

Optimal Power Flow in Distribution Network Considering DG Penetration and Isolated Grid Operation.

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Abstract

This research investigates the optimal power flow (OPF) in a Libyan 30 kV distribution network with a case study focused on the **Bir-Alganm** substation. The search addresses critical operational challenges such as voltage instability, high system losses, and reduced efficiency, which threaten the reliability of power supply. To overcome these issues, both conventional methods such as re-planning an expansion and advanced approaches through distributed generation (DG) penetration are examined. Using the NEPLAN software and the extended Newton–Raphson method, simulations are performed to determine system weaknesses, evaluate DG placement and sizing, and compare network performance under grid-connected and isolated operation. The results demonstrate that integrating DG significantly reduces losses, enhances voltage stability, and provides a flexible and cost-effective alternative to traditional expansion. Moreover, load growth analysis over a ten-year horizon highlights the sustainability advantages of DG compared to conventional solutions. The findings underscore the practical role of DG in improving reliability, efficiency, and resilience of Libya’s distribution networks.

Keywords: *Distributed Generation (DG), Optimal Power Flow (OPF), Load Flow Analysis, Isolated Grid Operation, Distribution Network.*

I. Introduction

Penetration of distributed generation (DG) is a new challenge for traditional electric power systems. Power injections from DGs change network power flows, modifying energy losses and voltage profile of the system. Proper locations of DGs in power systems are important to obtain the maximum potential benefits [1].

The changes due to the insertion of DG are mainly caused by the differences in location and operation principle between the DG units and the conventional generators and loads. The most important differences are [2].

- The DG units are mostly connected to the distribution networks (DN); this introduces generators in the DN, which historically only contained loads [2,3].
- A large percentage of the DG units are connected to the grid via power electronic converters, which have a behavior that is fundamentally different from the behavior of the conventional synchronous machine-based generators.
- Distribution networks that contain DG units can be considered as active networks, because it can control the active and reactive power generated by DG units [4].

The distribution system plays a fundamental role in ensuring reliable electricity delivery [5]. In Libya, however, it faces persistent challenges such as voltage instability, high power losses, and low operational efficiency. These issues underline the urgent need for re-planning and redesign of the network using both conventional methods and modern optimization-based approaches [6]. In this context, the present research focuses on the reconfiguration of a 30 kV Libyan distribution network by incorporating distributed generation (DG). The adopted methodology relies on optimal power flow (OPF) using the extended Newton-Raphson method, supported by the NEPLAN program for the simulation of losses and voltage profiles. The main objectives are to minimize network losses, enhance voltage performance, determine the optimal placement and sizing of DG units, and assess the contribution of renewable-based DG under both grid-connected and isolated operation. Ultimately, this research provides a practical case for Libya, demonstrating how optimal planning and DG integration can enhance the reliability, efficiency, and resilience of the distribution system in the face of modern challenges.

The organization of this paper is as follows. Section II provides a literature review on DG integration and optimal power flow. Section III details the research methodology. Section IV presents the studied distribution system and working assumptions. Section V explains the operational principles of the Byr Alghanam system. Lastly, Section VI presents the results and discussion, followed by Section VII with recommendations for future research.

II. Related Work

In recent years, the integration and optimal placement of distributed generation (DG) in distribution networks have been extensively studied to minimize power losses and improve voltage stability. Peres in proposed a probabilistic optimal power flow approach for balanced islanded microgrids, highlighting the impact of uncertainties on system operation [7]. Similarly, Badoozadeh in investigated probabilistic optimal power flow in wind-integrated power systems using K-medoids data clustering to account for correlated uncertain variables [8]. Several studies have focused on optimal DG placement and sizing for loss minimization Adepoju et in utilized a particle swarm optimization technique to determine the optimal loction and capacity of DG units in distribution networks[9], while M'hamdi, Teguar, and Tahar emphasized both loss reduction and voltage stability enhancement in radial networks[10]. Optimization-based approaches for active distribution networks with high penetration of DG have also been reviewed, as presented by Wang et al.in providing insights into scheduling strategies under variable generation conditions[11]. Hybrid and metaheuristic optimization methods have shown promising results in network reconfiguration and DG allocation for loss minimization (Smart Grids and Sustainable Energy) [12]. Das, Fosso, & Marafioti[13]. Moreover, Saeed, Yadav, and Choube and the study published in SN Applied Sciences demonstrated that teaching-learning-based and ant colony algorithms, respectively, effectively optimize DG placement for real power loss reduction and improved voltage profiles[14,15] collectively, these studies underscore the critical role of advanced optimization techniques in enhancing the performance and reliability of modern distribution systems.

III. Methodology of work

In this research, the optimal power flow analysis will be applied for a chosen real distribution circuit within the Libyan Electrical Network.

The following assumptions will be considered as the standards of electrical distribution system:

- The system can be a part of all Libyan Electric System and /or as an isolated grid.
- The voltage regulation is $\pm 5\%$ of nominal at system buses during normal operation mode and $\pm 10\%$ at contingency.

- The line maximum load ability is 100% of their current carrying capacities, and 120% for contingency in two hours' time range duration.
- The Distribution Generation may be installed at any system buses, at chosen power sizes according to OPF results.
- System control and operation facilities are considered available at any time.
- Any other standards accepted by IEC standers.

For the application of (OPF) to study the system performance the following steps will be considered as like in finger1.

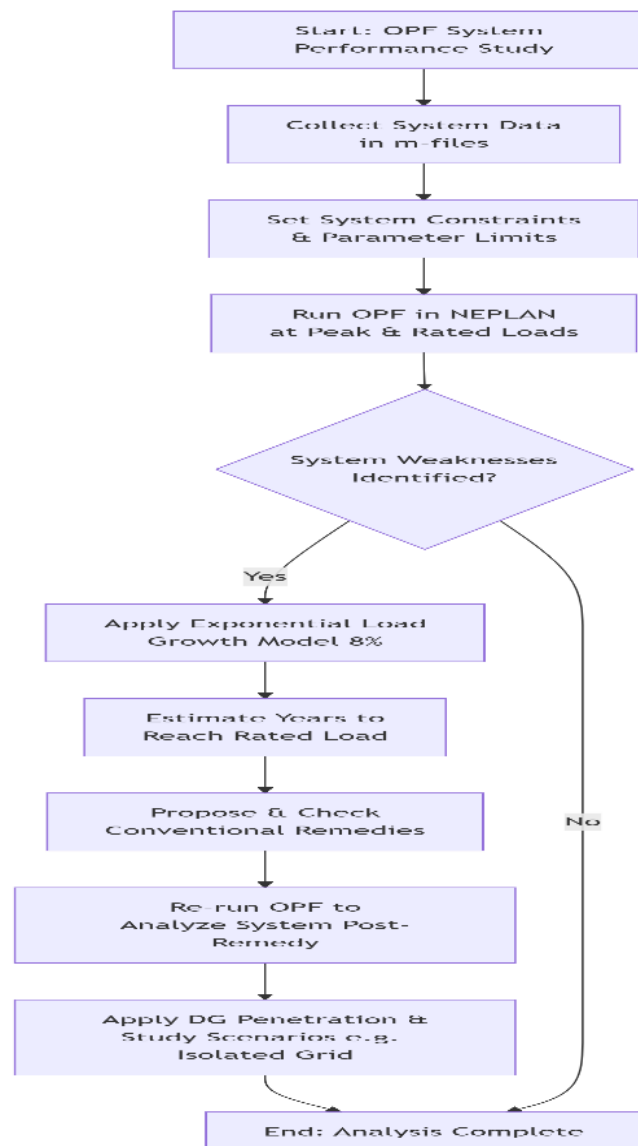


Figure 1: shown the application of (OPF) to study the system performance

IV. Description of the Distribution System and work assumptions

Figure 2 shown the description system under investigation which consists of (Voltage source, 220KV bus, Two Transformers (220/30) kV, of 63mva size each, Transformers (30/11) kV, Bus bars 30 kV, Bus couplers & Bus sections, Loads).

The distribution system is fed from (Bir Alganm) 220KV substation, and supplying the local loads. The data for actual peak loads at year 2014, and the rated loads here, the (30/11) KV transformer sizes that are considered as the rated loads. The network transformer sizes are shown in Table 1:

Table 1: System bus names and connected transformers rated sizes.

No	Substation buses	Transformer number	Voltage ratio	Capacity MVA
1	Byr Alghanam1	TR(1)	30/11Kv	10
2	Byr Alghanam2	TR(1)	30/11Kv	20
3	Wadi Alhayi	TR(1)	30/11Kv	20
4	Janub sirman	TR(1)	30/11Kv	20
5	Byr hwysh	TR(1)	30/11Kv	20
6	Byr alghanam alqarayih	TR(1)	30/11Kv	20
7	Ras allafe	TR(1)	30/11Kv	10
		TR(2)	30/11Kv	10
8	Bin rabah	TR(1)	30/11Kv	20
		TR(2)	30/11Kv	20
9	Beer ayad	TR(1)	30/11Kv	10
		TR(2)	30/11Kv	20
10	Bin nasser	TR(1)	30/11Kv	20
		TR(2)	30/11Kv	10-

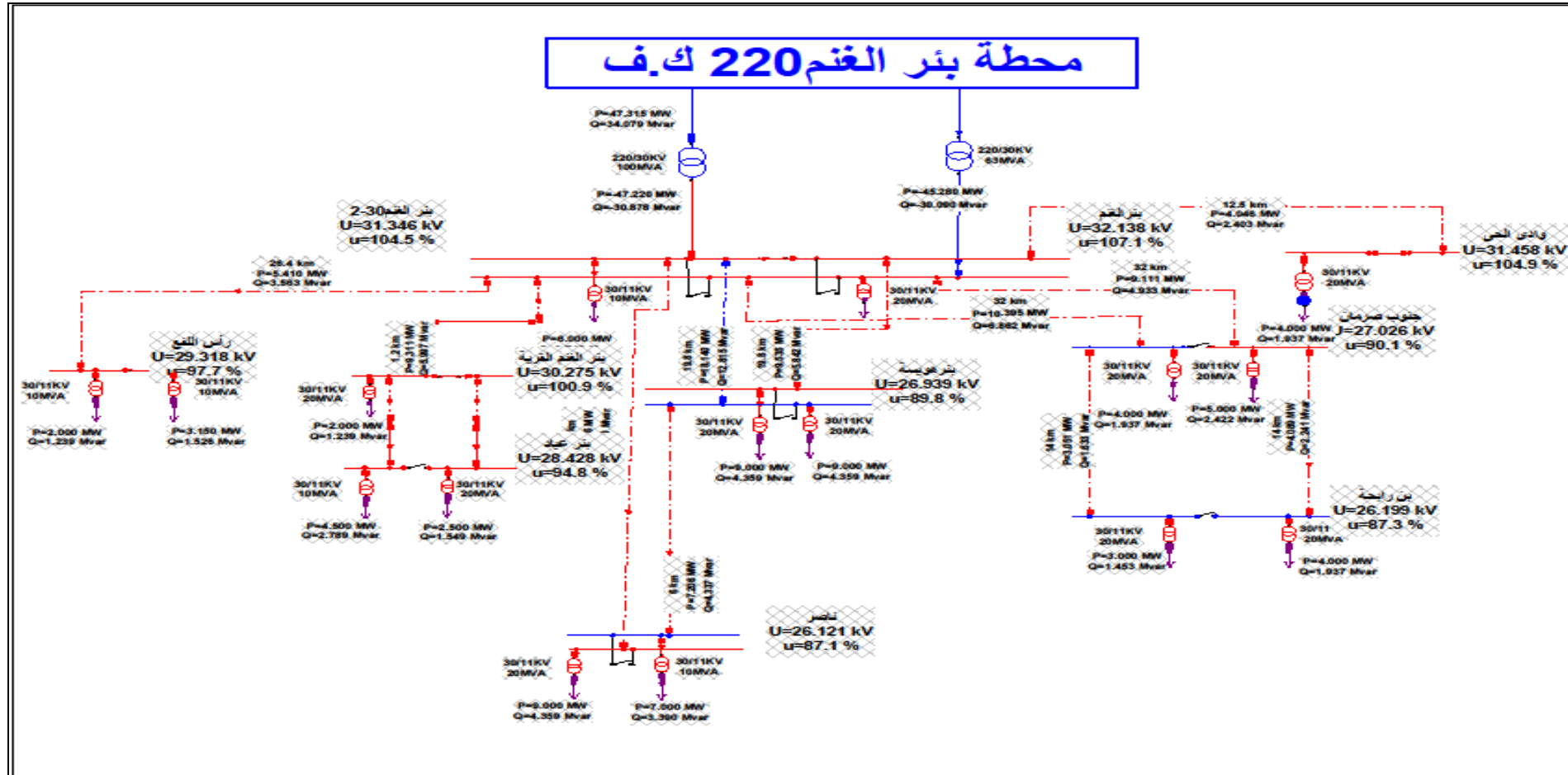


Figure 2: 30KV distribution network with peak loads of 2014

V. The Operational Basis for the Byr Alghanam System

1. Case Studies and Analysis

To study the performance of an electric distribution system the software NEPLAN is applied for optimal power flow analysis (OPF). Also the unconventional methods of DG penetration will be applied with (OPF) to enhance the system performance.

1-1 System Performance Using Optimal Power Flow

The system grid that shown in Figure3 and described in section 1 the peak loads of the network are considered that occurs on august 2014, according to GECOL data.

Run the system using the NEPLAN software the results are shown in Table 2 that shows the system weakness.

Table 2: The Name and Voltage violated System Buses.

No	Substation Name	Voltage Level %	Status*
1-	Byr Alghanam1	107.1%	Overvoltage
2-	Byr Alghanam2	104.5%	Overvoltage
3-	Wadi Alhayi	104.9%	Overvoltage
4-	Janub sirman	90.1%	Undervoltage
5-	Byr hwysh	89.8%	Undervoltage
6-	Byr alghanam alqarayih	100.9%	Overvoltage
7-	Ras allafe	97.7%	Overvoltage
8-	Bin rabah	87.3%	Severe Undervoltage
9-	Beer ayad	94.2%	Undervoltage
10-	Bin nasser	87.1 %	Severe Undervoltage

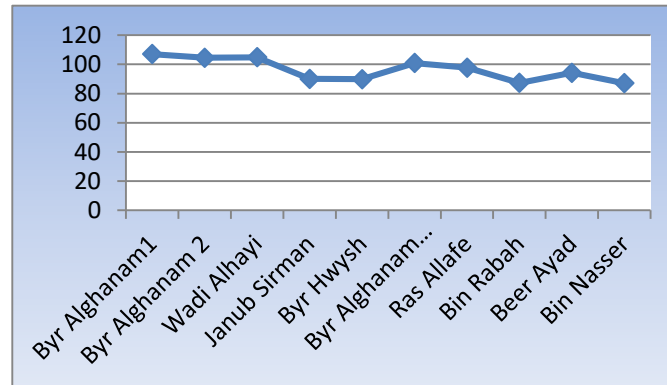


Figure 3: shown the buses voltage profile

1-2 Case Discussion

From the results it is seen that the system suffering from the voltage violation at some bus-bars, and the system losses are about 6.7% of the total load, since the total power input was 92.83MW and the losses are 6.25MW, the losses are considered within the range.

Violations can be solved by conventional methods of replanning and redesign, such as adding substation and expansion the distribution system that can be done, but it needs a continuous monitoring, and replacement that takes a lot of efforts and time, besides its high costs and cause a delay of economic and social activates of the society.

Noticed that the chosen system is suffering of low power factor due to the high inductive pump load of agricultural are, besides the high diurnal peak loads.

2. Applying DG Penetration Case Study

In this case, the DG penetration will be considered since the renewable energy has a high bright future in Libya, and to avoid the high cost of replanning, besides the possibility of DG up grading as the load demand increasing.

The DG output power will be estimated depending on the OPF solution that gives the size of DG unit that may installed at the lowest voltage buses as shown a Figure 4. on buses of Janub surman, Byr hwys, Bin rabaha, Bin nasser.

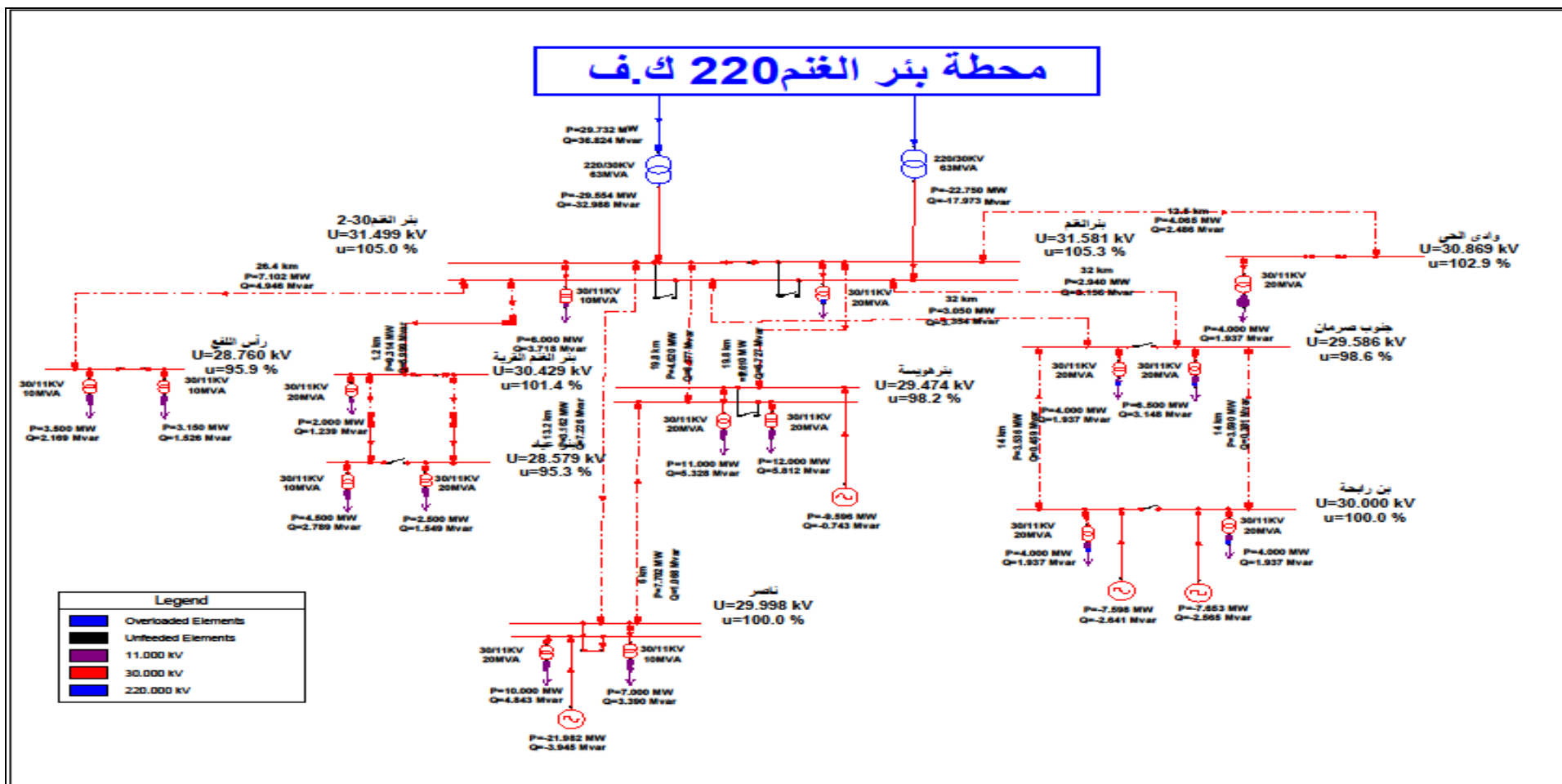


Figure 4: Optimal power flow with DG penetration

Choosing the lowest voltage buses for installing DG units to enhance the voltage profile of the system and to reduce system power losses.

In this case, the same peak loads of year 2014 are considered, and the results for power losses are shown in Table 3 .

Table 3: OPF real and reactive losses with DG penetration.

OPF WITH DG									
From	To	P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load
Area/Zone	Area/Zone	MW	MVar	MW	MVar	MW	MVar	MW	MVar
Network		2.803	15.275	52.554	56.341	99.382	66.236	96.579	50.961
Area 1		2.803	15.275	0	0	99.382	66.236	96.579	50.961
Zone 1		2.803	15.275	0	0	99.382	66.236	96.579	50.961
Node	U	u	P	Q	I	Angle I	Loading	P Loss	Q Loss
Name	kV	%	MW	MVar	kA	°	%	MW	MVar
Beer ayad	28.58	95.26	-2.934	-6.933	0.145	110.6	40.25	0.0178	0.1427
Byr alghanam1	31.5	105	3.162	7.226	0.144	-69.3	40.05	0.0421	0.041
Ber alghanam2	31.58	105.28	-4.365	-5.872	0.143	123.2	37.71	0.0421	0.041
Bin rabah	30	100	0	0	0	0	0	0.2275	0.2929
Janub sirman	29.58	98.59	0	0	0	0	0	0.2275	0.2929
Binnasser	30	99.99	6.5	3.148	0.356	-31	0	0.2548	0.4056
Ras allafe	28.76	95.87	-6.5	-3.148	0.356	149	36.11	0.2548	0.4056
Byr alghanam al	30.43	101.43	-2.914	-3.19	0.084	129.3	22.2	0.0316	0.4006
Byr hwysh	29.47	98.25	-3.172	-1.792	0.073	145.5	0	0.149	0.2133
Wadi alhayi	30.87	102.9	3.525	2.474	0.086	-40.1	43.06	0.149	0.2133

In this case, different locations for DG units and sizes that are estimated by (OPF) analysis are applied and the best results of minimum power losses are considered.

All system voltage levels are within the range and also lines loading when DG's are installed, also the imported and generated power are shown in the Table (3), with the system voltage level of bus bars.

2-1 Case Study Discussion

The DG penetration shows the great benefits of using DG for distribution method for replanning that enhance the system performance of lowering the losses and reducing the line loading as well as the good voltage profile.

If the cost analysis are considered the reduction of system losses and good system performance will show the high reduction of cost. The 55% reduction of losses means gaining this amount as cost benefits. Besides saving the cost for constructing new substation and lines.

3. Case of Considering Load Growth for Next 10 Years

For this case a yearly growth rate of 8% is consider according to GECOL estimation and according to this growth rate using the exponential growth equation :

$$P_n = P_o (1+x)^n \quad (1)$$

Where:

P_n =power growth after n years.

P_o = base load power.

x = growth rate %.

n = number of years.

Table 4: shows the ten years growth of system load also Figure 5: shows the growth rate curve.

Table 4: Table (4) Shows the yearly load growth

YEARS	P MW
2014	100
2015	108
2016	116.64
2017	125.97
2018	136.04
2019	146.93
2020	158.68
2021	171.38
2022	185.09
2023	199.90

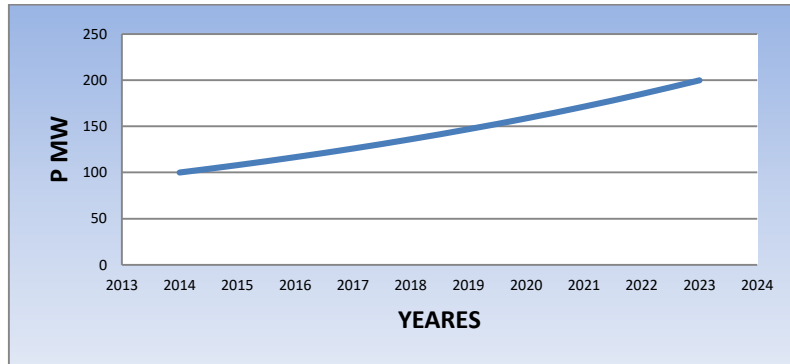


Figure 5: shows the load growth curve

Considering the same growth on all system transformers starting form 2014 peak load for the future of 10 years. Applying the optimal load flow analysis, the result as shown in Figure 5 and Table 5 that shows the whole network is collapsed, also the main (220/30) KV feeding substation transformer are already unable to feed the system since the main transformer before growth almost reaching their capacity level.

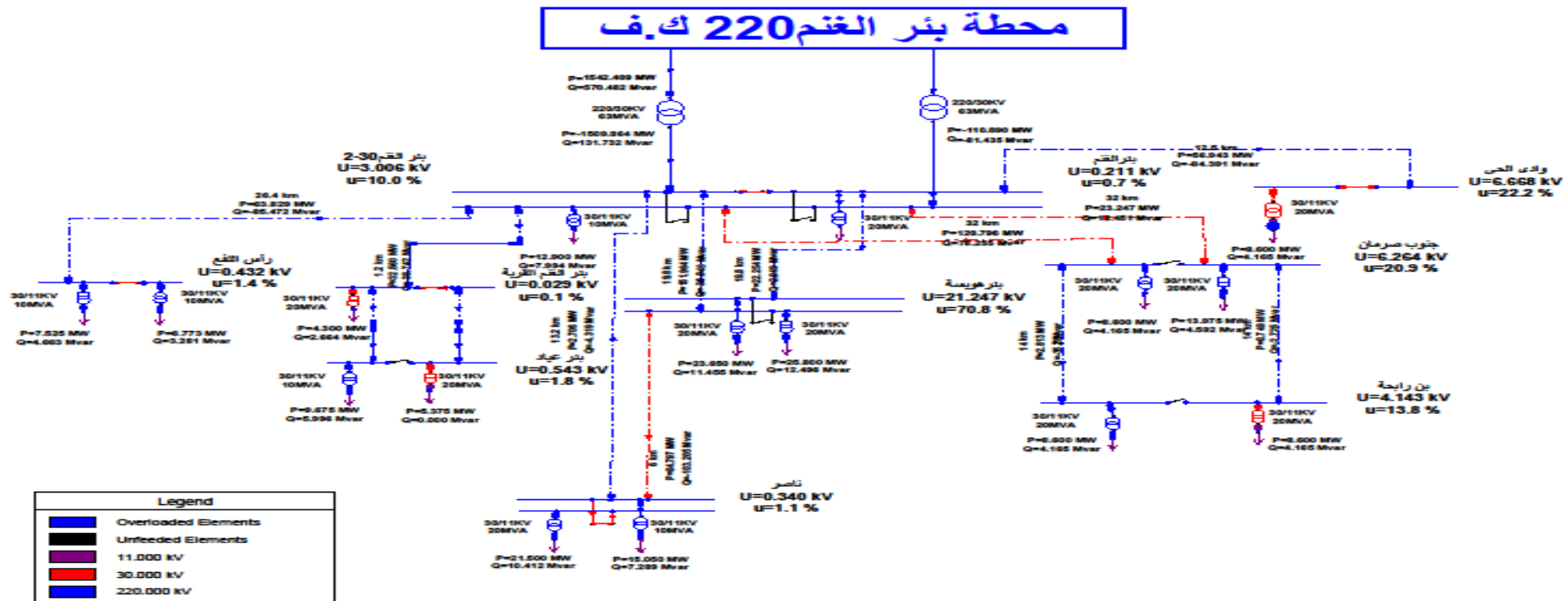


Figure 6: System analysis after Load growth of 10 years

Table 5: System Analysis After Load Growth of 10 years

No	Parameter	Value
1-	Total Active Power Loss (MW)	400.82
2-	Total Reactive Power Loss (MVar)	2745.82
3-	Total Active Load (MW)	400.82
4-	Total Reactive Load (MVar)	-2745.82
5-	Total Active Generation (MW)	~2428.81
6-	Total Reactive Generation (MVar)	~421.07
7-	Minimum Bus Voltage (p.u.)	0.37
8-	Maximum Bus Voltage (p.u.)	1.79
9-	Highest Node Loading (%)	~7178.4

3-1 Case of Applying DG Penetration For System Remedy After Ten Years Growth

In this case to remedy system performance after 10 years load growth considering DG penetration for system remedy by considering five DG units at buses that suffering low voltage profile of Ben Rabha, Ben naser, Ber hwesa, Ber aead and Ras alfah respectively as shown in Figure 7 and applying OPF analysis, the results of load flow also shown on Table 6.

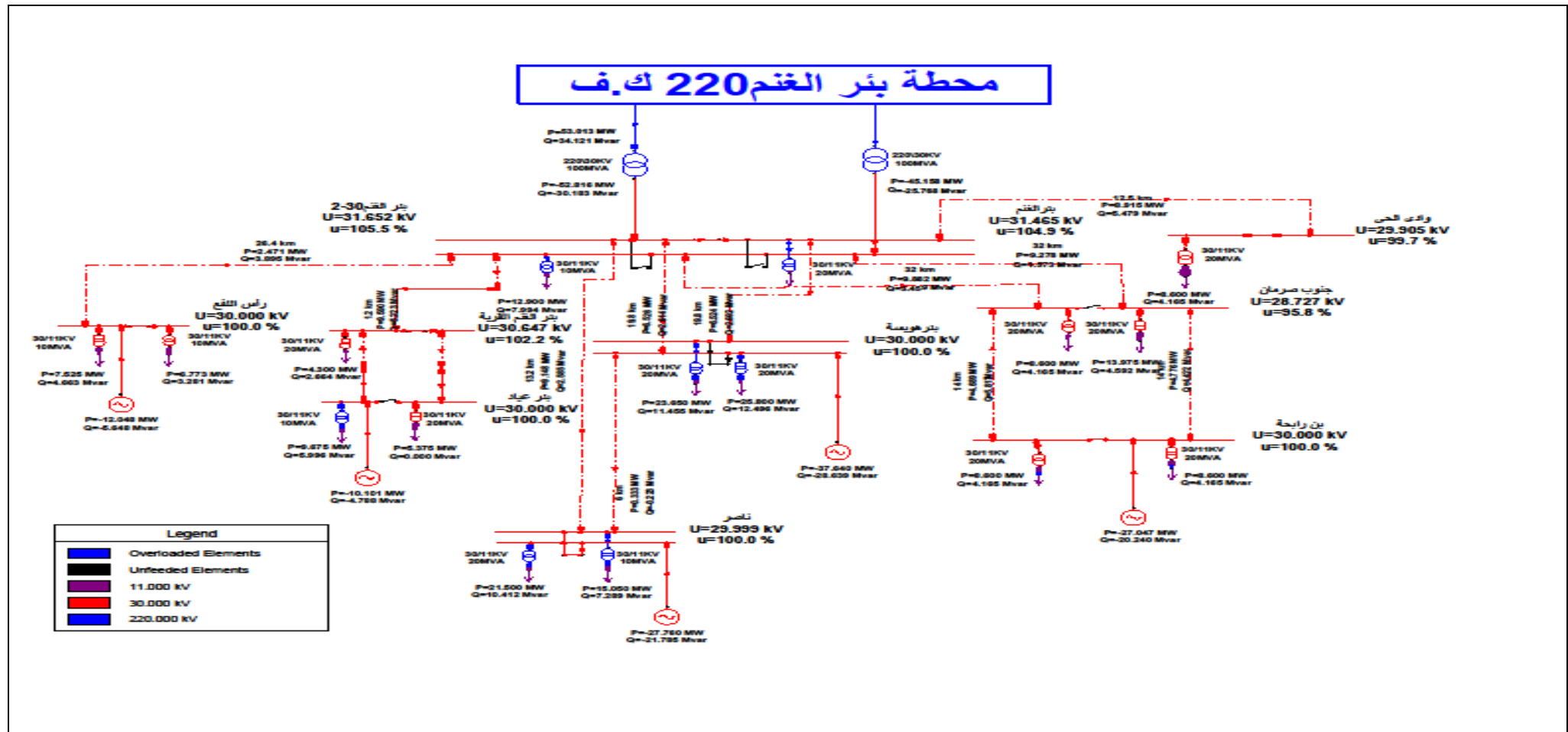


Figure 7: Analysis of Load growth case after 10 years applying DG penetration

Table 6: Analysis of Load growth case after 10 years applying DG penetration

No	Parameter	Value
1-	Total Active Power Loss (P Loss)	5.26 MW
2-	Total Reactive Power Loss (Q Loss)	39.74 MVar
3-	Total Active Power Import (P Imp)	58.82 MW
4-	Total Reactive Power Import (Q Imp)	30.18 MVar
5-	Total Active Generation (P Gen)	212.91 MW
6-	Total Reactive Generation (Q Gen)	143.80 MVar
7-	Total Active Load (P Load)	207.65 MW
8-	Total Reactive Load (Q Load)	104.06 MVar
9-	Minimum Bus Voltage	10.82 kV
10-	Maximum Bus Voltage	220 kV
11-	Highest Node Loading (%)	181.1 %

From results it seen that some (30/11) transformers need to be upgraded on buses of Ras Allfe, Bin Rabah, Beer ayad, Bin nasser, Wadi alhayi, and Janub surman.

Also DG units may be relocated for better performance of the system.

4. Case Study of Isolated Grid Operation Considering Minimum and Maximum Loading Cases:

In this case, the grid system performance will be checked considering the case of disconnection of the grid from the main network and operates as an isolated grid. The DG units will be the main supply to the system keeping the same locations as before the isolation of the grid, in this case the DG size is estimated by the OPF program.

4.1 Considering Minimum Loading Case:

The minimum loading of year 2014 during month of April is considered and the OPF analysis is shown in Figure 8 and Table7.

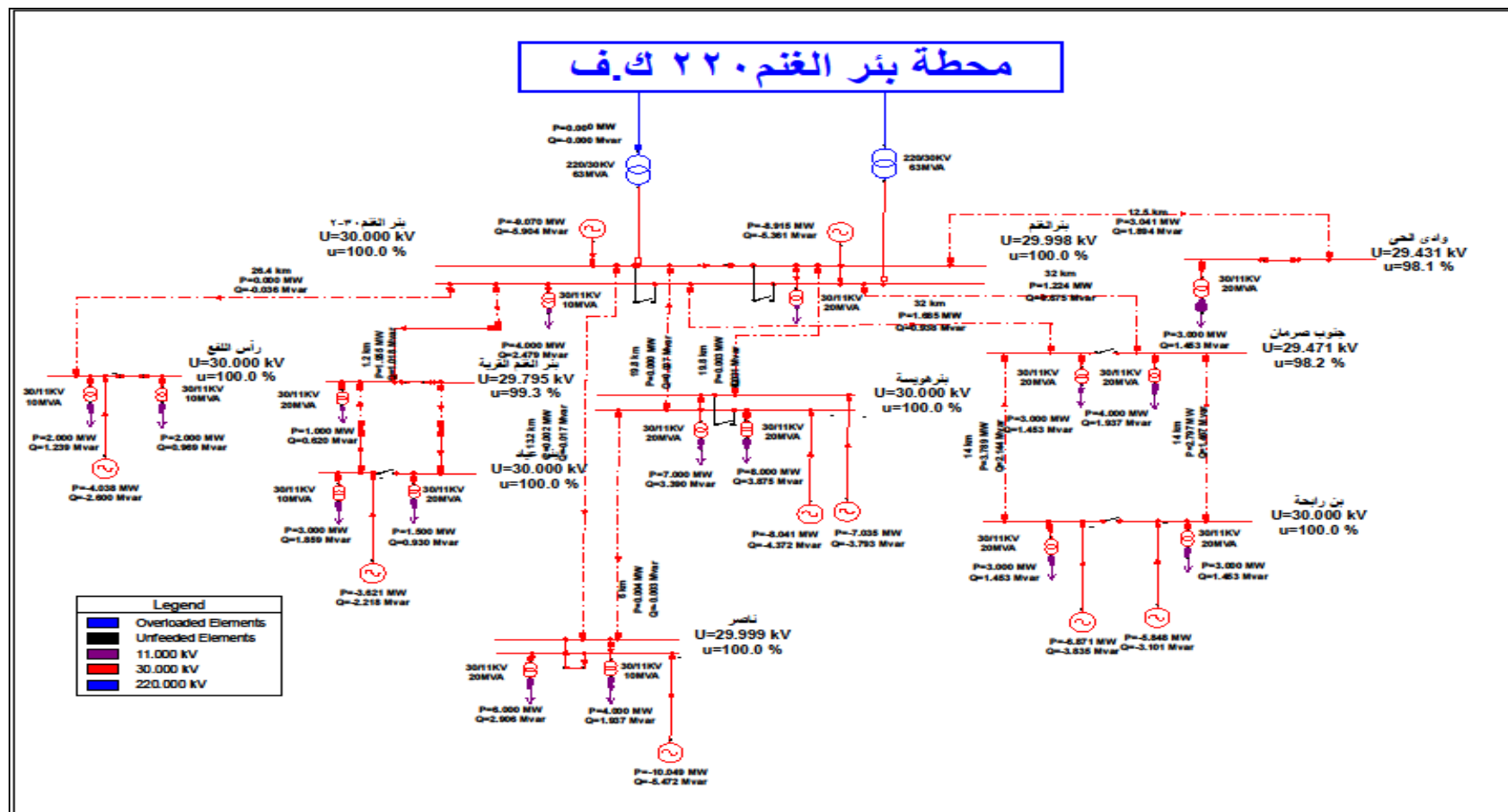


Figure 8: Isolating grid with DG at minimum load of year 2014

Table 7: Isolating grid with DG at minimum load of 2014

Item (system-wide)	Value (MW)	Value (MVar)
Active Power Loss (P Loss)	0.56	—
Reactive Power Loss (Q Loss)	—	3.48
Imported Power (P Imp / Q Imp)	17.99	11.27
DG Output (P Gen / Q Gen)	63.49	36.66
Total Load (P Load / Q Load)	62.93	33.18

4.2 Considering Maximum Loading

The results of OPF program analysis shown in Figure 9 and the results shown in Table 8 from which one can see the following comments:

- All power is generated by DG units.
- All losses are highly reduced due to non-central locations of DG.
- Voltage system profile is great and close to 100% level.
- All system performance are enhanced.

Table 8: Isolating grid with DG in max load

Item (system-wide)	Value (MW)	Value (MVar)
Active power loss (P Loss)	0.95	—
Reactive power loss (Q Loss)	—	7.15
Imported power (P Imp / Q Imp)	27.75	18.04
Distributed generation (P Gen / Q Gen)	97.53	58.11
Total served load (P Load / Q Load)	96.58	50.96

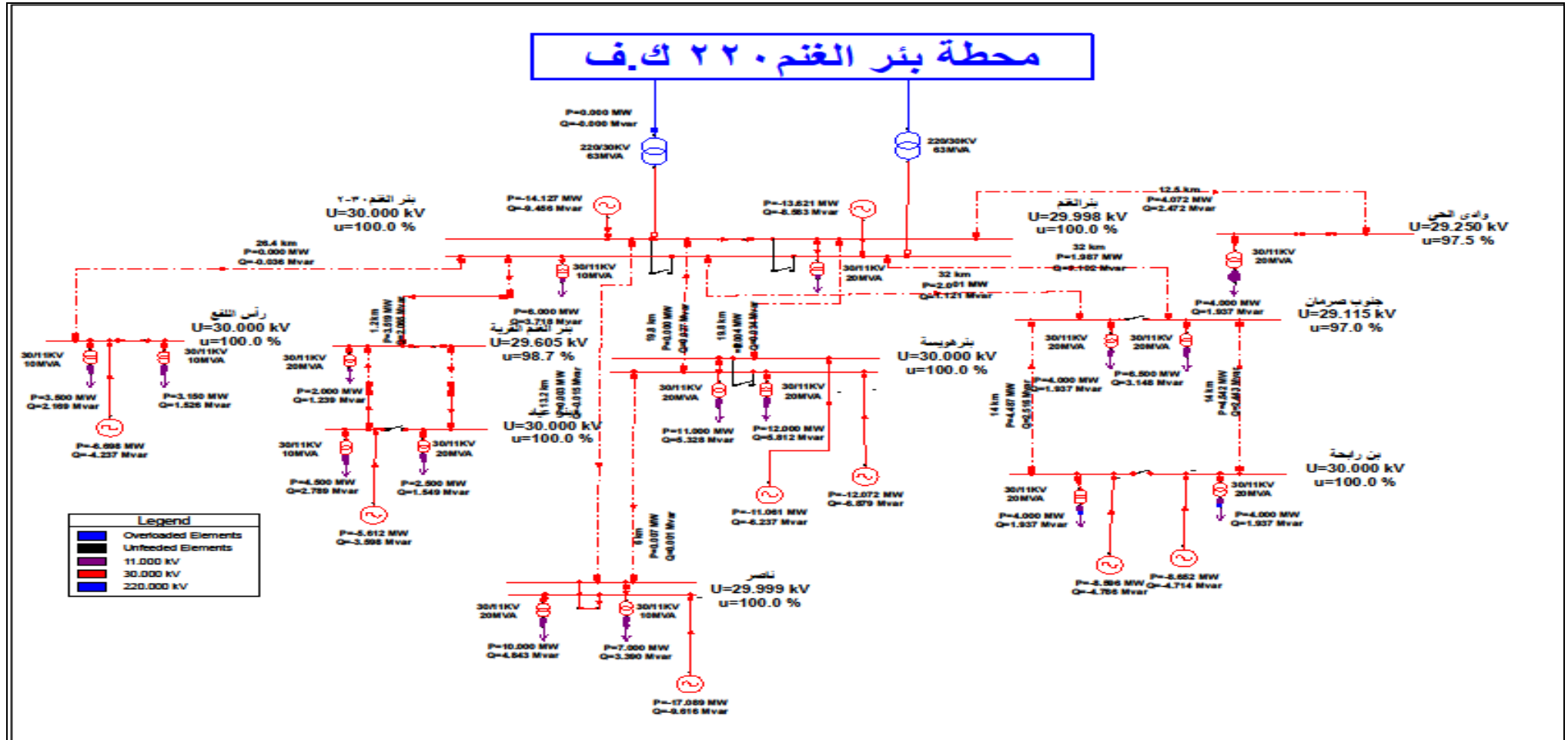


Figure 9: Isolating grid at peak load of 2014

4.3 Case Discussion

In the above two cases for minimum and maximum loading with the considered network isolated from the main grid, the following are noticed:

- All voltage profiles are within the acceptable range.
- The differences of P and Q imported from the main network and installed DG unit together are 34MW and 21.5 MVAR respectively.
- This differences can be used as a storage from DG unit during the day and use during night time since the peak is duranly.
- Power factor for maximum loading case was 0.883 and for minimum load 0.884 that means the system power factor is good.
- Using DG with network the power lose not exceeding 0.929 MW
- And reactive power losses is 7.14MV comparing with base case the losses that was 8.194MW, reactive power losses 29.428MVAR.

Which means saving more than 7MW for active power and 21.5MVR for reactive power. That means saving a great amount of money yearly that estimated To be 61320MWH yearly if 20,000D is the cost of MW the money saved yearly will be 1.226400D.

5. Case Study Considering the Conventional Methods of Re-planning

The conventional methods for re-planning known as adding and/or expanding. First, the adding method will be used, and second the expanding method will be applied.

5.1 Considering Traditional Solution of Adding

In this case the ten years load growth is considered where the system was collapsed and the traditional method of adding new transfo mers and new lines will be considered. The added elements are shown in Table 9 blew, and shown on Figure 10 by dotted lines.

Also the system analysis results are shown in Table 10.

Table 9: Shows the add elements to the network

Elements	Bus	Location
Transform(1)	100mva	Byr Alghanam(1-30)
Transform(2)	100mva	Byr Alghanam(2-30)
New line	Line length	Between
line(1)+line(2)	32KM	Byr Alghanam& Janub Sirman
Line(3) + line(4)	19.8 KM	Byr Alghanam & Byr Hwysb
Line (5) + line(6)	132 KM	Byr Alghanam & Bin nasser
Line (7)	26.4 KM	Byr Alghanam & Ras allafe



Figure 10: Analysis of Load growth after 10 years with add new transformers & line at peak loads

Table 10: Analysis of Load growth after 10 years with add new transformers & line at peak loads

Item	Value (MW)	Value (MVar)
Active Power Loss (P Loss)	15.7	—
Reactive Power Loss (Q Loss)	—	52.5
Imported Power (P Imp / Q Imp)	212.6	100.6
Generated Power (P Gen / Q Gen)	212.6	100.6
Total Load (P Load / Q Load)	196.9	48.1

5.2 Case of considering traditional solutions by adding new substation:

In this case instead of expansion new substations are added to compensate for voltage violations and system load ability, the considered added substations are given in Table 11.

Table 11: Show the add new substation

Elements	Location
New substation (1)	Byr Alghanam (1-30)
New substation (2)	Byr Alghanam (1-30)
New substation (3)	Byr Alghanam (2-30)

The analysis results are shown in Figure 11 where system performance has greatly enhanced but not as the case of DG penetration case. Table 12 shows the results of details analysis

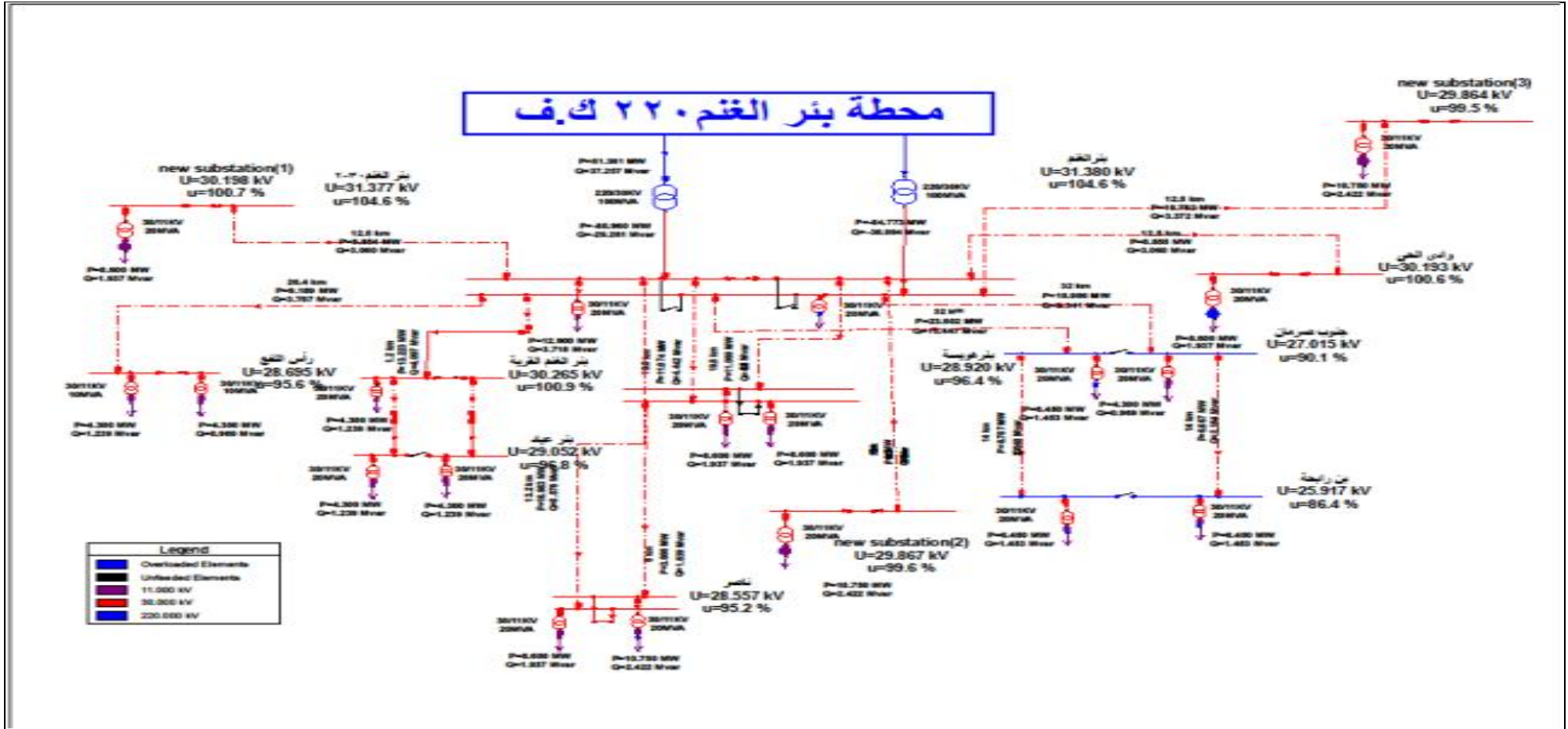


Figure 11: Load growth after 10 years add new substation in max

Table 12: Load Growth After 10 Years add new Substation in max load

Item	Value (MW)	Value (MVar)
Active Power Loss (P Loss)	13.0	—
Reactive Power Loss (Q Loss)	—	48.1
Imported Power (P Imp / Q Imp)	166.6	85.8
Generated Power (P Gen / Q Gen)	166.6	85.8
Total Load (P Load / Q Load)	153.6	37.8

5.3 Cases Discussion of System Remedy By Conventional Methods:

The system remedy by a conventional method of expanding and adding shows a good remedy to the system performance even though still system to be enhanced through the details of using a transformer tapping's or capacitor compensation at the faraway busses that still needs a lot of efforts and extra cost all the time as load is increased.

Adding of new transmission and / or new substations need time to be added for buying, shipment, and installing, and a lot of detailed studies to confirm the accuracy of best performance by using such conventional methods, as well as its impacts on delaying the development growth of society.

From results it shown that DG penetration PP methods for electrical distribution developments are the best solution to face the demand growth.

VI. Discussion of Results

The results obtained from the analysis of the 30 kV distribution network in Bir El Ganem confirm the effectiveness of distributed generation (DG) integration in improving network performance under varying loading conditions.

Regarding the base case losses, the network initially exhibited active power losses of 8.194 kW and reactive power losses of 29.428 kVAR without any DG integration. Following the introduction of DG, these losses dropped substantially to 2.803 kW and 15.275 kVAR respectively, representing a marked improvement in system efficiency.

When compared with conventional expansion strategies, DG demonstrates clear advantages. Traditional approaches such as adding transformers and lines resulted in active and reactive losses of 15.704 kW and 52.493 kVAR, while the option of adding a new substation yielded losses of 13.041 kW and 45.659 kVAR. Both conventional alternatives, therefore, produced higher losses than the DG-based solution, confirming that conventional reinforcement methods, despite being technically feasible, are less efficient in loss reduction.

The load growth scenario further reinforces this conclusion. Without DG, losses after ten years of load growth escalated dramatically to 400.816 kW and 2745.82 kVAR, reflecting the severe strain that conventional networks face under sustained demand increase. However, when DG was incorporated into the ten-year load growth scenario, losses were contained to only 5.263 kW and 30.737 kVAR, an outcome that highlights the long-term sustainability and scalability benefits of DG in managing future load growth.

Finally, under islanded (isolated grid) operation, the network maintained notably low losses even with DG support, ranging from a minimum of 0.56 kW and 3.48 kVAR to a maximum of 0.949 kW and 7.146 kVAR. This demonstrates that DG not only reduces losses under grid-connected conditions but also ensures stable and efficient operation when the network is isolated from the main grid.

Taken together, these findings validate that DG integration offers a technically superior and more cost-effective alternative to conventional network expansion techniques such as transformer tap adjustments and capacitor compensation. Beyond loss reduction, DG offers practical advantages including ease of installation, flexibility in sizing, and suitability for peak load conditions, particularly when combined with renewable energy sources and energy storage systems. The comparable and more efficient loss levels achieved through DG, relative to conventional capacity expansion methods, confirm its viability as a sustainable and effective solution for enhancing the reliability, efficiency, and long-term performance of distribution networks.

VII. Recommendations for Future Work

Based on the findings of this study, several directions for future research are recommended:

A detailed investigation into different DG types and their optimal sizing and penetration levels, with particular focus on their impact on system stability and short-circuit behavior.

Further study of the impact of DG penetration on the protection coordination of distribution systems, as this remains an area requiring more in-depth analysis.

Investigating the use of PV and wind generation systems to address energy demand in remote areas and densely populated regions.

Exploring the use of off-peak periods to charge energy storage systems using DG-generated energy, enabling this stored energy to be utilized during peak-load and emergency conditions.

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