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A Load Flow Analysis Method for Kufa Cement Plant

A B S T R A C T

The energy needs have been enlarged extremely. The electricity power generators are utilized and distributed in the national (local) grid. Many factors can affect on national distribution grid stability, such as load flow. It is utilized to evaluate various operating states for energy generation and distribution systems. In this article, six different generators are distributed in Kufa (Iraq) cement plant based on load flow balancing. Behinds, these distributed generators work under two modes, such that island mode and regular operation. The proposed modules are analyzed using Electrical Transient Analyzer Program (ETAP) software. The achieved analysis can help to reduce the distribution grid shutdown. Furthermore, the load balancing can be achieved at both modes. Load flow analysis takes consideration for the total energy demands and losses of the system separately in order to balance load and optimize operation. The results show that the buses' voltage drop in island mode was more than the voltage drop when the local grid connected to the national grid. The problems of drop voltages and power factor were solved.

تحليل انسيابية الاحمال في معمل سمنت الكوفة

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الخلاصة

ان الحاجة الى الطاقة تتصاعد يوما بعد يوم, مولدات الطاقة الكهربائية تستخدم وتتوزع على شبكة التوزيع (المحلية) الوطنية, هناك عدة عوامل يمكن ان تؤثر على استقرار شبكة التوزيع الوطنية مثل انسيابية الاحمال. يعتبر تحليل انسيابية الاحمال طريقة مهمة لأغراض التشغيل, وتستخدم لحساب حالات العمل المتنوعة لنظم توليد وتوزيع الطاقة. في هذا البحث, تم توزيع ستة مولدات مختلفة في معمل سمنت الكوفة (العراق) على اساس موازنة انسيابية الاحمال, بالإضافة الى ذلك, هذه المولدات الموزعة تعمل بنظامين هما نظام الجزيرة island mode والنظام العادي normal mode. نظام الجزيرة island mode هو طريقة لتجهيز القدرة محليا دون الحاجة للشبكة الوطنية وخاصة في حالة حدوث خطا او عطل فيها (الشبكة الوطنية في العراق تصنف على انها غير مستقرة بسبب عدة مشاكل منها اعطال انظمة التوليد والتوزيع المتكررة). تم اقتراح تصاميم ونماذج لتحليلها باستخدام برنامج ETAP. هذه التحليلات مهمه في مساعدتنا على تقليل انقطاع القدرة التام في الشبكة. بالإضافة الى ذلك من الممكن انجاز موازنة الاحمال باستخدام نظامي التشغيل. ان تحليل انسيابية الاحمال يأخذ بنظر الاعتبار الحاجة للطاقة والمفقودات في المنظومة بشكل منفصل لغرض موازنة الاحمال والوصول الى المثالية في العمل. ان النتائج اظهرت ان هبوط الفولتية في الوسط الناقل خلال نظام الجزيرة Island mode اكثر منه في النظام العادي Normal mode .وتم معالجة مشكلة هبوط الفولتية وكذلك عامل القدرة.

الكلمات الدالة: تحليل تدفق الحمل, ETAP ، وضع الجزيرة، الشبكة المحلية.

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1. INTRODUCTION

Recently, electricity require has increased enormously. Fossil fuels are depleting rapidly as a result of energy manufacturers are considering sustainable energy such as wind and solar energy sources [1, 2]. These energy generators can work as a group or an individual generator called Distributed Generators (DGs). In the electrical energy system, the power distribution network (grid) has become more complicated; therefore many issues need to be considered, such as safety, efficiency, power factor, emergency shutdown, load flow, etc. Load flow analysis is a very significant study for investigating issues in electricity system operating and designing [3]. The power distribution grid is incapable to supply the comprehensive requirement of electricity due to these issues [4].

For the last few years, it was highlighted and interested in many researches [5]. The latest developments in electrical engineering have established a revolution in this science after the improvement of computer software [4]. For the electrical operation system, load flow was analyzed, simulated, and modeled in different ways. Many articles are [6, 17, 20], present a load flow fundamental equation in order to help researchers to find a suitable numerical methodology. Moreover, energy efficiency was considered by the proposed new methodology [7]. In [8], a mathematical model was proposed to study smart monitor effects on the distributed system.

According to [9] a novel model was developed for small scales load forecasts. In fact, distributed generators depend on loads of energy demands. Therefore, the short term load forecast was suggested to optimize a power system operation. Additionally, a hyper-forecast engine was utilized in numerical methodology [10, 11]. Using load flow analysis can give accurate results that help to mitigate unwanted black-downs due to alternative demands and generating [2].

In reference [12], a novel optimization algorithm is associated with the fuzzy system and practical swarm intelligent that can enhance the stability of the electricity distribution system through deploying generators at selective locations. Similarly, the other proposed algorithm was designed to optimize a distribution system scale by employing the distributed generators at a suitable position [13].

The simulation of an enormous electrical energy system was adopted in this article to study the load flow as well as load balancing. Overloading of power/distribution grid, voltage drop, demands, line conductors, cables current carrying ability, power factor, short circuits, the power dissipated, total harmonic distortion, etc., can be analyzed at any preferred workplace (i.e., Kufa Cement plant). Furthermore, we can simulate the comprehensive energy system and can combine many grids as they are essentially connected, referring to this study. The proposed simulation can also be coupled with any project designer or manager based on a trusted plan and cheap establishment. This article emphasizes the professional use of Electrical Transient Analyzer Program (ETAP) software in order to analyze and study load flow in an electrical generation system to establish a stable energy system; it may be very helpful to modifying a local grid [14].

A novel method was proposed to examine the electrical system network based on ETAP outcomes of one line diagram. The followed diagram was executed to implement load flow and short circuit examination under a steady state for Kufa Cement Plant in Iraq. Moreover, voltage and current analyses are achieved for a non-linear load. An analytical module was suggested to analyze the power factors, voltages, currents, and power flow throughout the power system on both normal an island mode [15]. Load flow analysis can provide a balanced steady operation state of the electrical system, without considering transient system processes. In ETAP, for power balance equations, a load flow study is performed by estimating many variables, such as ignoring transient state [16, 17].

ETAP (Electrical Transient Analyzer Program) is also complicated, similar to the real electrical power system; however, it is a significant required tool to examine and analyze the proposed energy system. Additionally, it provides an important procedure to enhance system efficiency and reduce project operation cost at the same time. In this article, two load flow analysis have been studied. First case, six distributed generations were connected with national network (Normal Mode), then the second case, DGs connected locally (Island Mode). Utilizing synchronized island mode on any device that is matched can supply power domestically when the connection broken or when any fault happen in the national grid emergently.

A new strategy based on location of deployment distributed generators, namely scenario A and scenario B. System losses, line loading capability, and generated power has been determined, with and without the existence of the distributed generators deployment in the distribution network [18].

Shunt capacitors are widely used, in different sizes, in power systems as they supply reactive power and boost local voltages. The optimum location of shunt compensation is presented to boost local voltages at the system load buses, taking the voltage as a constraint. The proposed method is applied to an 11-bus power system [19].

The rest of this article is organized as follows. Section 2 defines the ETAP software and outlines the simulation procedure. Section 3 presents the problem being considered in this article, which is load flow analysis with the national grid (Normal Mode) and explains our developed design. Then, Section 4 studies and analyzes load flow in island mode. Finally, Section 5 presents conclusions and suggests some useful recommendations for future work.

2. SIMULATION AND ANALYTICAL MODULE

Before starting, it should present the significance of load flow analysis for the power system. The angles at each bus in the steady state and voltage magnitudes can be obtained. Additionally, the magnitudes of the buses' voltage are necessary to be kept with some limitations.

Previously, the load flow was used to calculate the voltage magnitudes and their angles by the real and reactive power flow through each bus [20].

Besides, the diversity of power flow in the sending and receiving ends can be calculated, as well as the losses can also be figured on a particular bus. Moreover, the over and under load conditions can be found out. To design a new power system network, the load flow study of a power system is important to choose the optimum process of a system with minimum losing [5].

For a deeper understanding, an ETAP is the most inclusive simulation software in order to design an optimal generating and distributing electricity power network [1]. ETAP gives a set of solution scenarios for many regular issues such as load flow, load forecasting, short circuit, flashing, relay coordination, optimal power flow, voltage sags, transmission line capacity, load shedding, sub-synchronous resonance, transient period, harmonic waves, network stability, etc. It can be modified to offer the requirements of any massive power system [2, 21] All instruments, devices, and equipment (i.e., Transformer, Generators) are obtainable, which decreases the substantial time of the programmer. ETAP highlights the network's trouble-shootings, and it reports all operation's faults by simple error reports [22, 23].

As early introduced, according to grid topology with the loads and devices' impedance combining with generators and consumers, load-flow analysis can compute voltage profiles for each bus as well as examining individual and overall loads of grid terminals, such as transmission lines. Additionally, many limitations were considered by the proposed method, such as the highest load and range of voltage.

In this context, six distributed generation units have been connected with the national electricity grid. Fig. 1 shows a single line diagram drawing by using ETAP software.
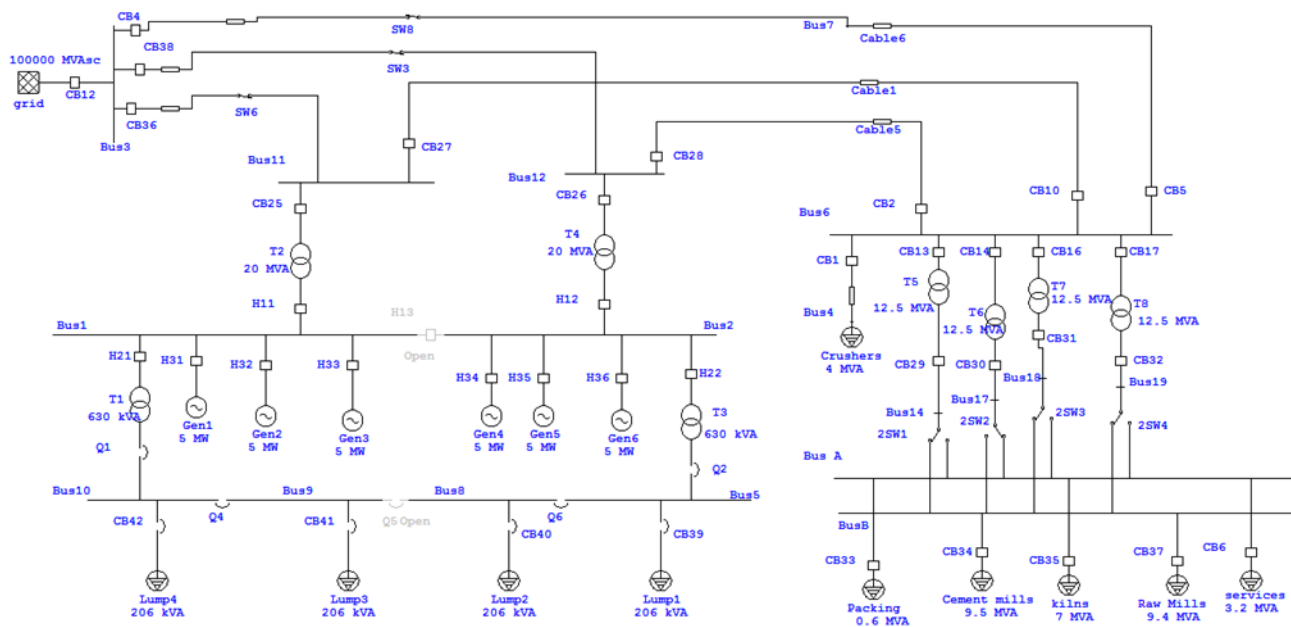

Fig. 1. Single Line Diagram Drawing.

According to the electrical crisis in Iraq, that was related to industry field development. Fig. 1 shows the drawing of the Kufa Cement Plant as a case study to demonstrate our simulation. The generation units work individually to supply the demanded energy for all plant's departments. Behinds, those units were connected as distributed generators to the national grid whenever the demands less than the generated amount. There is no doubt; the cement industry needs uninterruptable sources with stable electricity distributing networks. Using ETAP simulation can strongly minimize energy consumption and losses based on scheduling shutdown and mitigate unacceptable interrupt as well as balancing load flow.

3. LOAD FLOW ANALYSIS FOR A PROPOSED CEMENT FACTORY CONNECTED TO A NATIONAL GRID (NORMAL MODE)

In the ETAP simulation, the buses' color is changed based on the voltage value. For example, black color refers to stable voltage (there is no change in the voltage value). Additionally, the pink color means an acceptable voltage drop. However, red color indicates inacceptable dropped voltage. Also, ETAP was designed based on simplicity and variety by using simples, icons, and tags [24, 25]. ETAP focuses on load flow, short circuit, currents loop, RMS, phase shift, and power dissipated. In general, load flow analysis is a very significant method for project planning and energy system scalability as well as optimization of operation.

Table 1 presents the simulation results such that buses 5, 8, 9, and 10 were under voltage, which was 97.54% (390 volts) instead of (400 volts). Furthermore, the simulation scenario shows that the color of those

previous buses be pink, and it was different from the others.

Table 1. Load flow with national gird.

Device ID	Condition	Rating/Limit	Unit	Operating	%Operating
Bus 10	Under Voltage	0.40	kV	0.39	97.8
Bus 5	Under Voltage	0.40	kV	0.39	97.8
Bus 8	Under Voltage	0.40	kV	0.39	97.8
Bus 9	Under Voltage	0.40	kV	0.39	97.8

Fig. 2 shows the load flow analysis for Kufa Cement Plant whenever the local grid is connected to the national grid by using ETAP.

Load flow analysis takes consideration for the total energy demands and losses of the system separately to balance the load and optimize operation. From the results, the proposed module schedules energy cut off, minimizes operation cost, and recommends an optimal distribution.

Table 2 summarizes total generation, loading, and demands. The recorded data show that the total generated energy was (25.8MW), and the required energy was (26.66MW). This demands energy is important to operate and execute plant's departments such as horizontal and vertical kilns, raw and cement mills, rock crushers, etc.. Kiln's stages have high load and energy consumption when compared to others. The difference between generation and demands can be taken from the national grid (0.861MW) which called **swing buses** (source), However, when the load less than the local generation (less than **non-swing buses** (source)), the cement plant's distribution grid (local grid) can export energy to national grid reversely instead of import it forwardly.
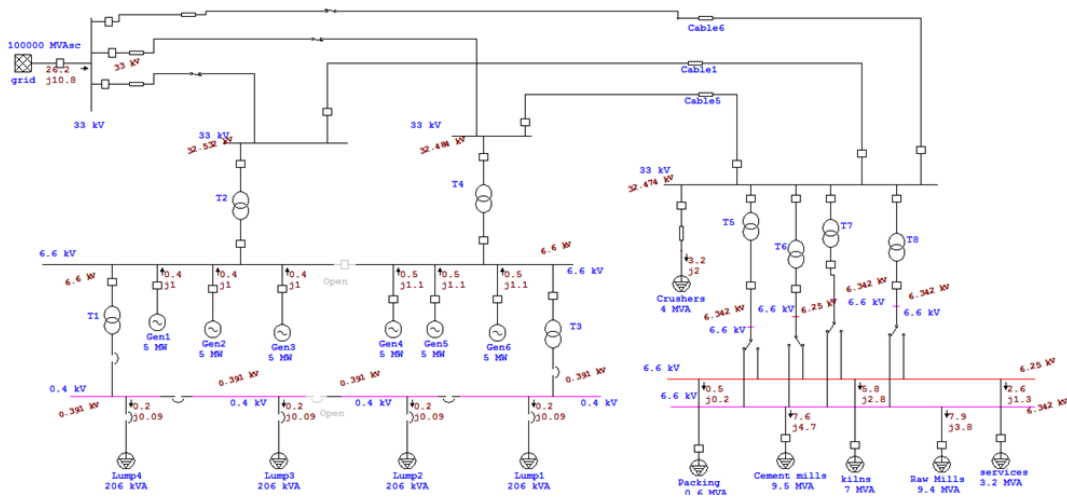

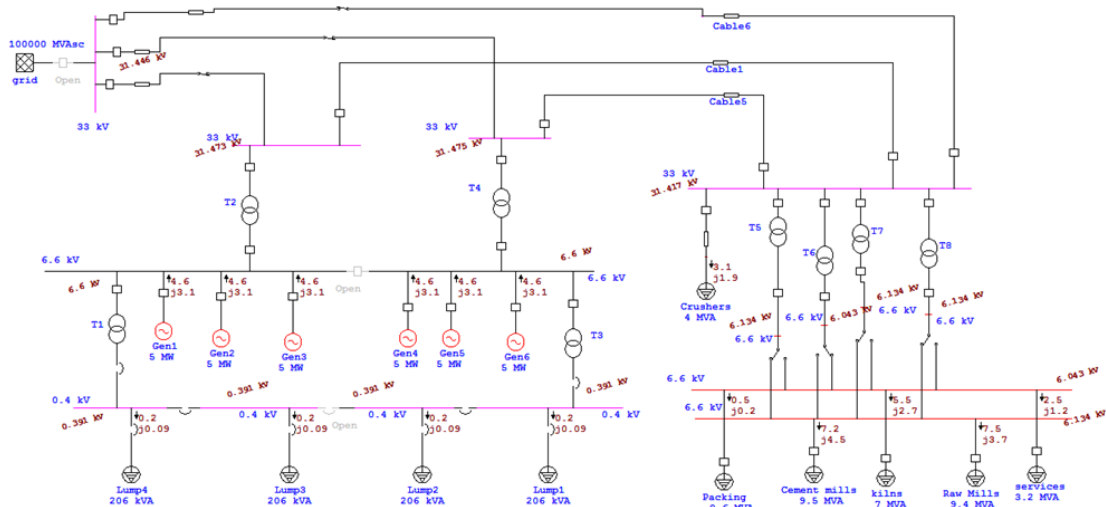**Fig. 2.** Load Flow Analysis with national gird.

Fig. 3. Load Flow Analysis in island mode.

Table 2. Total generation, loading, and demands.

	MW	Mvar	MVA	%PF
Source(Swing Buses)	0.861	6.166	6.226	13.83 Lagging
Source(Non-Swing Buses)	25.8	0.702	25.810	99.96 Lagging
Total Demand	26.661	6.868	27.531	96.84 Lagging
Total Motor Load	5.399	2.834	6.098	88.55 Lagging
Total Static Load	21.031	1.272	21.069	99.82 Lagging
Total Constant Load	0	0	0	
Total Generic Load	0	0	0	
Apparent Losses	0.231	2.762		

Table 3 presents the voltage drop and summarizes individual losses, i.e., (cables and transformers). Additionally, the total frequency cannot be controlled, and the balance voltage drop cannot be balanced in terms of synchronization whenever the local generators are connected to the national grid.

4. LOAD FLOW ANALYSIS FOR A PROPOSED CEMENT FACTORY CONNECTED TO DISTRIBUTED GENERATORS (ISLAND MODE)

The load flow analysis for the distributed generation system in island mode can be examined by using ETAP, as shown below in Fig. 3 and Table 5.

Fig. 3 shows the cement plant's load flow diagram based on island mode; the voltage and frequency can be easily controlled domestically. In addition, the load flow can be balanced and distributed symmetrically (load sharing)

Table 4 shows the marginal report, which presents the voltage drop at each bus when the local grid is separated from the national grid (island mode). According to data, the buses' voltage drop in island mode was more than the voltage drop when the local grid connected to the national grid. For instance, as shown in Table 1, four buses were changed in voltage drop. However, five buses' voltages were alternated in island mode (Table 4). Next tables show the demands, losses, generation and load flow reports to summarize and compare the results for island mode

Table 5 summarizes the total generation, loading, and power demands based on island mode. According to Table 6, the demands were (26.003 MW), and the local generators can supply all demands without needing the national grid. On other words, the demands equal to or less than the generated energy, and the load flow were balanced directly. Also, the report presents the voltage drop, total generation, and demands in island mode

.

Table 3. Losses report.

CKT/Branch ID	From-To Bus Flow MW	Mvar	To-From Flow MW	Bus Mvar	Losses kW	kvar	%Bus Voltage From	To	Vd % Drop
T1	0.364	0.182	-0.358	-0.173	5.8	8.7	100	97.8	2.23
T2	12.536	0.147	-12.497	0.637	39.2	784.9	100	99.8	0.19
T3	0.364	0.182	-0.358	-0.173	5.8	8.7	100	97.8	2.23
T4	12.536	0.191	-12.497	0.594	39.3	785	100	99.8	0.21
Line7	-0.169	3.148	0.177	-3.142	8.2	6.5	100	99.8	0.19
Line14	1.030	3.018	-1.021	-3.011	8.4	6.6	100	99.7	0.28
Cable1	-12.307	-2.532	12.320	2.504	13.3	-27.8	99.7	99.8	0.12
Cable5	-12.484	0.566	12.497	-0.594	13.1	-27.9	99.7	99.8	0.10
Cable6	-1.021	-3.050	1.021	3.011	0.9	-38.8	99.7	99.7	0.03
T5	5.391	1.555	-5.375	-1.344	16.2	211.0	99.7	98.4	1.25
T6	9.639	0.352	-9.591	0.272	48.0	623.5	99.7	99.2	0.52
T7	5.391	1.555	-5.375	-1.344	16.2	211.0	99.7	98.4	1.25
T8	5.391	1.555	-5.375	-1.344	16.2	211.0	99.7	98.4	1.25
Line12	0	0	0	0	0	0	99.8	99.8	0
					230.7	2762.5			

Table 4. Report of voltage drop in island mode.

Device ID	Condition	Rating/Limit	Unit	Operating	%Operating
Bus A	Under Voltage	6.60	kV	6.44	97.6
Bus10	Under Voltage	0.40	kV	0.39	97.8
Bus14	Under Voltage	6.60	kV	6.39	96.9
Bus17	Under Voltage	6.60	kV	6.44	97.6
Bus18	Under Voltage	6.60	kV	6.39	96.9
Bus19	Under Voltage	6.60	kV	6.39	96.9
Bus5	Under Voltage	0.40	kV	0.39	97.8
Bus8	Under Voltage	0.40	kV	0.39	97.8
Bus9	Under Voltage	0.40	kV	0.39	97.8
Bus B	Under Voltage	6.60	kV	6.39	96.9

.

Table 5. Total Generation, Loading and Demands (island mode).

	MW	Mvar	MVA	%PF
Source(Swing Buses)	26.003	6.938	26.912	96.62 Lagging
Total Demand	26.003	6.938	26.912	96.62 Lagging
Total Motor Load	5.399	2.834	6.098	88.55 Lagging
Total Static Load	20.384	1.272	20.421	99.82 Lagging
Apparent Losses	0.231	2.762		

.

Table 6. Losses report (island mode).

CKT/Branch	From-To Bus Flow		To-From Bus Flow		Losses		%Bus Voltage		Vd % Drop
ID	MW	Mvar	MW	Mvar	kW	kvar	From	To	
T1	0.364	0.182	-0.358	-0.173	5.8	8.7	100	97.8	2.23
T2	12.642	3.293	-12.599	-2.441	42.6	852.2	100	98.2	1.76
T3	0.364	0.182	-0.358	-0.173	5.8	8.7	100	97.8	2.23
T4	12.634	3.281	-12.591	-2.430	42.5	850.8	100	98.2	1.76
Line7	-0.611	-0.084	0.611	0.084	0.3	0.3	98.2	98.2	0.06
Line14	0.611	0.084	-0.611	-0.083	0.3	0.3	98.2	98.1	0.06
Cable1	-11.975	-2.383	11.988	2.357	12.9	-26.8	98.1	98.2	0.12
Cable5	-12.577	-2.456	12.591	2.430	14.2	-25.7	98.1	98.2	0.13
Cable6	-0.611	-0.122	0.611	0.083	0.0	-38.3	98.1	98.1	0.01
T5	5.256	1.528	-5.240	-1.320	15.9	207.3	98.1	96.9	1.25
T6	9.395	0.378	-9.348	0.233	47.0	611.6	98.1	97.6	0.54
T7	5.256	1.528	-5.240	-1.320	15.9	207.3	98.1	96.9	1.25
T8	5.256	1.528	-5.240	-1.320	15.9	207.3	98.1	96.9	1.25
Line12	0	0	0	0	0	0	98.2	98.2	0
					219.5	2863.6			

Table 6 summarizes the losses at each part of our generation and distribution grid. The results show that the losses at each transformer and each cable as a part of island mode.

5. EFFECT OF ADDING THE SHUNT CAPACITOR IN THE PROPOSED CEMENT INDUSTRY

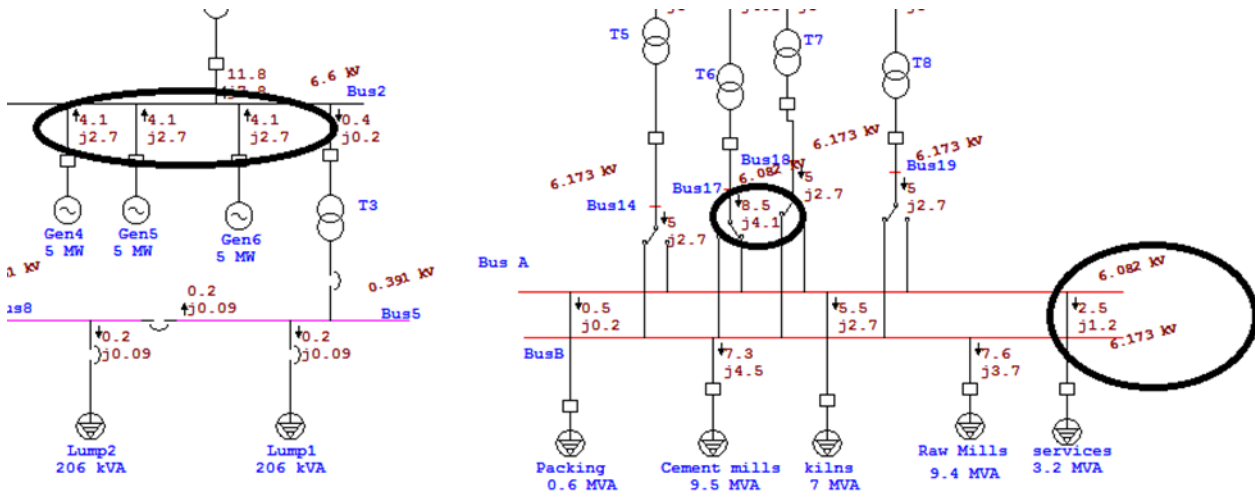The following figure shows the voltage and power factor improvement by capacitors

Fig 4. Load flow analysis without capacitors

From Fig. 4, we can present and calculate many variables such that the generators' power factor is an optional value, as well as the incidence of a dropped voltage in Buses A and B. we can summarize our numerical module as following

PF at Gen1 ….Gen6

S = P + j Q = 4.1 + j 2.7

$S = \sqrt{P^2 + Q^2} = \sqrt{4.1^2 + 2.7^2} = 4.91$ MVA

$PF = \cos_\varphi = \dfrac{P}{S} = \dfrac{4.1}{4.91} = 0.84$

The voltage at Bus A = 6.1 KV

The voltage at Bus B = 6.2 KV

Consequently, capacitors must be added at Buses A and B to addressing this problem and to finding capacitors value by using numerical computations such as the following list:

P_n stands for the real power losses

Q_n stands for the reactive power losses

Q_{source} is the reactive power magnitude at the source

$Q_{C,fixed}$ denotes the size of the fixed shunt capacitor bank

n denotes the nodes of the section being analyzed

$PF_{Desired} = 0.95$

For Bus A

$P_{Total} = \sum_{n=1}^{n=4}(8.5 + 0.5 + 5.5 + 2.5) = 17$ MW

$Q_{Total} = \sum_{n=1}^{n=4}(4.1 + 0.2 + 2.7 + 1.2) = 8.2$ MVar

$Q_{source} = P_{Total} * \tan(\cos^{-1}PF_{Desired}) = 17 * \tan(\cos^{-1}0.95) = 5.59$ MVar

$Q_{C,fixed} = Q_{Total} - Q_{source} = 8.2 - 5.59 = 2610$ KVar

For Bus B

$P_{Total} = \sum_{n=1}^{n=5}(5 + 5 + 5 + 7.3 + 7.7) = 30$ MW

$Q_{Total} = \sum_{n=1}^{n=5}(2.8 + 2.8 + 2.8 + 4.5 + 3.7) = 16.6$ MVar

$Q_{source} = P_{Total} * \tan(\cos^{-1}PF_{Desired}) = 30 * \tan(\cos^{-1}0.95) = 9.86$ MVar

$Q_{C,fixed} = Q_{Total} - Q_{source} = 16.6 - 9.86 = 6740$ KVar

As shown in Fig.5, by utilizing a shunt capacitor to both Buses A and B, the magnitude of the source current can be minimized, the power factor can be enhanced, and therefore the dropped voltage between the sending end and the load is also reduced.
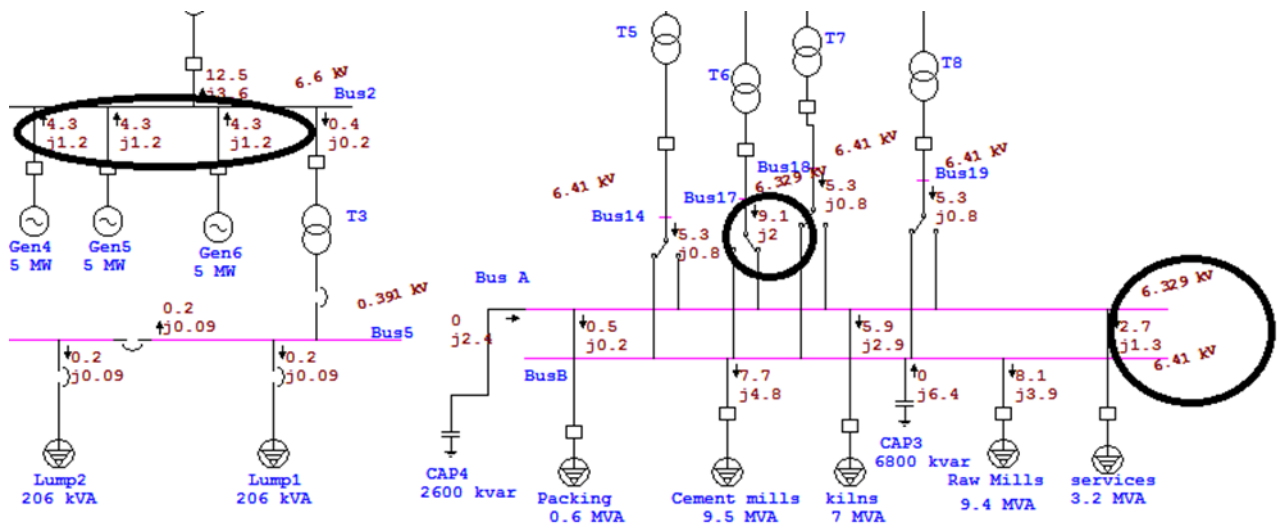
Fig. 5. Load flow analysis with capacitors.

It can also be concluded that:

Pf at Gen1 ….Gen6

S=P +j Q= 4.3 +j 1.2

$S= \sqrt{P^2 + Q^2} = \sqrt{4.3^2 + 1.2^2}$ =4.46 MVA

$PF = \cos_\varphi = \frac{P}{S} = \frac{4.3}{4.46} = 0.96$

The effect of appended capacitors was represented by Table 7

Table 7. The effect of added capacitors.

	Before adding capacitors				After adding capacitors			
	MW	MVar	PF	kV	MW	MVar	PF	kV
Gen1-Gen6	4.1	2.7	0.84	6.6	4.3	1.2	0.96	6.6
Bus A	8.5	4.1	0.90	6.1	9.1	2	0.97	6.3
Bus B	15	8.1	0.88	6.2	15.9	2.4	0.98	6.4

6. CONCLUSIONS

A load flow analysis was utilized to estimate various operating states of any energy system. Using the ETAP program formulates load flow very easily. In addition, it can be used to establish the best size and location of the energy system in order to avoid the issues of voltage drop and energy losses. The advantages of the simulation and analyzing the load flow were achieved via using ETAP program. The results show that the buses' voltage drop in island mode was more than the voltage drop when the local grid connected to the national grid, which can help to give high stability in the distribution system.

Moreover, simulation results established that the new strategically sized and located parallel capacitors within the distribution network assists to neutralize losses because of inductive loads and develop the voltage set by the whole network. Therefore the current has declined at the distributed generators. The magnitude of current was decreased, and power factor was optimized by capacitors. In industrial plants, improving the power factor has several benefits, which can give optimum electrical operation, high financial conservation and a longer lifetime for electrical equipment.

7.ACKNOWLEDGMENT

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