Participation of Unified Power Flow Controller (UPFC) and its impacts on the power System Operation based on optimal and economic dispatch algorithms in Libyan Electric Network.

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Abstract

The optimal power flow becoming more important because of its capabilities to deal with various situations of power system operation, this problem involves the optimization of system objective functions for power generation operation and control.

To satisfy the equality and inequality constrains for the highly nonlinear model of power system witch facing problems of voltage variations due to high load changes that leads to voltage collapses, needs to add tools that preventing such conditions to keep system stability, such as FACTS Devices.

This paper investigating the optimal power flow (OPF) and Economic Dispatch (ED) of the western area of Libyan National Electric Network of (220 &400kv) system, for optimizing power system losses and reducing fuel costs, by using different scenarios to keep the network operating in good condition.

OPF and (ED) are formulated as an optimization problem for minimizing the total fuel cost and power loss of all committed plants while meeting the network operation constraints. Applying the OPF and ED as base for system analysis with a Unified Power Flow Controller (UPFC) solved most power system problems and maintains system stability even during difficult operation condition.

Keywords — OPF, ED, UPFC, PF, optimization, MBTU, Heat rate curve, Cost rate curve

I- Introduction

A power system generally has several power plants, in which each have several generating units. The total load in the power system should be met by power generated of all power units in different power plants. Economic dispatch control determines the optimal power output of each power plant, and allocating the optimal power output of each generating unit within a power plant for each load, that will minimize the overall cost of power production, that includes the fuel cost, power loss, and operation and maintenance (O&M).

In economic dispatch practices there are many choices for determining the economic operating points of generators, the main aim of the economic dispatch is to analyze the system variables that affect the generator performance such as operational cost, the generator location, type of fuel, load capacity, and transmission line losses [1].

By including these variables one can be able to perform an economic dispatch problem for minimizing the operating cost functions.

The generation cost is typically represented by many curves, namely: Input/output curve (I&O), heat rate curve, fuel cost carves and incremental cost curve. (OPF) and (ED) are used for allocating loads to generator plants for minimum cost while meeting the network constraints [1].

The increasing complexities of large interconnected networks had fluctuations in reliability of power supplies, which resulted in system instability due to the difficulties to control the power flow and security, problems that resulted large number blackouts in different parts of the world [1].

Flexible Alternating Current Transmission System (FACTS) devices are used to enhance the controllability of power systems and improve all the restricted conditions in the structure of transmission lines to create smooth power transfer between areas. Energy demand has increased in recent years, which raise some energy issues and environmental problems that exceed the main issue of land availability and transmission line installation for utility companies.

The technology of power system utilities around the world has rapidly evolved with considerable changes in the technology along with improvements in power system structures and operation. The ongoing expansions and growth in the technology, demand more optimal and profitable operation of a power system with respect to generation, transmission and distribution systems [2].

II- HEAT RATE EQUATION MODE OF WESTERN LIBYAN (220KV&400KV) NETWORK.

Each thermal unit operating data for fuel inputs and power output is considered. And by using the transformable procedure for the heat rate and cost relation with power outputs a curve fitting algorithms will be used to perform equation, relating such data; the heat rate and cost rate equations can be performed to consider only the second order for quadratic form since the higher order power can be neglected, for simplify calculation and iteration procedure of solution, the form of these equation as following:-

Heat rate equation $(H) = AP_{gi}^2 + BP_{gi} + C$ (1) -or-

Cos rate equation $F(P_{gi}) = A'P_{gi}^2 + B'P_{gi} + C'$ (2)

Where:-

A, B, C, A', B', C' are constants

Pgi is the output power in MW.

I- ECONOMIC DISPATCH MODEL OF POWER SYSTEM.

a. Economic Dispatch Neglecting Losses.

A cost functions are assumed to be a known parameter for each plant. The variation of the dispatch functions with respect to active power generation is shown in Figure (1) ideally; they are monotonically increasing quadratic functions given by the equations (1) or (2) above.

Now, the problem is to find the real power generation P_{gi} for each generator in which the operating cost becomes minimums & the generating limits are satisfied $P_{gi.min}$ & $P_{gi.max}$ which is the minimum and the maximum limits. Let there be a generating station with NG generators committed & the given active load demand be PD ,The real power generation P_{gi} for each generator has to be allocated so as to minimize the total cost. Economic Dispatch attains its simplest form when the transmission losses are neglected. So, the total load demand PD is equal to the sum of power generated by the units, the optimization objective function can be written as:

$$Min\{F_i(P_{gi})\} = \sum_{i=1}^{N_g} F_i(P_{gi}) \qquad (3)$$

Equation (3) is subjected to

1-The equality constraint equation is the energy balance equation.

$$\sum_{i=1}^{N_g} P_{gi} = P_D \qquad (4)$$

2-The inequality constraint equation which is the generating limits, of each unit.

$$P_{gi_{min}} \le P_{gi} \le P_{gi_{min}} \qquad (5)$$

b. Economic Dispatch Considering System Losses

Transmission losses are neglected when they are small in magnitude but when the length of transmission is large in case of large network; transmission losses become accountable and cannot be neglected. They affect the process of economic load dispatch [3]. The economic load dispatch problem, considering the transmission power loss PL, for the objective function, is same as, equation (2) & equation (3). But what changes are the constraints to which the equations are subjected are changed as follows:-

1-The equality constraint, Energy Balance Equation gets modified to, be:

$$\sum_{i=1}^{N_G} P_{gi} = P_D + P_L \qquad (6)$$

Where:

PL is the transmission power losses, in MW.

2-The system power losses PL should be formulated in terms of generated power and system parameters, in a quadratic form.

The general loss formula using B-coefficients is given by decoupling solution method, or extended Newton-Raphssain method as [4].

$$P_L = \sum_{i=1}^{N_G} \sum_{i=1}^{N_G} P_{gi} B_{ij} P_{gi} + \sum_{i=1}^{N_G} B_{0i} P_{gi} + B_{00} \qquad (7)$$

II- WESTERN LIBYAN POWER GENERATORES HEAT RATE CURVES.

The thermal heat rate (THR) test was originally designed as a diagnostic type of test. This test provides a broad range of data on the thermal efficiency and operating costs of the turbine steam cycle, and consequently of the entire unit. Moreover, it is standard practice to run a THR test in order to determine the overall efficiency of the system (since efficiency is the reciprocal of heat rate). And used load fitting to get quadratic function from real data as shone below, the graph in each plant uses a quadratic cost function such as the Fuel Cost Curve.

The western Libyan network heat-power data is collected through tests and those tests were implemented practically in the system power plants [5], the data are collected for:-

1. Misrata CCGT Generation Units HRC.

Figure (1) GT & (2) shows the real test data for the generators starts from (85.5) & (40) MW input up to (285) & (110) MW output respectively.

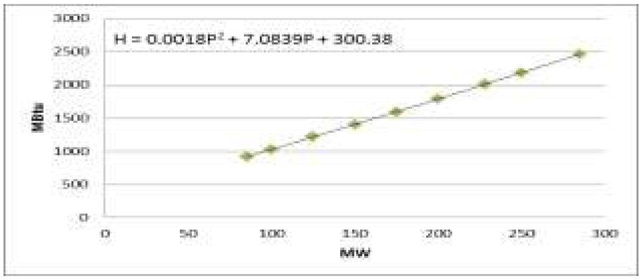


Fig (1) Heat rate curve for Misrata GT power plant with heat rat equation (H).

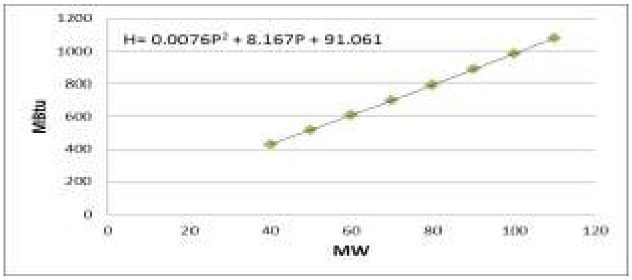


Fig (2) Heat rate curve for Misrata ST power plant with heat rat equation (H).

2. **Khoums GT&ST Generation Units HRC**.

Figure (3) GT& (4) ST shows the real tests data for the generators starts from (26.7) & (60) MW input up to (136) & (110) MW output respectively.

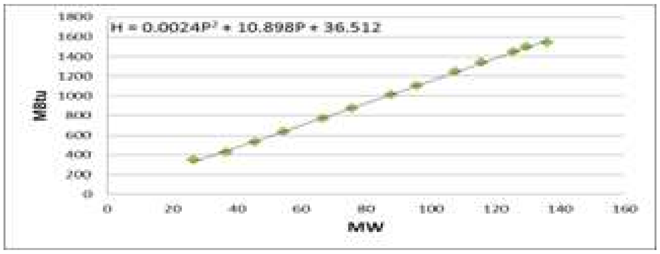


Fig (3) Heat rate curve for Khoums GT power plant with heat rate equation (H)

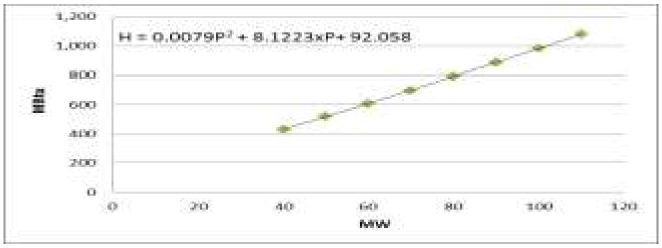


Fig (4) Heat rate curve for Khoums ST power plant with heat rat equation (H)

3. **West Mountain GT Generation Units HRC.**

Figure (5) shows the real test data for the generators start from (15) MW input up to (150) MW output the last column is calculated.

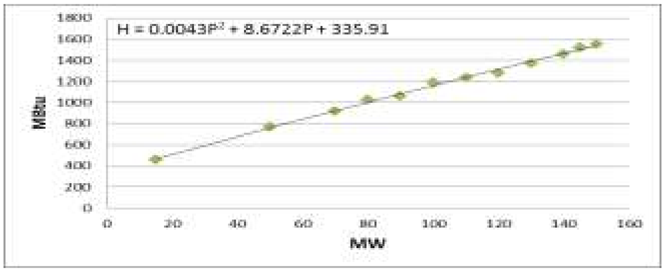


Fig. (5) Heat rate curve for West Mountain GT power plant with heat rat equation (H)

4. South Tripoli GT Generation Units HRC.

Figure (6) shows the real test data for the generators starts from (20.6) MW output up to (96.1) MW output the last column is calculated.

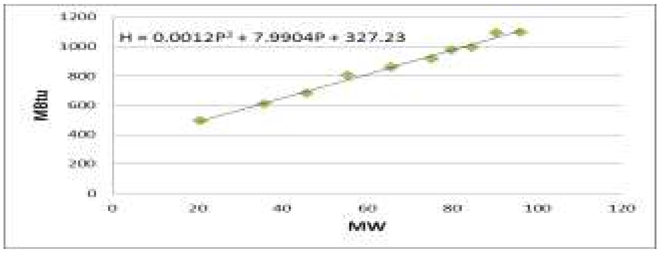


Fig (6) Heat rate curve for Tripoli South GT power plant with heat rate equation (H).

5. Tripoli West GT&ST Generation Units HRC.

Figure (7) GT& (8) ST shows the real tests data for the generators starts from (60) & (12.5) MW input up to (105) & (40) MW output respectively.

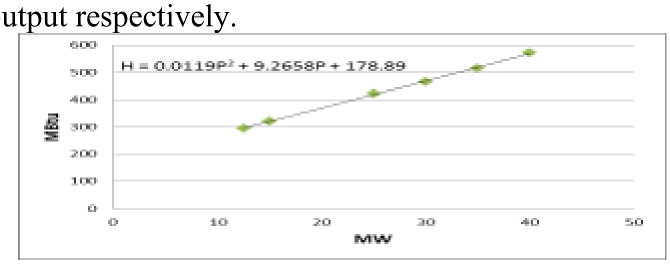


Fig (7) Heat rate curve for Tripoli West GT power plant with heat rat equation (H).

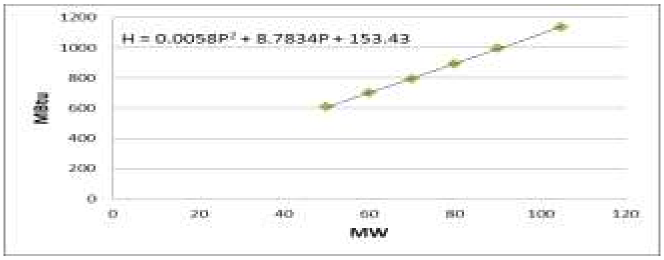
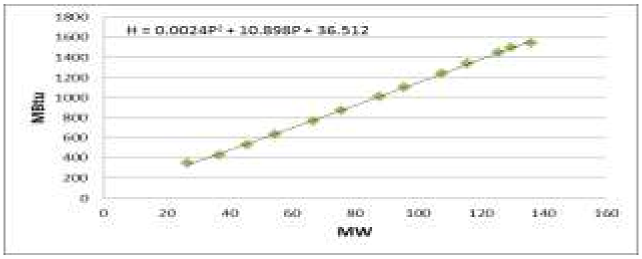


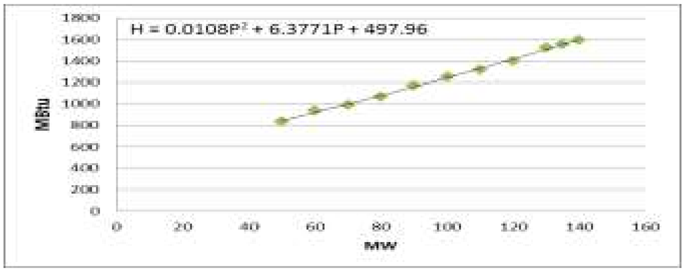
Fig (8) Heat rate curve for Tripoli West ST power plant with heat rat equation (H)

6. Zawia GT&ST Generation Units HRC.

Figure (9) GT& (10) ST shows the real tests data for the generators starts from (50) & (12.5) MW input up to (140) & (40) MW output respectively and the last column is calculated



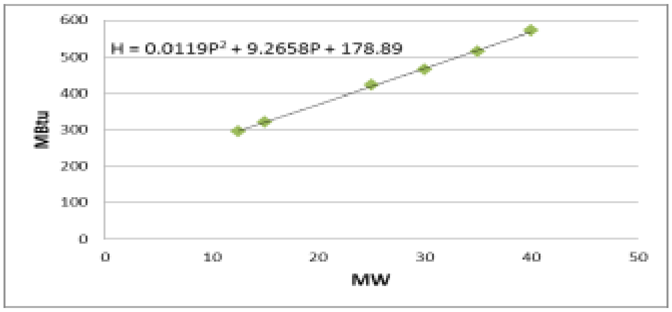
Fig(9) Heat rate curve for Zawia GT power plant with heat rat equation (H).



Fig(10) Heat rate curve for Zawia ST power plant with heat rat equation (H).

7. AL Zahra GT Generation Units HRC.

Figure (11) shows the real test data for the generators starts from (20.6) MW output up to (96.1) MW output the last column is calculated.



Fig(11) Heat rate curve for AL Zahra GT power plant with heat rat equation (H).

III- UPFC OPERATION AND CONTROL

A UPFC is one of the most useful FACTS devices and is used to control power transfer. In general, the FACT Device UPFC is able to control voltage, impedance and angle at the same time. One of the other important features of this component is its control of active and reactive power in transmission lines at the same time. In this device, a Static Var Compensator SVC is one of the parts of this device that makes active and reactive power transactions. Using a UPFC for controlling power transfer is better than increasing system transfer capability. Basically, a UPFC is used to adjust the power transfer between two transmission lines that are parallel together [3].

This leads to maximum power transfer capability in the power system. UPFC is one of the most frequently applied FACTS devices in power networks. This component has several benefits for static and dynamic operation of transmission lines. This feature includes static synchronous compensator (STATCOM) and static synchronous series compensator (SSSC) characteristics. UPFC has a unique capability in terms of the control of active power in transmission lines and reactive power at a requested point. If two transmission lines have different characteristics they will have different thermal limits. To achieve the same power transfer through the lines, they should have the same impedance. In this case, the UPFC is connected to the system and both transmission lines will operate within their own nominal thermal limits. Generally, a UPFC has got all the other

Compensator features. Also, it is able to adjust the voltage, compensate the impedance of the transmission line and shift the angle. [3] Basically, a UPFC is able to control voltage, impedance and phase angle at the same time. Also, it is able to control active and reactive power through the transmission lines to achieve maximum load-ability [4]

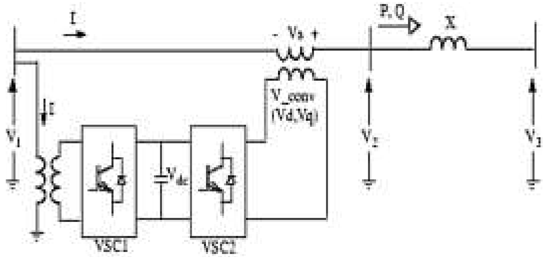


Fig (12) UPFC structure diagram connected on transmission line

A UPFC structure includes two converters that are connected back to back via a DC capacitor. Each of the converters is connected to a transformer separately; the first converter is called a static synchronous compensator (STATCOM), which injects a sinusoidal current with variable magnitude where it is connected. The second converter is called a static synchronous series compensator (SSSC), which injects series sinusoidal voltage with variable magnitude into the transmission line [1], [3]; as shown in figure (12).

IV- UPFC PHASE DIAGRAM ANALYSES.

Power flow through a transmission line is a function of the impedance of the line, the voltage of the source, loads and the angle of those voltages. Basically, power flow depends on the crossing voltage through the impedance of the line. Figure (13) shows a diagram of a simple transmission line [5].

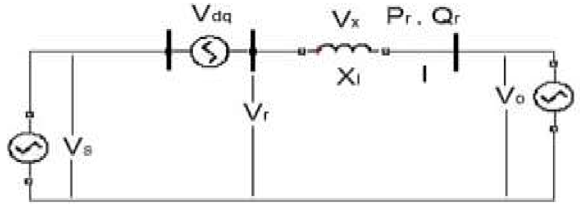


Fig (13).Simple transmission line circuits diagram

In this case, Xl is the inductive reactance of the line, Vdq is the series-injected voltage, Vs is the sending end voltage and Vr is the receiving end voltage, the crossing voltage through the reactance of the line is equal to:-

$$V_r - V_o = V_x \qquad (1)$$

$$V_r = V_s \pm V_{dq} \qquad (2)$$

$$V_x = V_s \pm V_{dq} - V_o = IX_L \qquad (3)$$

Where:-The I is the current of the transmission line. Vx changes whenever Vdq is changed and as a result the current will be changed. Initially it can be assumed that Vdq=0, then the vector diagram shown in figure (14).

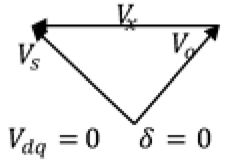


Fig (14).Vx variation when Vdq is changed.

δ is the angle between Vs and $Vr.I$ is the transmission line current. Pr And Qr are the active and reactive powers in the receiving end. Injecting Vdq as a series voltage into the lines Vo and Vr makes $\delta 1$, and figure (4) system vector diagram when $V_{dq} > 0$

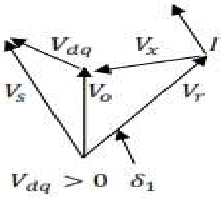


Fig (15).Creation of (δ_1)

As mentioned above, the transmission line current will be changed. If V_{dq} increases more, Vo and V_r will make δ_2, which is lagging. At this moment the current and power are in reverse positions as shown in figure (16).

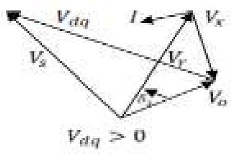


Fig (16).Creation of (δ_2).

I- UPFC CONTROL MODES

To demonstrate these modes, the UPFC is connected to the power network as shown in figure (17).

1- *Parallel Converter*

This converter absorbs controlled current from the transmission line. Some of this current is provided according to the requested active power in the series converter, another part of this current is reactive; a parallel converter operates in two modes.

i. Var control mode

The var request is inductive or capacitive. In this control mode, the converter's gates are adjusted to generate a convenient current. This control uses current feedback signals that are sent from the transformer.

ii. Automatic voltage control mode

In this case, the reactive current in the parallel converter is adjusted which sets line voltage in connected point according to source one.

2- *Series Converter*

This converter controls the voltage and phase angle that are injected into the transmission line in series. This injected voltage wants to have an impact on the power flow in the transmission line. This voltage can be provided in different ways:

i. Injecting direct voltage mode

A series converter simply generates voltage magnitude with angle, which is requested by the source.

ii. Emulation mode (phase shift)

The series converter injects voltage whose V2 phase angle is shifted towards the V1 phase angle with an angle specified by the source point.

iii. Emulation mode (line impedance)

Proportional injected voltage with line current is controlled if one looks at series transformer from line side; it will be assumed such impedance. Generally, in this case, creating negative resistance or capacitive inductance should be avoided; otherwise it will create instability in the power network.

iv. Automatic power flow control mode

In this case, the injected series voltage is determined, in terms of automatic and continuous modes by system control. In this situation, P and Q are held constant [6]

II- WESTERN LIBYAN (220,400kv) SYSTEM DISCREPTION

The Western 220kv, 400kv electric system consists of:

- (115) 220kv buses, (8)400kvbuses.
- (9) Generation plants and the total generation units are (40), and still there are some generation units under installation and the network map fig (18) clarify western Libyan network with buses that suffering by low voltage profile.

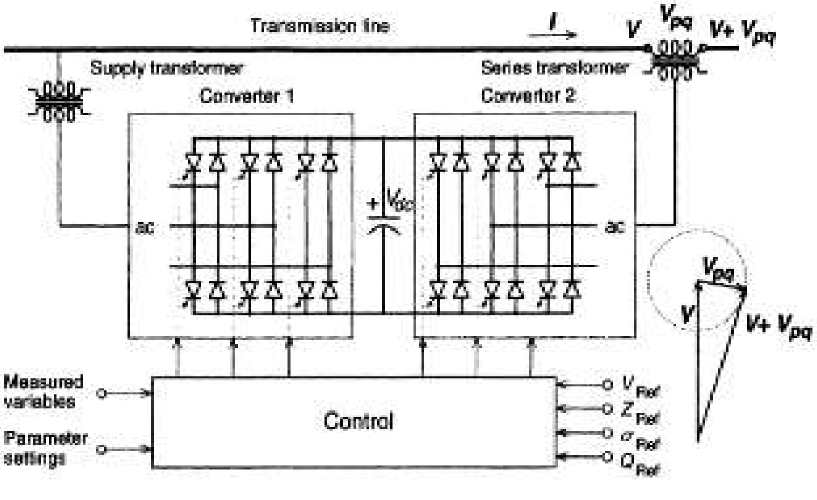
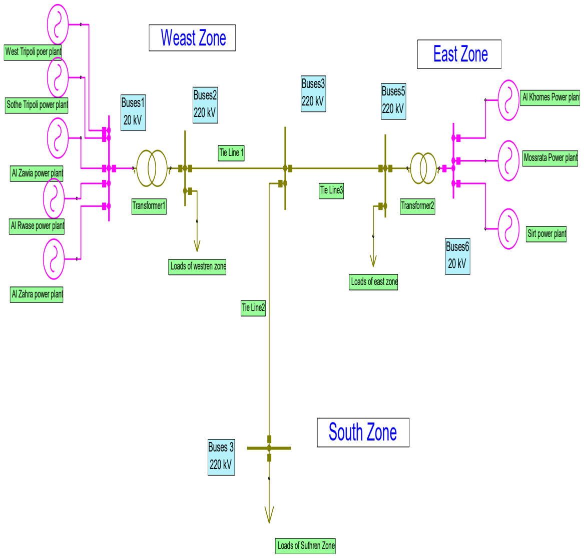


Fig (17) basic circuit arrangement of the UPFC.



Fig(18) Typical of western Libyan power system.

III- CASE STUDY FOR WESTREN LIBYAN NETWORK.

Applying power flow of the western network and the result showed as below.

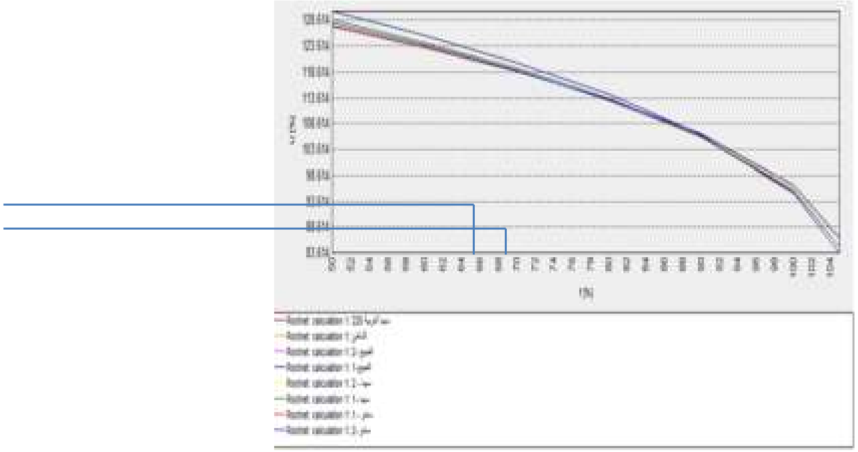
Table (1) summarizes the power flow results of normal case study.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load
MW	MVar	MW	MVar	MW	MVar	MW	MVar
74.21	-1680.35	290.421	50.857	3794.56	1136.9	3720.4	1795.5

The results of this case study shows weaknesses in the voltage profile of buses, where the voltages were below the permissible limits, and those violations might cause voltage collapsing and disconnect the network as shown in figure(19).

Fig (19).Variation voltage profile of buses in a network

To find a solution for these problem UPFC device may be used, but before that a voltage stability test could be conformed to check for voltage collapses of different buses of the southern zone, and some connecting buses such as Sabha buses, Alshatiy and Semno, all these buses are tested and figure (20) shows the voltage stability test (VST) curves for such buses where the power loading limits are found other that those limits UPFC should be used.



Fig(20).Voltage stability test for southern bus-bars.

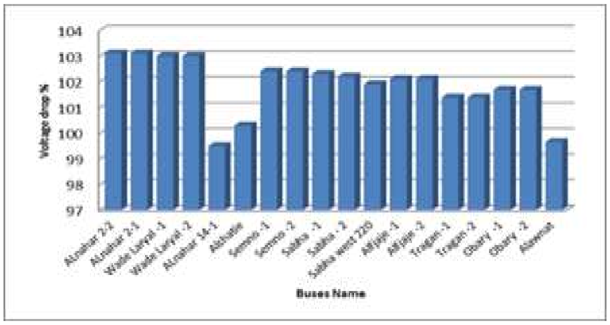
IV- CASE STUDY INJECTING UPFC WITH WESTREN LIBYAN NETWORK.

In this case adding (UPFC) with the western electric power system between Alshatiy and Sabha bus bars (These location are chosen by trial and error testing for the best location), and applying load flow with UPFC, and the tables (2) clarifies the improving result with UPFC such as, power loss reduction about (4MW).

Table (2).Summarizes power flow results with UPFC

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load	Gen. Cost
MW	MVar	MW	MVar	MW	MVar	MW	MVar	Mbtu/h
70.803	-1920.063	287.011	28.985	3791.153	976.03	3720.35	1795.456	39332.784

The figure (21) shows the participating of UPFC with Libyan electric power system which solves the weaknesses of the voltage profile for buses in the southern zone, that are keeping the voltage within requiring limits.



Fig(21).Improving voltage profile of buses with UPFC.

Table (3) clarifies the improving result with UPFC in optimal power flow to reduce losses and cost for western power system.

Table (3).Summarizes optimal power flow results with UPFC.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load	Gen. Cost
MW	MVar	MW	MVar	MW	MVar	MW	MVar	Mbtu/h
59.977	-2000.027	262.347	28.582	3780.327	895.849	3720.35	1795.456	36867.838

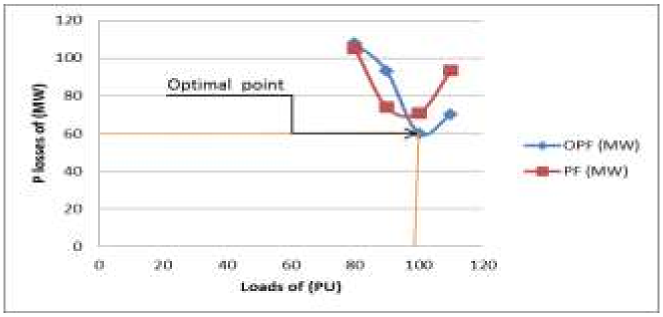


Fig (22) Comparing result between power flow and OPF.

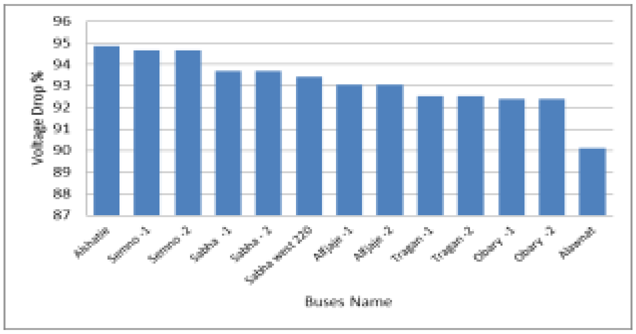
V- CASE STUDY CONNECTING SIRT POWER PLANT WITH WESTREN LIBYAN NETWORK

In this case study connecting SIRT power plant without using UPFC controller and Applying power flow analysis and the result is showing in table (4)

Table (4).Power flow results with Sirt power plant.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load
MW	MVar	MW	MVar	MW	MVar	MW	MVar
70.85	-1794.12	32.057	-26.28	3791.2	985.83	3720.4	1795.5

In this study of this case shows approximately the same of the first case regarding to voltage profile as showing in the figure (11).



Fig(23).voltage profile of buses with Sirt power plant.

VI- CASE STUDY INJACTED SIRT POWER PLANT AND USING UPFC CONTROLLER.

In this case the problems in case three are all solved by adding UPFC device that can be connected in the seam place in the first case, and applying load flow and optimal power flow with UPFC analysis for the western Libyan power system, tables (5) (6) summarize the power flow and optimal power flow results respectively with UPFC.

Table (5).SIRT power flow results with UPFC.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load	Gen. Cost
MW	MVar	MW	MVar	MW	MVar	MW	MVar	Mbtu/h
69.029	-1938.022	30.237	-37.232	3789.379	888.433	3720.35	1795.456	42000.62

Since the UPFC location is chosen to result a lower power losses possible of the network which accomplished after many trials, the figure (24) shows the supporting UPFC with Libyan electric power system.

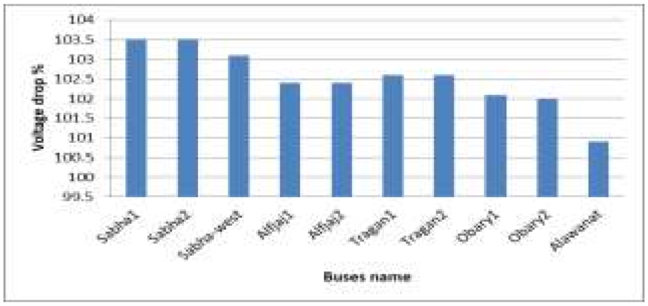


Figure (24) shows the improvement of voltage profile in western Libyan network.

Table (6). optimal power flow results after connected SIRT and UPFC with western Libyan network.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load	Gen. Cost
MW	MVar	MW	MVar	MW	MVar	MW	MVar	Mbtu/h
58.119	-2016.042	187.911	-43.53	3778.469	806.431	3720.35	1795.456	37674.927

power system with SIRT and UPFC ,which solves a voltage profile and contributed for applied optimal power flow.

VII- THIRD CASE STUDY ADDING OBARY AND SIRT POWER PLANTES WITH WESTREN LIBYAN POWER SYSTEM.

In this case connecting OBARY and SIRT power plant in southern zone so that increasing generation, and disconnecting compensation has already connected with network and Applying normal load flow analysis for the western grid system for different loads in order to specify optimal point, and considering ED and OPF operation of the system.

Table (7) Power flow result for western Libyan network with OBARY and SIRT power plants.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load	Gen. Cost
MW	MVar	MW	MVar	MW	MVar	MW	MVar	MBtu/h
62.481	-1894.93	-61.311	-10.513	3844.142	1025.162	3781.661	1805.969	42840.79

The result in table (7) shows the participating OBARY power plant with western Libyan electric power system and solved the problem in the voltage profile of buses in the southern zone, which are keeping the voltage with requiring limits.

Table (8) optimal power flow result of western Libyan network with OBARY power plant.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load	Gen. Cost
MW	MVar	MW	MVar	MW	MVar	MW	MVar	Mbtu/h
46.741	-2043.216	162.146	-35.39	3767.091	872.173	3720.35	1795.456	38033.663

Table (8) clarifies the improving result with OBARY power plant in optimal power flow for western electrical grid, and the results are more improved in the benefits of OPF analysis such as power loss reduction of about 16MW, fuel cost reduction that equivalent of about 4800 MBtu/h.

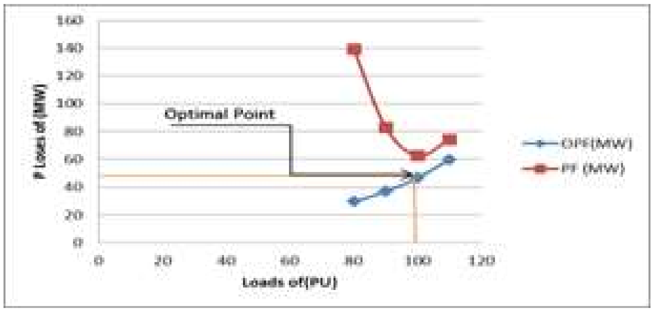


Fig (25) Clarify result between power flow and OPF.

VIII -CONCLUSION

All the activities above have been completed successfully, what can be concluded here is that the grate impacts optimal Power Flow for western Libyan power system and participating of using UPFC in very long distance to increasing power transfer and maintaining system stability, also the problem of high low voltage profile in the southern zone is completely solved , as well as reducing system power losses and generation cost.

IX. REFERENCES

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