2) From (8am- 10am) :
A= 0.5 * 2h * (82 – 56) MW = **26 MWh.**
3) From (18 – 24) or (6pm -12am):
A = 0.5 * 6h * (142 – 56) MW = **258 MWh.**
Total rating of Batteries **= 288.5MWh.** ⟶ **300MWh.**
The power needed for charging is: **(300MWh / 24h) = 12.5 MW.**
The batteries can be charging from the generators at Samno because there is access power (**80 > 56+12.5) MW**.
Figure 16 shows the Samno network isolated from the Libyan network.

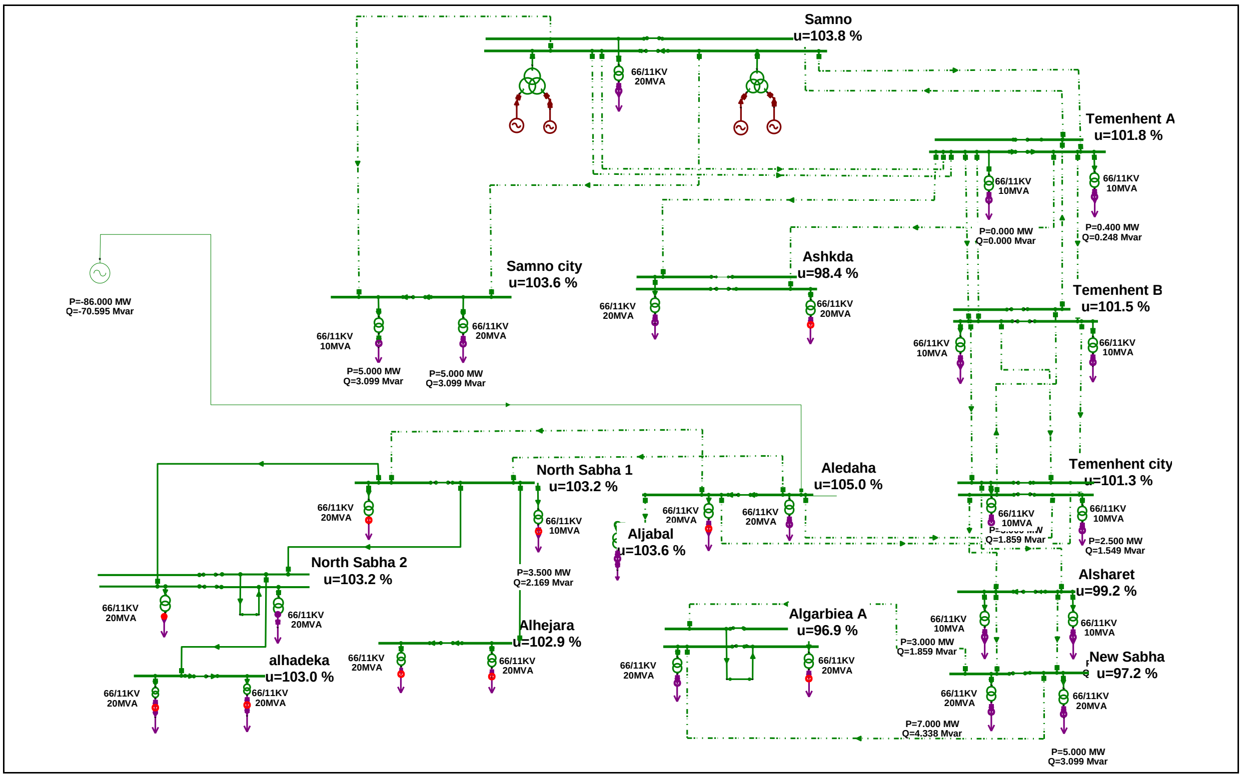

Figure 16: Samno network isolated from the Libyan network

From figure 16, the voltages are within limits, and the losses are decreased to **(3.395 MW)**. Table 8 and figure 17 show the voltages at buss in the network, which demonstrates very good results (up 95%)

Table 8 Voltage values at buss in the network

Locations	V %
samno	103.8
Temenhent A	101.8
Temenhent B	101.5
Temenhent City	101.3
Alshareet	99.2
New Sabha	97.2
Samno city	103.6
Aledaha	105
North Sabha 1	103.2
Alhejara	102.9
Ashkda	98.4
Algarbiea A	96.9
Aljabal	103.6
North Sabha 2	103.2

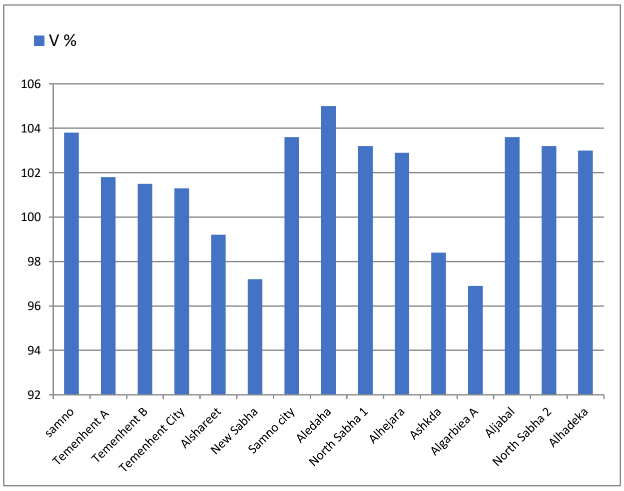

Figure 17: Voltage values at buss in the network

6.2 Operating PV system with 25% penetration:

In this case, the magnitude of PV and STATCOM is (P=21.5MW & Q=101.896MVAR), as shown in figure 18.

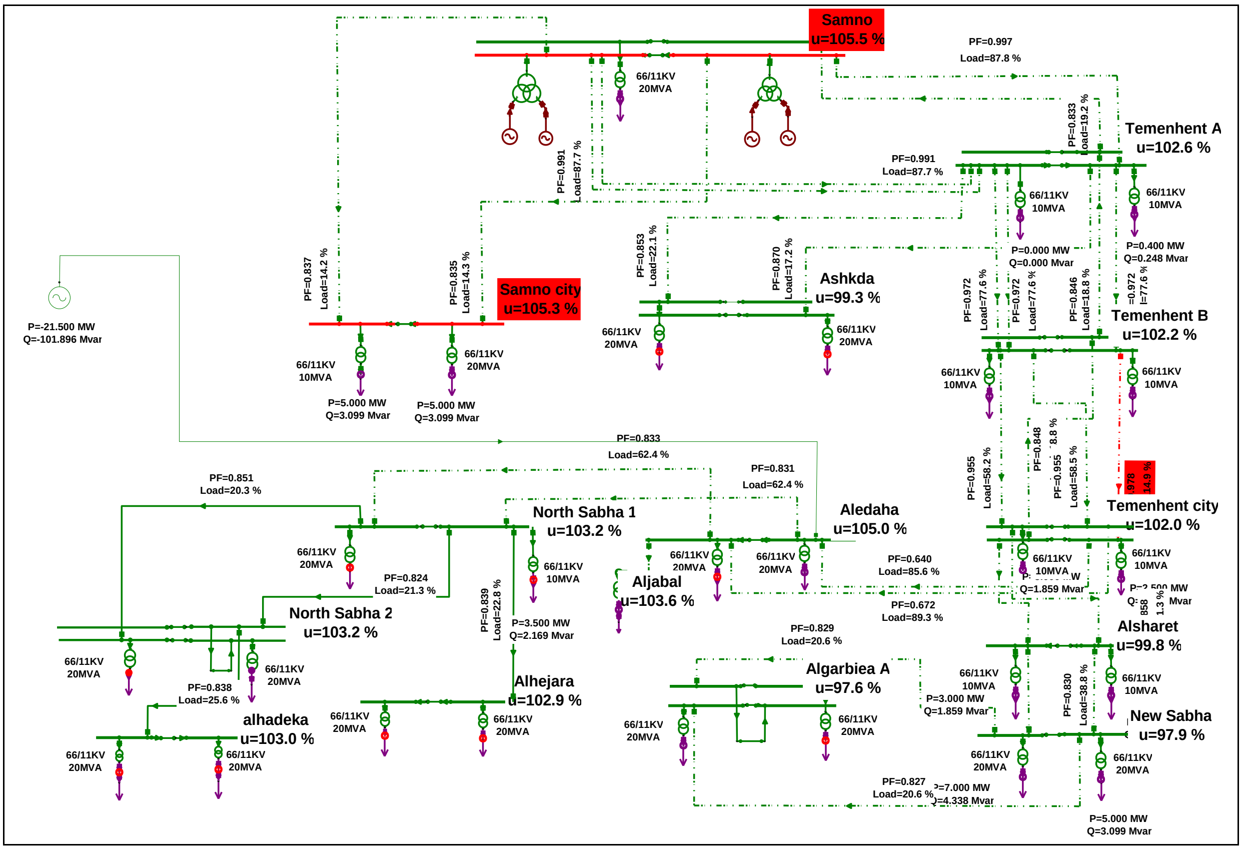

Figure 18: Operating PV system with 25% penetration

6.3 Operating PV system with 50% penetration:

In this case, the magnitude of PV and STATCOM is (P=43MW & Q=89.35 MVAR), As shown in figure 19.

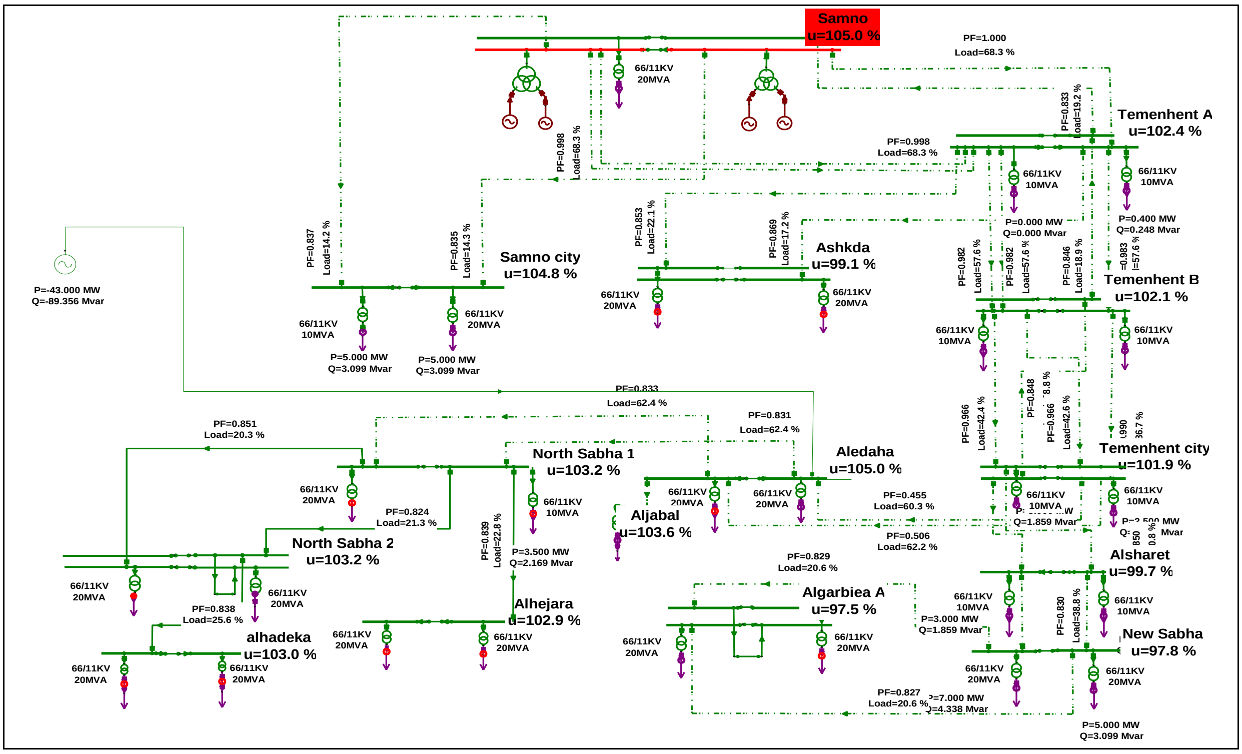

Figure 19: Operating PV system with 50% penetration

6.4 Operating PV system with 100% penetration:

In this case, the magnitude of PV and STATCOM is (P=86 MW & Q= 70.6 MVAR), As shown in figure 20.

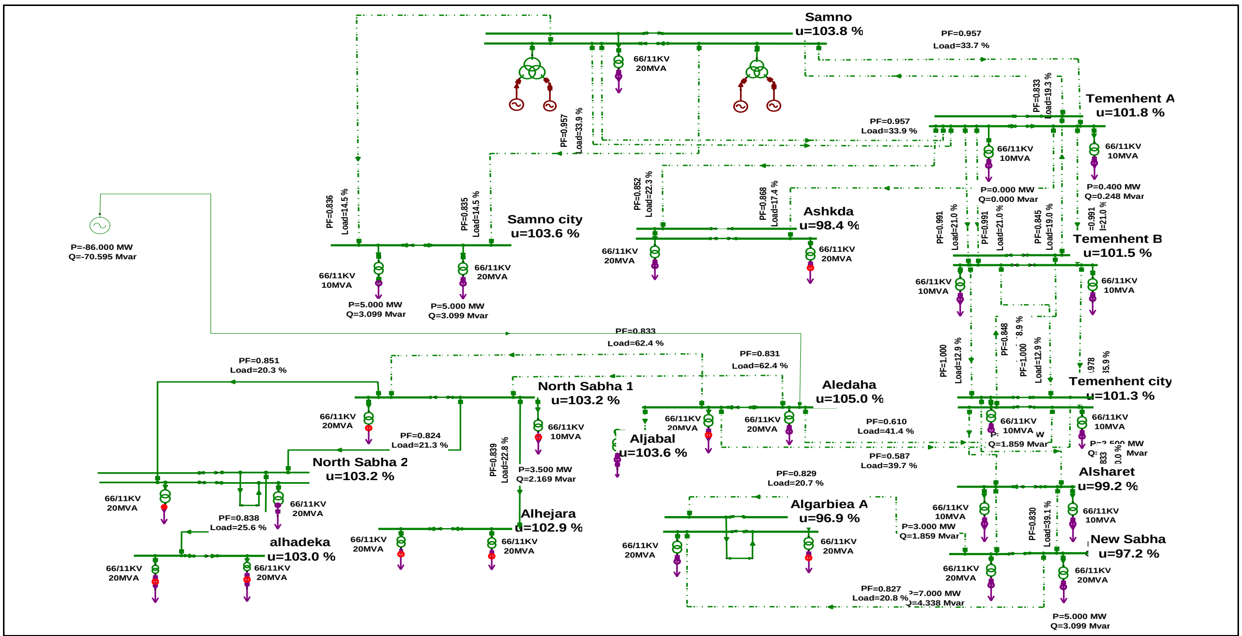

Figure 20: Operating PV system with 100% penetration

Table 9 Operating PV system with (25% to 100%)

PV % penetration	P (MW)	Q (MVAR)	Network losses (MW)	Voltage range %
25% penetration	21.5	101.896	9.47	97.6 -105.5
50% penetration	43	89.35	6.224	97.5 - 105
100% penetration	86	70.6	3.359	96.9 - 105

Last but not least, it is clear that the losses in the network as shown from the obtained results in table 9 have decreased while the percentage of PV penetration has been increased. Also, the magnitude values of the voltage have improved up 95% as the percentage of PV penetration increased. Furthermore, P & Q values at the operating PV system with (25% to 100%) penetration illustrates in figure 21. And network losses are explained in figure 22 (MW). Lastly, maximum and minimum voltage values at the operating PV system with (25% to 100%) penetration demonstrate very good results up 95% as can be seen in figure 23.

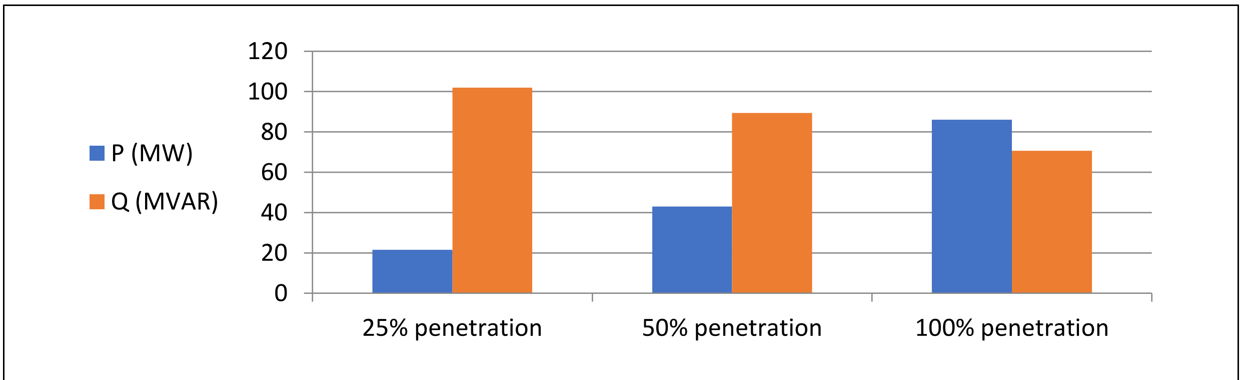

Figure 21: P & Q Value at Operating PV system with (25% to 100%) penetration

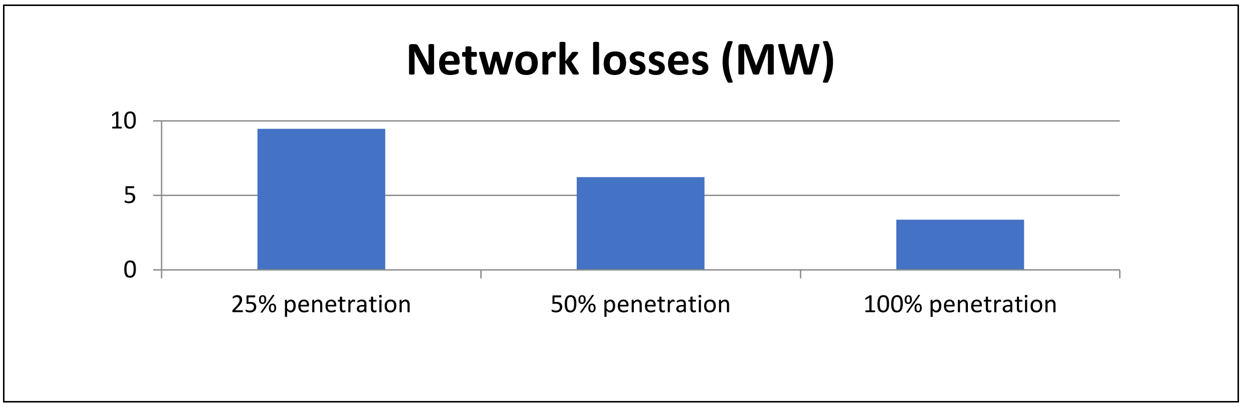

Figure 22: Network Losses (MW)

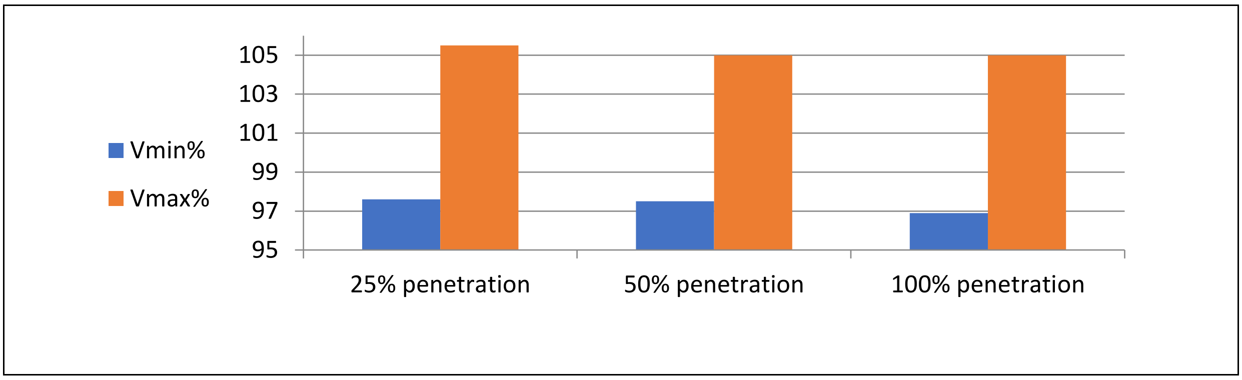

Figure 23: Voltage value at Operating PV system with (25% to 100%) penetration

Finally, the Samno network with PVDG was simulated and performed well, proving that it can be used for improving the semi-desert area network, which was the main objective of this research. The final results were analysed and figured out with a very good performance after DG connected. Summing up the results, it can be concluded that the proposed The Samno network with PVDG has high-performance results; maximum and minimum voltage values at the operating PV system with (25% to 100%) penetration demonstrated a very good results upper 95%. Also, the power losses in the network are reduced from [17.68 MW to 3.897MW] after DG connected

7. Conclusion

This work demonstrated an innovative design and modeling of the semi-desert network that is capable of achieving minimum power losses characteristics in different operating case. The aimed design of the PVDG for the semi-desert area has been successfully achieved by using NEPLAN software. The PVDG was presented and simulated with the help of using Newton Raphson beside NEPLAN software; this paper has clearly shown that various simulations and tests were conducted on the PVDG network. At the beginning of the chapter, the simulation and its results as normal operation networks were tested. Then, the optimal operation was analyzed from the simulation. Last but not least, the Samno isolated network was simulated, and its results explained. Finally, the optimal Samno network isolated was clearly defined. So, they supported the idea that required to a designer for confirming that the renewable energy resource as DG has been successfully achieved.

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