The effect of variable load on the steam power plant in Kuwait

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Abstract

This research aims to study the effect of changing loads during one day at the rate of fuel consumption as well as the efficiency of the steam unit, and with the rate of flow of steam and boiler feed water. Also, this research includes a study of the electric energy consumed in the operation of pumps, fans and compressors, which is affected by changing unit loads required at peak times and throughout the day. This project is a case study carried out on the Doha West power plant and water production in the State of Kuwait, the study showed that the optimum load is at 80% of the design load of the steam unit, which has the lowest fuel consumption per kilowatt. We have concluded from the study the rate of fuel consumption per kilowatt that increases whenever the load of the steam unit falls below the optimal load, and it reached the highest rate of 15% when carrying 40% of the maximum load of the steam unit. This study showed that optimum load is at 80% of unit design maximum load and the maximum efficiency also at 80% of unit design maximum load.

List of abbreviations

Abbreviation	Description
CO.	Condenser
DE.	Deaerator
BFWP	Boiler Feed Water Pump
L.P.H	Low Pressure Heater
H.P.H	High Pressure Heater
EC.	Economizer
S.H. S	Super Heat Steam
C.R.H	Cold Reheat
H.R.H	Hot Reheat
H.P. T	High Pressure Turbine
I.P. T	Intermediate Pressure Turbine
L.P. T	Low Pressure Turbine
CV/V	Control Valve
Ch.	Chimney

Introduction

The electrical power that consumers demand is provided by the power plant through transmission and distribution networks. Therefore, whenever the electrical load demand of consumers changes, and accordingly, the required power supply from the power plant changes accordingly. The load on a power station varies from time to time due to uncertain demands of the consumers and is known as variable load on the station. A power station is designed to meet the load requirements of the consumers as figure (1).

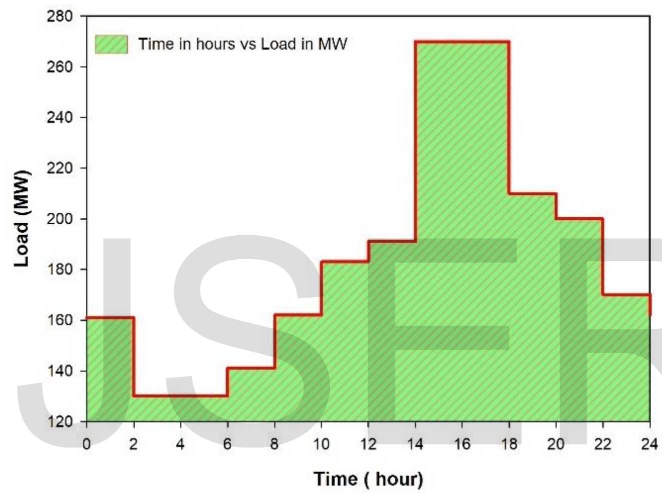

Figure 0- Daily Load (power generated MW)

In the optimum load on the power station, from estimation of equipment needed and operating routine, it will be one of fixed size and fixed duration. However, such a fixed load on the station is not achieved in actual practice. The Consumers require a small or large mass of power according to their demand's activities. The electrical load produced from any power plant varies from time to time due to the different loads required for consumers according to their needs for one day and during the four seasons of the year. The variable load on the power plant introduces many puzzles in its operation. Therefore, it is important to study some of the important effects resulting from changing electrical loads produced by power plants in the State of Kuwait. The change of electrical loads on the power plant requires the operation of additional equipment, for example, in the steam power plant you need to operate additional air fans and water pumps feeding the boiler also or fuel pumps to raise the load to the required electrical load that requires an increase in the flow rate of air, fuel and water. These are essential factors in increasing the electrical load produced by the steam unit. To produce variable electrical power, an increase or decrease in the previously mentioned variables is required. For instance, if the power demand on the plant increases, it must be followed by the increased flow of fuel, air, and water to the boiler to meet the increased demand. Therefore, additional equipment must be installed to accomplish this task [1]. In modern electric power plants, there is a lot of equipment completely dedicated to adjusting the rates of factors affecting the increase or decrease of electrical loads according to the demand for energy in the station, such as fuel, air and boiler feed water. The aim of this study is to determine the effects of changing electrical loads on the units of the steam station, and the Doha electrical station was taken as a case study in this project.

Important Terms in variable load problems

A power station supplies load to thousands of consumers. Each consumer has certain equipment installed in his premises. The sum of the continuous ratings of all the equipment in the consumer's premises is the "connected load" of the consumer.

Maximum demand is the maximum load on the power station during a given period [1]. Where the load on the power station varies from time to time at the same day. The period of maximum demand is generally less than the continuous load because all the consumers do not switch on their connected load on the system at the same time. The maximum load of power station demand is very important for determining the installed capacity of the power station. The power station must be capable of supplying the maximum demand.

Demand factor is the ratio of maximum demand on the power station to its connected load [1]. The demand factor is usually less than 1, because the maximum load demand on the steam power station is less than the continuous load. The demand factor is used in determining the capacity of the power station equipment.

Average load is the average load that occurs in a power plant in a given period (day, month or year) [1]. Also, the average daily load can be defined as the sum of all units (kilowatt hours) that are generated in one day in twenty-four hours. Also, the average monthly load is the sum of all units (kilowatt hours) generated in the month for every number of hours in the month. Same way, the yearly average load is summation all the units (kWh) generated in a year/8760 hour [1].

Load factor defined as the ratio of average load to the maximum demand load during a given period.

If the power station is in operation for T hours, Load factor = Average load T/Max. Demand T = Units generated in T hours/Max. Demand × T hours. The load factor may be a daily load factor, a monthly load factor or annual load factor if the time considered is a day or month or year. Load factor is always less than 1 because average load is smaller than the maximum demand. The load factor plays key role in determining the overall cost per unit generated [1].

Diversity factor is the ratio of the sum of individual maximum demand loads to the maximum demand on power station is known as diversity factor. Diversity factor is the sum of individual max. Demand loads /Max. Demand on power station. Diversity factor will always be greater than 1, therefor increasing the diversity factor, reducing the cost of power generation.

The power plant power factor is the ratio of the actual power produced to the maximum possible power that can be produced during a given period [1].

Related Literature

The related literature is regenerative, reheat Rankine cycle, energy, and Exergy analysis.

Reheat cycle

The efficiency of Rankine cycle can be improved using reheat as well as by regenerative heating. In reheat cycle, the steam is extracted at a suitable point in the turbine preferably when it becomes just wet and is reheated with the help of flue gases in the boiler furnace as shown in figure (2). The main purpose of reheating is to increase the dryness fraction of steam passing through the last stages of the turbine, additionally using reheat cycle, the specific steam consumption decreases, and thermal efficiency also increase marginally. [2]

Regenerative cycle

The Rankine efficiency of a steam cycle is less than that of a Carnot cycle as all the heat is not supplied at the highest temperature. The heating of feed water takes place with a large temperature difference. The Rankine cycle will be as efficient as Carnot if the temperature of feed water is raised to saturation temperature by reversible interchange of heat before it enters the boiler [2]. An arrangement for reversible heat transfer to feed water before entering the boiler is shown in figure (2). For calculating the efficiency of the regenerative cycle, the following assumptions are made:

a) The bled steam is condensed at the saturation temperature and the feed water is heated to the saturation temperature both at the pressure of the bled steam.
b) The condensate leaves the heater at the saturation temperature corresponding to the bleeding pressure.

Methodology and data collection

This research describes the procedure followed in the investigation of the performance of the steam power plant. The topics discussed include desk research and experimental investigation at the Doha WEST power station in Kuwait, data collection and analysis and economic analysis. The data used for this study were both base parameters for the steam turbine and measured value recorded in the station operational logbook for period of May to June 2019. The data collection was steam pressures, steam temperatures and steam flow rates, feed water flow rates and fuel flow rate at various loads. In this paper, the statistical were computed using in the analysis of the data, mean values of daily parameters. This was followed by daily average. This study is going to cover the following areas: -

- Describe the effect of changing loads on steam power station.
- Analyzing of all major energy consuming systems.
- A description of all recommended energy conservation measures with their specific energy impact.
- A review on the implantation costs benefits and payback period.

Description of the power plant

Fig. (2) Shows the schematic of the Doha west power plant, which demonstrating all its relevant components of the power plant unit. DOHA west power station consists of 8 units (8 boilers,8 Turbines and 8 generator) each unit capacity is 300 MW and the fuel used is natural gas, heavy oil, or crude oil. The power station unit thermodynamics data are shown in table (1), the process parameter operation condition for the unit is obtained as given table (2).

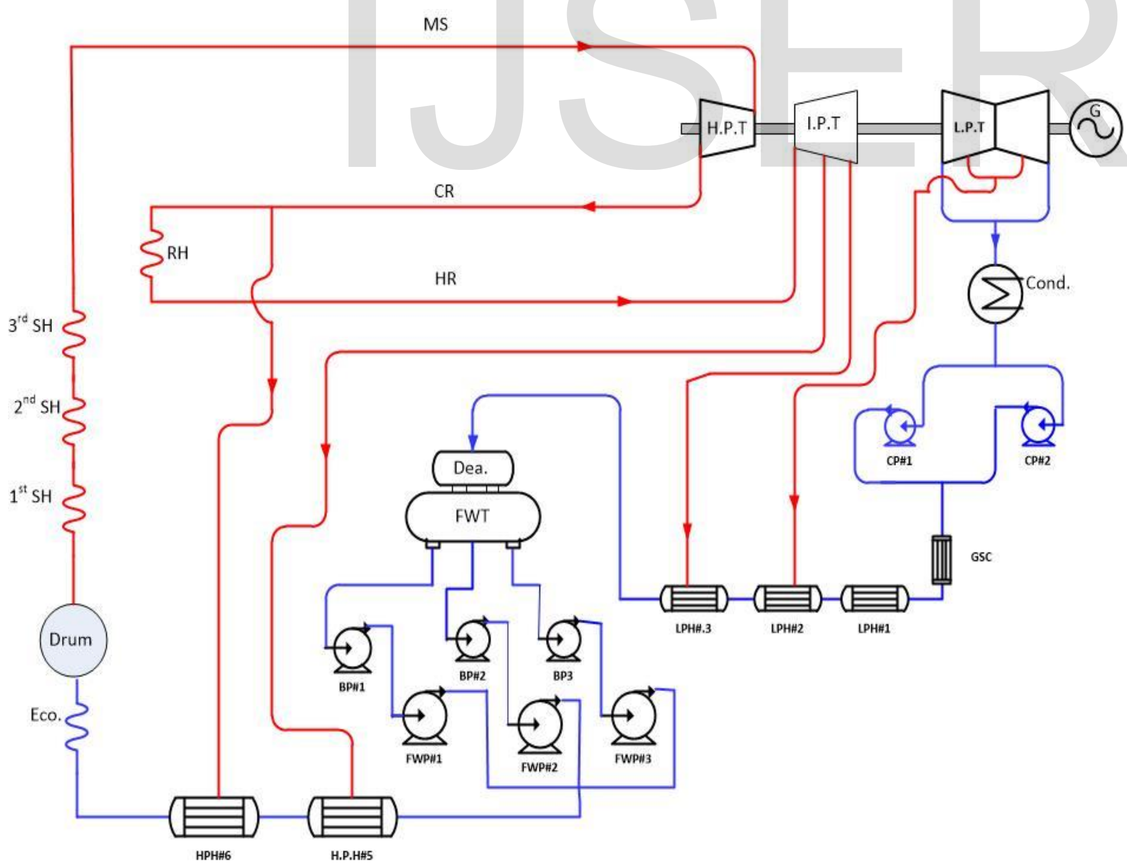

Figure (2) 1The schematic of the DOHA west power plant

Technical specification

Technical specification for DOHA west power station as given in table (1)

Table 1- DOHA west Technical specification.

Item	Discerption
Station installed capacity	▪ 2400MW (8 units X 300MW)
Boiler manufacture	▪ DEUTSCHE BABCKOK-GERMANY
Boiler circulation	▪ Natural feed water circulation -steam drum
Boiler firing	▪ Front firing
Boiler outlet condition	▪ Steam Pressure = 146 bar - Steam temperature = 540 °C - Steam flow = 1100 T/h
The fuel used in the boiler	▪ Heavy oil , Crude oil or Natural gas
Turbine type	▪ Tandem compound, 3 cylinders - Double flow exhaust - Extraction, Condensing and Reheat
Number of turbine stages	▪ HPT stages= 10 stage - IPT stages = 12 stage - LPT stages = Double flow 6 stage
Turbine extraction	▪ 6 extraction
Closed feedwater heaters	▪ 6 heaters

The process parameters operation condition

The process parameters operation condition for the unit which was selected. these parameters recorded in unit operator daily log sheet [2], the reading was taken for 60 days, recorded in the table (2) as average value for two months, as show in the table (2).

Table 2- unit operator daily sheet

Time		00:00	02:00	04:00	06:00	08:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Generator load	**MW**	**180**	**161**	**150**	**155**	**153**	**190**	**220**	**280**	**240**	**230**	**201**	**181**
Main steam pressure	**bar**	**140**	**140**	**140**	**140**	**140**	**140**	**140**	**140**	**140**	**140**	**140**	**140**
Main stream flow	**t/h**	**680**	**508**	**480**	**490**	**479**	**633**	**715**	**910**	**795**	**765**	**650**	**680**
Main steam temperature	**°C**	**540**	**540**	**536**	**536**	**540**	**540**	**540**	**540**	**538**	**540**	**540**	**540**
HRH steam pressure	**bar**	**23**	**17**	**16**	**17**	**16**	**21**	**24**	**27**	**25**	**24**	**22**	**22**

HRH steam temperature	**°C**	**525**	**510**	**500**	**500**	**520**	**521**	**526**	**530**	**527**	**520**	**515**	**522**
BFW flow	**t/h**	**669**	**500**	**465**	**475**	**484**	**628**	**710**	**900**	**755**	**730**	**640**	**671**
BFW pumps in service	**No.**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
BFW temperature	**°C**	**225**	**212**	**207**	**208**	**202**	**221**	**227**	**235**	**225**	**223**	**220**	**218**
Fuel oil flow	**m^3/h**	**57**	**41**	**40**	**41**	**40**	**35**	**40**	**60**	**46**	**44**	**43**	**46**
Natural gas flow	**Kg/s**	**0**	**0**	**0**	**0**	**0**	**3**	**3**	**3**	**3**	**3**	**3**	**0**
Burners in service (oil/gas	**No.**	**16**	**14**	**14**	**14**	**14**	**12/4**	**12/4**	**12/4**	**12/4**	**12/4**	**12/4**	**16**
Consumption air flow	**Kg/s**	**205**	**162**	**157**	**159**	**163**	**206**	**221**	**240**	**226**	**221**	**200**	**197**
Furnace pressure	**mb**	**21**	**13**	**13**	**13**	**13**	**24**	**26**	**28**	**26**	**24**	**22**	**18**
Flue gas temp.at Chi.	**°C**	**156**	**155**	**153**	**154**	**155**	**155**	**156**	**160**	**156**	**156**	**155**	**153**
FWT pressure	**bar**	**4.7**	**4.1**	**3.8**	**3.9**	**3.7**	**4.9**	**5.1**	**7.1**	**6.4**	**6.2**	**6**	**4.7**
FWT temperature	**°C**	**153**	**149**	**146**	**147**	**144**	**196**	**204**	**220**	**208**	**203**	**192**	**160**
FW. Temp. after HPH#5	**°C**	**191**	**181**	**180**	**186**	**180**	**201**	**212**	**243**	**216**	**209**	**200**	**180**
CO. Temp. after LPT#3	**°C**	**136**	**141**	**138**	**139**	**136**	**147**	**152**	**155**	**152**	**151**	**150**	**145**
CO. Flow to LPH	**t/h**	**253**	**440**	**310**	**467**	**310**	**500**	**700**	**810**	**730**	**430**	**450**	**367**
Condenser vacuum	**mb**	**29**	**46**	**42**	**36**	**35**	**44**	**62**	**65**	**60**	**51**	**41**	**40**
LPT Exhaust temp.	**°C**	**34**	**36**	**34**	**34**	**35**	**40**	**42**	**44**	**41**	**40**	**38**	**36**

Data collection and analysis

The different parameters of the thermal power plant cycle were obtained and recorded from DOHA west power plant unit operator daily sheet.

- **Obtaining the energy input into the plant**

The energy input into the boiler/plant was obtained by obtaining the energy in the heavy fuel oil and natural gas were used to fire the boiler and indicated below

$$\dot{Q}_{fuel} = (\dot{m}_{hfo} * C.V_{hfo}) + (\dot{m}_{g} * C.V_{g}) \qquad KW \qquad \langle 1 \rangle$$

Where;

$\dot{Q}_{fuel}$ = energy flow rate into the boiler

$\dot{m}_{hfo}$ = the mas flow rate of the heavy fuel oil into the boiler in [kg/s].

$\dot{m}_{hfo} = \frac{\rho V}{t}$, ρ is density of heavy fuel oil [kg/m3], V is volume of fuel consumed (m^3) and (t) is time (s) .

$C.V_{hfo}$ = the calorific value of the heavy fuel oil (kj/kg).

$\dot{m}_{g}$ = the mas flow rate of the natural gas into the boiler in (kg/s).

$C.V_{g}$ = the calorific value of the natural gas (kj/kg).

- **Obtaining the electrical power output of the plant**

Electric power output of the plant was obtained by tacking readings using a digital multimeter which was used to obtain the power generated (MW).

- **Heat loss in the boiler plant**

The various ways in which heat is lost in boiler plant are listed below [3]:

- **Heat lost to flue gases**

The flue gases contain dry products of combustion and the steam generated due to the combustion of hydrogen in the fuel.

$$\dot{Q}_g = (\dot{m}_g * C_{Pg})(T_g - T_a) \qquad KW \qquad \langle 2 \rangle$$

$\dot{Q}_g$ = The heat lost through through dry flue gases (kw).

T_g = Temperature of the gases ºC.

T_a = Temperature of air entering the combustion chamber of the boiler ºC.

$\dot{m}_g$ = Mass of gases flow rate kg/s.

C_{Pg} = Specific heat of gases. Kj/kg. k

- **Heat loss due to incomplete combustion**

If the carbon burns into CO instead CO_2, it is known as incomplete combustion [4].

$$\dot{Q}_{inc.} = \dot{m}_{fuel} * C.V\left(\frac{CO \times C}{C.O_2 + CO}\right) \qquad KW \qquad \langle 3 \rangle$$

$\dot{Q}_{inc.}$ = Heat loss due to incomplete combustion.

- **Heat convection and radiation losses**

The hot surfaces of the boiler are exposed to the atmosphere and therefore heat is lost the atmosphere by convection and radiation. This heat loss is preoperational to the outer surface area of the boiler. From Bureau of energy efficiency, India [4] , the boiler radiation loss are given as :

$$\dot{Q}_{rad} = \frac{0.58\left[\left(\frac{T_s}{55.55}\right)^4 - \left(\frac{T_a}{55.55}\right)^4 + 1.957*(T_s - T_a)^{1.25}\sqrt{\frac{(196.85V_m + 68.9)}{68.9}}\right]}{1000} \qquad kw \qquad \langle 4 \rangle$$

Where,

$\dot{Q}_{rad}$ = Radiation loss in kw/m^2

V_m = wind velocity inside the boiler room (m/s).

T_s = Surface temperature (K).

T_a = Ambient temperature (K).

- **Thermal efficiency**

It is an indication of how well the plant is being operated as compared to the design characteristics.

$$\eta_{overall} = \frac{P}{Q_{fuel}} * 100 \qquad \langle 5 \rangle$$

Where,

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P = Power generated (MW).

Q_{fuel} = The energy flow rate into the boiler (MW).

Discussion of Rustles

From unit daily sheet, the peak load at 14 O'clock (2 PM) to 16 O'clock (4 PM) as show in the figure (3) and Optimum load start from 12 O'clock until 17 O'clock.

From the energy analysis and calculation, the maximum overall efficiency is 38.29% at load 240 MW, as shown in figure (4) and table (3). In figure (5) illustrated the optimum load is 240 MW which give us the maximum overall efficiency, while minimum efficiency is 33.08% at load 130 MW.

The overall efficiency at load 130MW is lower than maximum efficiency by 5.21%, while at 150MW decreased by 4.36 less than maximum efficiency and optimum load. At load 200 MW decreased by 1.21% and at 270MW also decreased by 1.35%.

Also, at load maximum load 300MW the overall efficiency decreased by 1.94%.

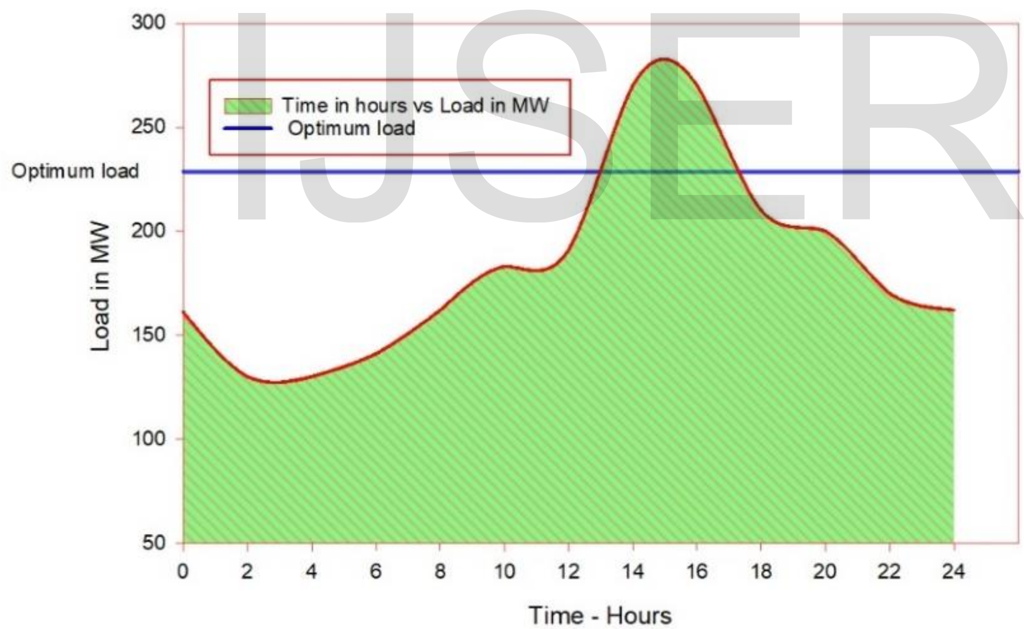

Figure 3- variable load (MW) for 24 hours

-Table 3 - illustrated variable load and Overall efficiency

Power output	Fuel oil flow	Energy input	Overall efficiency	Chang rate of overall efficiency

P	m· hfo	Q	ή overall	Δή overall
MW	kg/s	MW	%	%
130	9.33	393	33.08	-5.21
140	10.03	422	33.14	-5.15
150	10.50	442	33.93	-4.36
160	10.97	462	34.65	-3.64
170	11.62	489	34.75	-3.54
180	11.67	491	36.65	-1.65
190	12.25	516	36.84	-1.45
200	12.81	539	37.09	-1.21
210	13.3233	561	37.44	-0.86
220	13.7667	580	37.96	-0.34
240	14.89	627	38.29	0.00
250	15.56	655	38.16	-0.14
260	16.4267	692	37.60	-1.35
270	17.36	731	36.94	-1.35
290	18.67	786	36.90	-1.39
300	19.60	825	36.36	-1.94

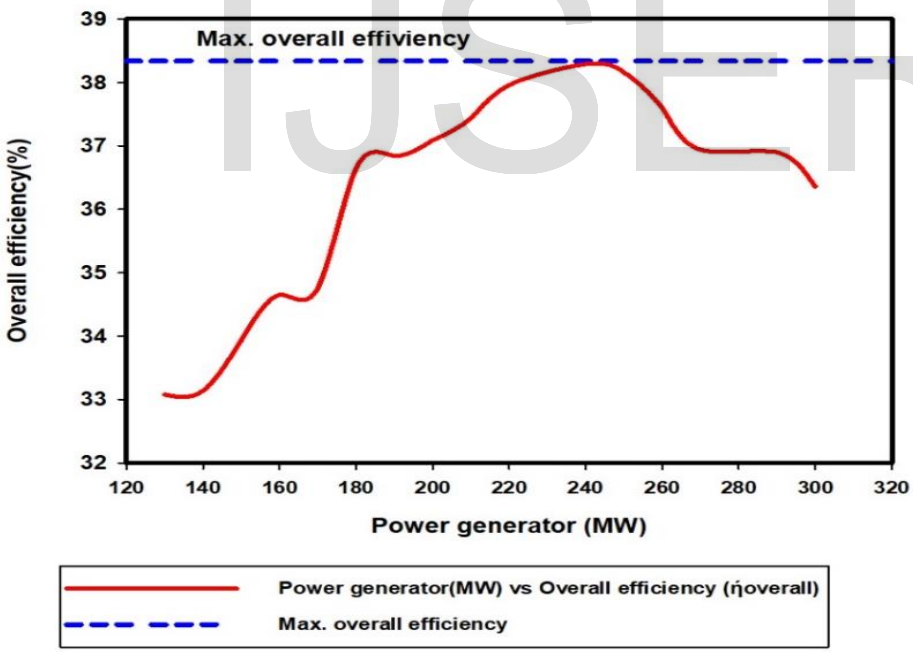

Figure 4- Power generator and overall efficiency

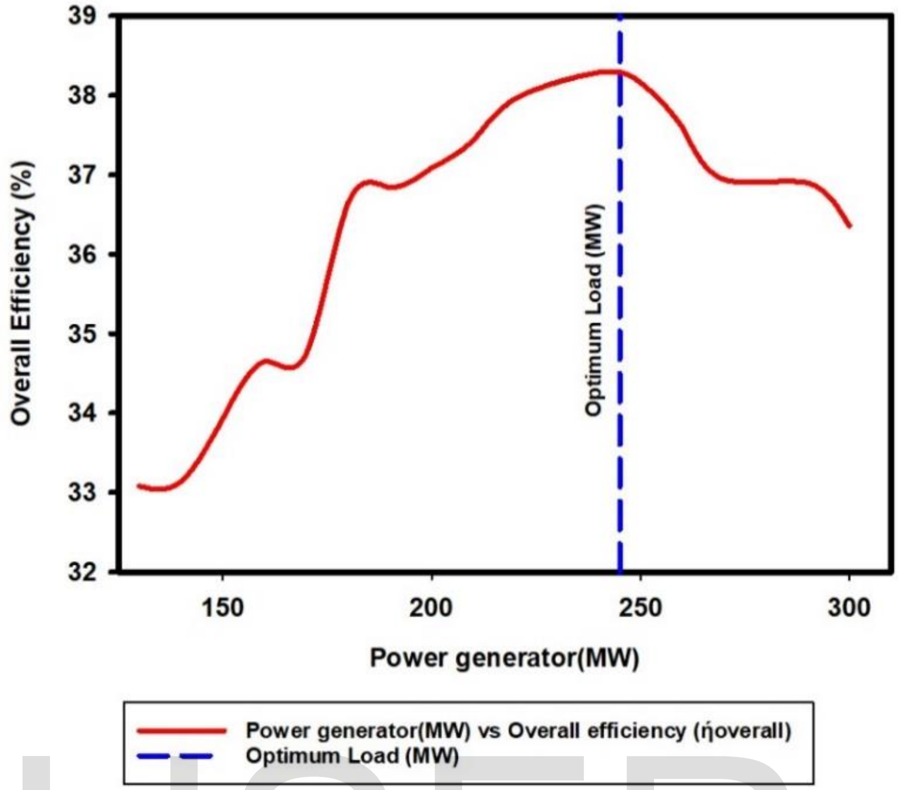

Figure 5- Optiumum load at maxumum load

Table 4- Fuel consumption with variable load per hour

Parameters	Variable load per hour									
Power output (MW)	130	150	160	180	210	220	240	260	270	300
Fuel oil flow (kg/hr)	33588	37800	39492	42012	47963.88	49560	53604	59136	62496	70560
Fuel consumption /kw	0.2584	0.2520	0.2468	0.2334	0.2284	0.2253	0.2234	0.2274	0.2315	0.2352
The difference in the rate of fuel consumption	15.68%	12.83%	10.51%	4.50%	2.26%	0.86%	Optimum	1.83%	3.63%	5.31%

From table (4) and figure (6), the optimum fuel consumption is at load 240 Mw which is 80% of maximum unit load (Power output).

At load 130 MW, the fuel consumption per kw.hr. is 0.2584 kg/kw.hr, this is maximum consumption value, it represents 15%.

At load 150 MW, the fuel consumption / kw.hr. is 0.252 kg/kw.hr, it is 12.83%

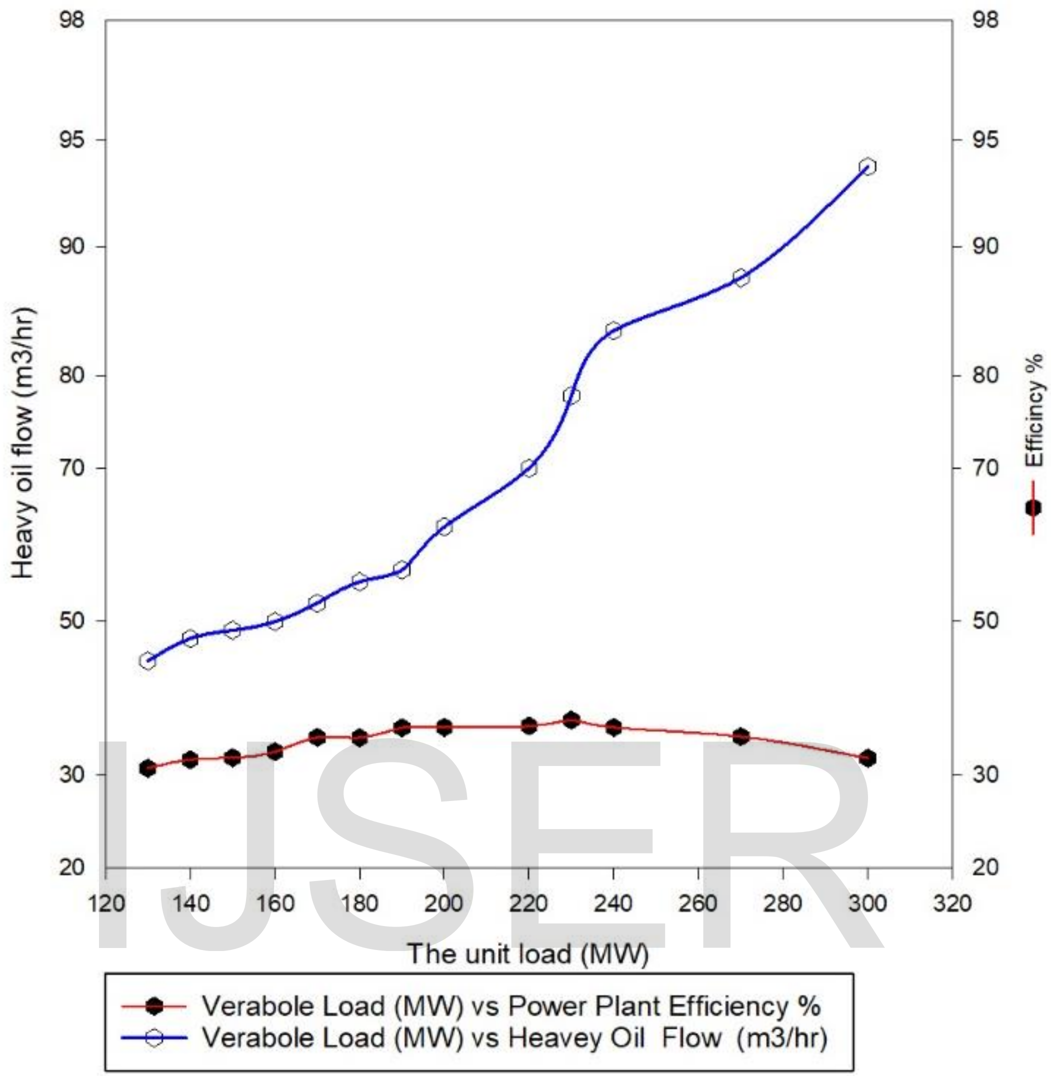

Figure 6- fuel consumption with efficiency

Conclusion

The summary of this study, which was conducted on the effect of changing loads in the thermal power plant, found the important effects resulting from changing the steam unit load in the following:

- Need for additional equipment: To produce variable power, if the power demand for the power plant increases, this should be followed by an increase in the flow of fuel, air and water to the boiler in order to meet the increasing demand. Therefore, additional requirements are applied to accomplish this task.
- An increase in the cost of production, and the variable loads of the power plant increases the cost of producing electrical energy. The steam unit operates at maximum efficiency near its engineered capacity. If a single steam unit is used, it will have poor efficiency during periods of light loads on the plant, thus,

in effect, several steam units of various capacities are installed so that most generators can run at nearly full load capacity.

- The use of several generating units increases the initial cost per KW of the power plant capacity as well as the minimum required, and this leads to an increase in the cost of energy production. It is better that, the unit load about 80% of maximum design load.

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