

## MINIMIZATION OF ENERGY LOSSES IN MID-DELTA ZONE

تقليل مفاقد الطاقة في منطقة وسط الدلتا

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الخلاصة:

يتناول هذا البحث تقليل مفاقد الطاقة في منطقة وسط دلتا وترجع أهمية هذا البحث إلى أنه يستنبط طريقه رياضيه عمليه تساعد متخذى القرار على تحديد نظم التشغيل المثلى للإستفادة القصوى من المحطات التكريرياتيه القائمه نتيجة لتقليل المفاقد لتوفير الإستثمارات اللازمه لمواجهة الطلب المستمر على الطاقة، كما أنه يتناول أنواع مفاقد الطاقة المختلفه والتوصيات اللازمه لتقليل كل منها.  
تم تطبيق النموذج الرياضى على شبكة وسط الدلتا وربنت النتائج دقة النموذج مقارنةً بالقيم المتسوره فى أحد تقارير البنك الدولى، كما أن مقارنة النتائج مع القياسات الحقيقيه للمفاقد خلال عسى ١٩٩٥ ، ١٩٩٦ تؤكد ان هناك فرصة حقيقه فى إمكانية تقليل المفاقد فى هذه الشبكة ومن ثم تحسين الأداء.

### ABSTRACT:

This paper aims at minimizing energy losses in the Mid-Delta zone using load flow methods. The mathematical model is applied to the Mid-Delta zone. The 220 kV network is modeled in the load flow program for each season of the year while the losses in the high voltage substations, medium voltage network and medium voltage substations are calculated using a heuristic approach.

This paper presents a practical approach that would assist the decision making process in an electric utility to optimize the operation procedures to save investments required to install new equipment to meet the growth on electric demand if the losses are minimized.

### 1. INTRODUCTION:

Power system losses in the transmission network are experienced in the components of such network. e.g. high voltage transmission lines, high voltage substations, medium voltage transmission lines, and medium voltage substations.

When generating costs are relatively low, network losses are not considered significant. However, the increasing cost of fuel makes electrical utilities weight these losses more heavily and study ways of reducing them[1-2].

Load flow studies are used to minimize network losses [3]. This is accomplished by running an extensive set of load flows during normal and emergency conditions for different load scenarios. Shunt losses, transformer's no load losses and corona losses are not included in load flow studies.

Electric utilities pay great attention to reduce transmission losses to save some of the investments paid in expanding both the generation facilities and electrical network to account for load growth and network losses [4-6].

Losses can be classified into built-in, technical, and commercial losses. The reduction of the built-in losses is the responsibility of the design team while the reduction of the technical and commercial losses is the responsibility of the operation personnel.

The paper aims at minimizing energy losses in the Mid-Delta zone using load flow methods.

### 2. POWER SYSTEM LOSSES:

The losses in an electrical network are defined as the difference between the energy input corresponding to local production and imports and the output, which is the local consumption and export.

When generating costs are relatively low, network losses are not considered significant. However, the increasing cost of fuel makes electrical utilities weigh these losses more heavily and study ways of reducing them. To reduce losses, we must first define the sources of losses[7] which can be classified into the following:

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**(i) Built-in Losses:**

Losses inherent in the system stemming from the technical aspects of transmission and distribution.

**(ii) Technical Losses:**

Deviations from optimal conditions.

**(iii) Commercial Losses:**

There are a consequence of errors induced by the quality of metering devices, management of accounts, the consumption ratio of some equipment, and power theft.

**2.1 Losses:**

Power system losses are experienced mainly in the transmission system (and its associated transformers). In transmission, the determination of losses is subject to relatively large errors because often the losses in a line is considerably less than the precision tolerance of the meters used. A common method to minimize power system losses is by means of load flow studies which calculate the losses during system load levels that simulate the actual loading during the daily load cycle. When performing such simulations, it is very important to take into account two categories of "shunt" losses:

- i) the transformer's no-load losses (which usually account for a significant proportion of the total losses), and
- ii) corona losses, especially in the very high voltage lines

Traditionally "shunt" losses are not included in load flow studies.

The Load Flow simulation [8-10] is only as good as the assumptions of the variations of each individual load in the various scenarios that are synthesized. Whereas it is recognized that the typical loadings that are selected should be representative, there will be times when these assumptions are not correct. However, the ensuing discrepancies should be very minor because each of these loads is only a small part of the total.

In the load flow simulation it is quite difficult to represent the conditions when some transmission lines may be out of service for relatively short periods of time (as it occurs when a transmission line is de-energized to clean its insulators), at which time the losses may be slightly larger than usual.

**2.2 Demand Losses (Power Losses):**

The demand losses are the summation of the square of the load current in each circuit element of the system, at the instant of the system maximum demand, multiplied by the resistance of the circuit element in which it is flowing:

$$\text{i.e. Power Losses} = I^2 R \quad (2.1)$$

The effect of the demand losses in the increased loading in the system elements by an amount equal to the magnitude of losses. In other words, the effect of the demand losses is the requirement to increase the installed capacity, and hence the capital investments in the distribution and transmission systems as well as in the generating station.

**2.3 Energy Losses:**

Energy losses correspond to the loss of energy production costs incurred in satisfying energy losses.

Since the consumer loads change from hour to hour then the demand losses also change from hour to hour, being maximum at the hour of maximum demand.

The energy losses is the time integration of the demand losses in successive time intervals.

The energy losses is calculated as:

$$\text{Energy losses} = I^2 R \times \text{Loss Factor} \times 8760 \quad (2.2)$$

**2.4 Loss Factor:**

A loss factor is introduced to calculate the energy losses if the demand losses at peak time is known. It is defined as the percentage of time required by the peak load to produce the same losses as produced by the actual loads over a specified time period. Loss factor may be calculated from the following relationship:

Loss factor = Square of actual demands/square of peak demand over 100% of the time.

$$\text{Loss factor \%} = \frac{\sum_{i=1}^n (\text{Hourly Demand})^2}{n(\text{Peak Demand})^2} \times 100 \quad (2.3)$$

### 3 MATHEMATICAL MODEL:

#### 3.1 Minimization of Yearly Loss Factor:

- i) Prepare a typical daily load curve for each season for the year.
- ii) Calculate the loss factor for each season using the following equation.

$$\text{Season loss Factor } (\lambda_s) = \frac{\sum_{i=1}^{24} P_i^2}{24 \times P_{\max}^2} \quad (3.1)$$

Where:

- $P_i$  = hourly load during the typical day for the season.  
 $P_{\max}$  = the max. load for the day.  
 $i$  = index for hour.

- iii) Calculate yearly loss factor as a weighted average from the four season loss factors

$$\text{Yearly Loss factor } (\lambda_y) = \frac{\sum_{s=1}^4 \lambda_s \times P_{\max_s}}{\sum_{s=1}^4 P_{\max_s}} \quad (3.2)$$

where:

- $\lambda_s$  = season loss factor.  
 $P_{\max_s}$  = max. load for the typical representing the season(s).  
 $s$  = index for season.

#### 3.2 Minimization of Demand Losses:

Demand losses are defined as the sum of the losses of individual components comprising the transmission system which are:

- (i) High voltage transmission network.
- (ii) High voltage substations.
- (iii) Medium voltage transmission network.
- (iv) Medium voltage substations.

Normally, extensive load flow studies are required to determine such losses both in the normal and emergency operating conditions. It is worth mentioning that corona losses are not modeled in load flow programs.

Due to the lack of information regarding the technical parameters including iron and copper losses of the individual (220/66/11) kV and (66/11) kV transformers and the details of (66 kV) transmission network, the following approach is followed to minimize the demand losses in the zone.

##### 3.2.1 220 kV Network Losses:

The 220 kV network and the generation facilities in the zone are modeled via an AC load flow program utilizing NEWTON-RAPHSON algorithm.

- i) Run load flow program for four cases, one for each season, during the max. load conditions.
- ii) Record the amount of power losses as derived from the output results of the power flow cases.
- iii) Average the four loss values to obtain an minimize for the yearly demand loss by the following equation:

$$P_l = \frac{\sum_{s=1}^4 P_s \times P_{\max_s}}{\sum_{s=1}^4 P_{\max_s}} \quad (3.3)$$

where:

$P_1$  = the yearly power loss of the (220 kV) network.

$P_s$  = season power loss of the (220 kV) network.

### 3.2.2 220/66/11 kV Substation Losses:

Generally, for any transformer, the power loss is determined from the following equation:

$$P_L = \left[ \left( \frac{\text{Load (MVA)}}{\text{Full Load (MVA)}} \right)^2 \times \text{Full Load Copper Loss} \right] + \text{No Load Loss} \quad (3.4)$$

then the total demand losses in the (220/66/11) kV substations are calculated as:

$$P_2 = \sum_{i=1}^n P_L(i) \quad (3.5)$$

where:

$P_L(i)$  = demand loss for each transformer.

$n$  = Number of these transformers.

### 3.2.3 66kV Network Losses:

Since the 66kV network is not modeled in the load flow because of the lack of information about such network, an approximation is followed in this paper based on the figure published in the 1982 world bank study [11] In this study the demand losses were minimized to be (2-4%) of the peak load.

i) Calculated the season demand loss as:

$$P_s = 2\% P_{\max_s} \quad (3.6)$$

ii) Average the four loss values to obtain an minimize for the yearly demand loss in the (66 kV) network by the following equation:

$$P_3 = \frac{\sum_{s=1}^4 P_s \times P_{\max_s}}{\sum_{s=1}^4 P_{\max_s}} \quad (3.7)$$

where:

$P_3$  = the yearly power loss of the (66 kV) network.

$P_s$  = the season power loss of the (66 kV) network.

### 3.2.4 66 kV Substation Losses:

Similar to 220/66/11 kV substation, the total demand losses in the 66/11 kV substation is calculated as:

$$P_4 = \sum_{i=1}^4 P_L(i) \quad (3.8)$$

where:

$P_L(i)$  = demand loss for each transformer from this type which can be calculated from equation (3.2).

The total demand losses for the zone is the sum of all the constituents starting from the 220 kV network up to the 66/11 kV substation.

$$P_y = P_1 + P_2 + P_3 + P_4 \quad (3.9)$$

the percentage demand losses is calculated by:

$$\begin{aligned} \% \text{Demand Losses} &= \frac{\text{Total Demand Losses}}{\text{Peak Load}} \times 100 \\ &= \frac{P_y}{P_L} \times 100 \end{aligned} \quad (3.10)$$

where

$$P_k = \text{Average of season maximum loads} = \frac{\sum_{s=1}^4 P_{\max SL}}{4} \quad (3.11)$$

$P_y$  = Total demand losses in the zone.

### 3.3 Minimization of Energy Losses:

According to equation (2.2), The yearly energy losses in the zone is given by:

$$E_y = P_y \times \lambda_y \times 8760 \quad (3.12)$$

$$\% \text{ Energy Losses} = \frac{\text{Energy Losses}}{\text{Total Energy (E}_t\text{) of the year}} \times 100$$

$$= \frac{E_y}{E_t} \times 100 \quad (3.13)$$

## 4 APPLICATION ON MID-DELTA ZONE:

The mathematical model developed in section 3 is applied to the Mid-Delta zone. The 220 kV network is modeled in the load flow program for each season of the year while the high voltage substations, medium voltage network, and medium voltage substations are handled by the method detailed in the previous section.

### 4.1 Loss Calculations For The 220kV Network:

Typical daily load curves for the four seasons of the year are prepared to calculate the loss factor for each season and consequently the yearly loss factor. The detailed calculations for the summer season is given here as an example while for other seasons, the final results are given Fig. (4.1) shows the typical daily load curve for the summer season.

$$\lambda_s = \frac{\sum_{t=1}^{24} P_t^2}{24 \times P_{\max}^2} = \frac{13464959}{24 \times (1107)^2} = 0.458$$

The solution of Load Flow program for the summer season is achieved in 4 iterations (see Appendix) and the single line diagram, Fig (4.2), illustrates the load flow results for this case.

From the above calculations, the loss factor and the active power loss for summer are 0.458, 8.822 MW respectively.

The same procedure is followed for the other seasons and the results are as follows:

For Autumn Season:

Loss Factor = 0.415

Active Power Loss = 9.209 MW

For Winter Season:

Loss Factor = 0.483

Active Power Loss = 6.127 MW

For Spring Season:

Loss Factor = 0.403

Active Power Loss = 5.997 MW

Calculation of Yearly Loss Factor and Demand Loss:

$$\text{Yearly Loss Factor } (\lambda_y) = \frac{\sum_{s=1}^4 \lambda_s \times P_{\max S}}{\sum_{s=1}^4 P_{\max S}}$$

$$= \frac{0.402 \times 1150 + 0.415 \times 1156 + 0.458 \times 1107 + 0.483 \times 1201}{1150 + 1156 + 1107 + 1201}$$

$$\lambda_y = 0.44$$

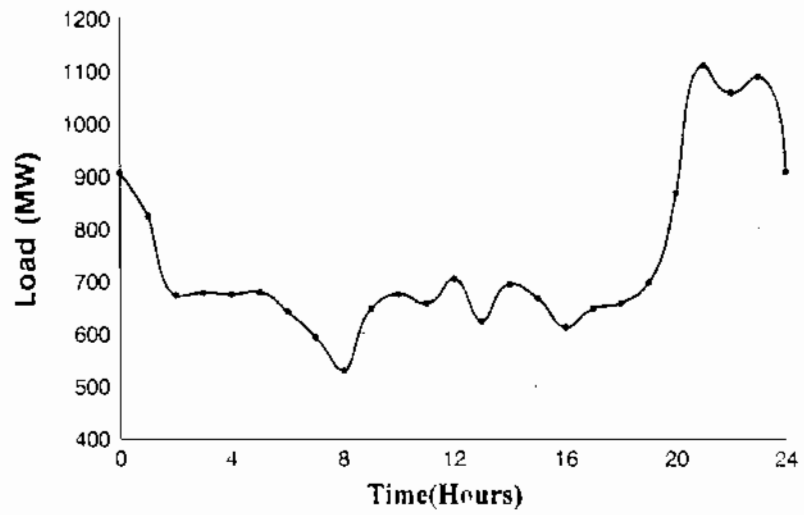


Fig. (4.1): Daily load curve for summer season

Using this curve, the following table is constructed to calculate the summer Loss Factor:

Hour	Load ( $P_i$ )	$(\text{Load})^2$ ( $P_i^2$ )
0	906	820836
1	824	678976
2	673	452929
3	678	459684
4	675	455625
5	679	461041
6	641	410881
7	592	350464
8	529	279841
9	647	418609
10	675	455625
11	657	431649
12	704	495616
13	623	388129
14	694	481636
15	667	444889
16	611	373321
17	647	418609
18	658	432964
19	697	485809
20	866	749956
21	$P_{max} = 1107$	1225449
22	1055	1113025
23	1086	1179396
24	906	820836
	$\Sigma P_i = 17591$	$\Sigma P_i^2 = 13464959$

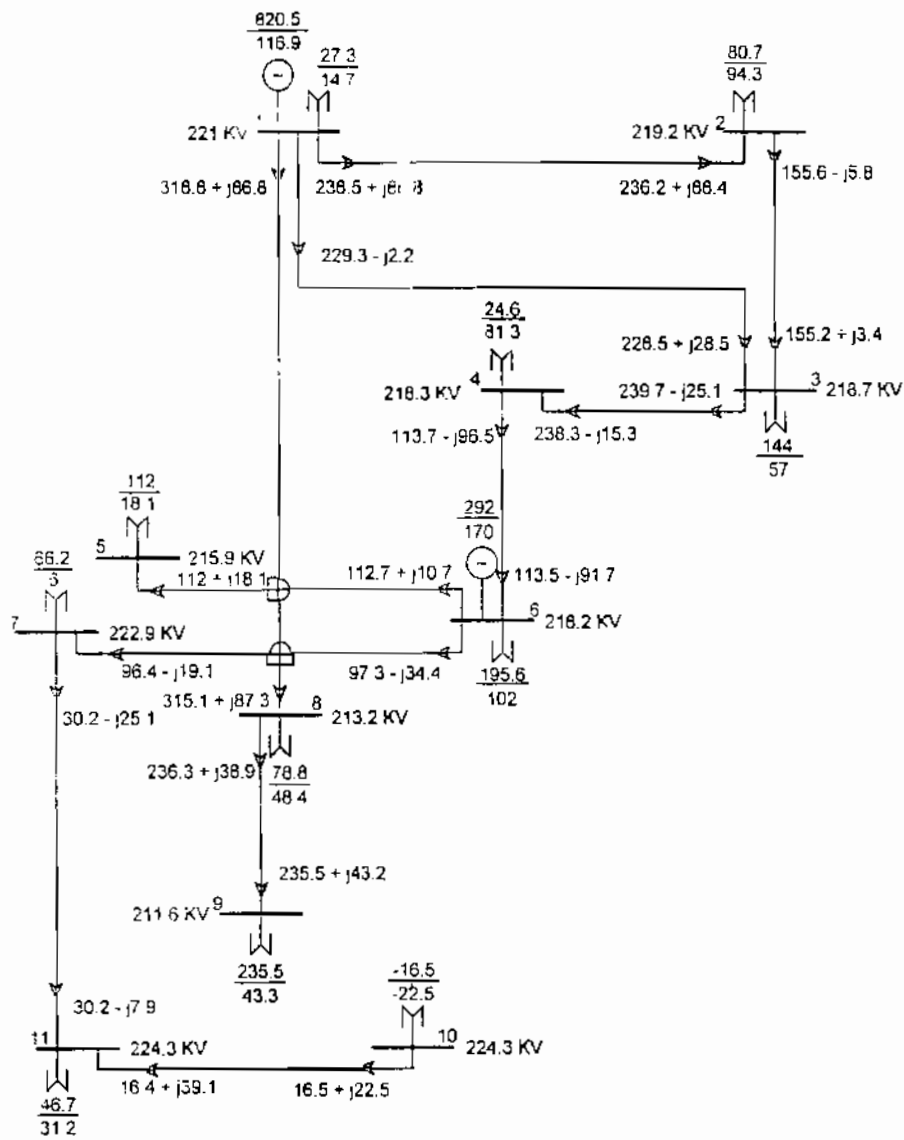


Fig. (4.2): Load Flow Program Results

$$\text{Yearly Demand Loss}(P_1) = \frac{\sum_{s=1}^4 P_s \times P_{\max_s}}{\sum_{s=1}^4 P_{\max_s}}$$

$$= \frac{5.997 \times 1150 + 9.209 \times 1156 + 8.822 \times 1107 + 6.127 \times 1201}{1150 + 1156 + 1107 + 1201}$$

$$P_1 = 7.513 \text{ (MW)}$$

**4.2 (220/66/11) kV Substation Losses:**

Assume all these substation transformers are 125 MVA and 50% loaded.

Number of these transformers = 25.

Full load copper loss = 368 kW.

No load loss = 82 kW.

According to equations (3.4), (3.5).

$$P_L = 174.00 \text{ kW}$$

$$P_2 = 4.35 \text{ MW}$$

**4.3 (66 kV) network losses:**

According to equation (3.6)

$$\text{For WINTER season} : P_s = 0.02 \times 1201 = 24.02 \text{ MW}$$

$$\text{For SPRING season} : P_s = 0.02 \times 1150 = 23 \text{ MW}$$

$$\text{For SUMMER season} : P_s = 0.02 \times 1107 = 22.1 \text{ MW}$$

$$\text{For AUTUMN season} : P_s = 0.02 \times 1156 = 23.12 \text{ MW}$$

According to equation (3.7).

$$P_3 = 23.089 \text{ MW}$$

**4.4 (66/11) kV Substation Losses:**

Transformer rating (MVA)	No. of Transformers	Copper Loss At Full Load (kW)	No Load Loss (kW)
25	18	136	22.5
20	63	115	19.5
16	9	97	17
12.5	39	82	15

According to eq. (3.8).

$$P_4 = 5.8125 \text{ MW}$$

Calculation of percentage demand and energy losses:

$$P_y = P_1 + P_2 + P_3 + P_4 = 40.764733 \text{ MW}$$

$$(1) \% \text{ Demand Losses} = \frac{P_y}{P_k} \times 100$$

$$P_k = \frac{1201 + 1107 + 1150 + 1156}{4} = 1153.5 \text{ MW}$$

$$\therefore \text{Demand Losses} = \frac{40.764}{1153.5} = 3.528$$

(2) % Energy Losses

$$\begin{aligned} \text{Yearly energy losses} &= \lambda_v \times P_y \times 8760 \\ &= 407643 \times 0.44 \times 8760 \\ &= 157123.59 \text{ MWH} \end{aligned}$$

Calculation of Energy during the year.

$$\text{Energy during WINTER season} = 1755285 \text{ MWH}$$

$$\text{Energy during SPRING season} = 1549972.5 \text{ MWH}$$

$$\text{Energy during SUMMER season} = 1596053.75 \text{ MWH}$$

$$\text{Energy during AUTUMN season} = 1590122.5 \text{ MWH}$$



The Total Energy During The Year = (Et) = 6791433.75 MWH

$$\% \text{Losses} = \frac{157123.59}{6491433.75} \times 100 = 2.42$$

### 5 CONCLUSIONS AND RECOMMENDATIONS:

a) The results achieved reveals the accuracy of the mathematical model developed in this paper if compared to the figures stated in 1982 world bank study [11-12]. The following table illustrates this conclusion.

Power System Component	% Demand Losses	% Energy Losses
220 kV network	0.6513	0.446
220/66/11 kV S/S	0.3770	0.258
66 kV network	2.0000	1.370
66/11 kV S/S	0.5000	0.346
%Total	Calculated = 3.528	2.42
Losses	Word bank study = 3.5	2.31

b) The actual figures of the percentage energy losses was reduced from 3.2% in 1995 to 2.9% in the first quarter of 1996 while the minimized value calculated in this paper amounts to 2.42% which allows for further reductions in the energy losses to improve the overall performance of the Mid-Delta zone.

To end this paper, it is recommended to apply the following procedures to reduce the losses.

#### 1. Built-in Losses:

This aspect is addressed by seeking to optimize the power system components and power delivery process during the design stage. Since the network already is in place, then the redesigns to center on network expansion and equipment replacement.

To reduce the built-in losses the following policies are recommended:

- (i) Locating new power sources close to consumers.
- (ii) Installing new 220/66/11 kV substations in areas of high consumption.
- (iii) Changing the conductor of old 220kV line sections to bundle conductors.
- (iv) Implying new technologies for example, new materials for power transformers are an effective way of reducing consumption.
- (v) Installing capacitor banks to improve the voltage profile.

#### 2. Technical Losses:

- i) Reducing technical losses can be accomplished primary by the optimal distribution of active and reactive facilities.
- ii) Adequate sectionalizing of the 220kV and medium voltage networks is the most important target for reducing such losses.
- iii) During the reduced-load periods, some of the 220 kV lines can also be disconnected to reduce the losses caused by corona effects.

#### 3. Commercial Losses:

Can be reduced by:

- i) Using high class meters (error class 0.5 or less).
- ii) Periodic calibration of meters.
- iii) Reviewing primary and secondary connections of meters.
- iv) Reviewing of reading constants.
- v) Fixing time and date of reading all meters.
- vi) Training the personal for accurate readings.
- vii) Minimizing thefts.

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**7 APPENDIX:****Load Flow Input Data For SUMMER Season.**

11,11,0,0,0,2,01,10  
100

**Bus Data:**

'SLACK',221,1,0,0,0,27.3,14.7  
'PQ',220,1,0,0,0,80.7,94.3  
'PQ',220,1,0,0,0,144.57  
'PQ',220,1,0,0,0,124.6,81.3  
'PQ',220,1,0,0,0,112,18.1  
'PV',217,1,0,292,0,195.6,102  
0,170  
'PQ',220,1,0,0,0,66.2,6  
'PQ',220,1,0,0,0,78.8,48.4  
'PQ',220,1,0,0,0,235.5,43.3  
'PQ',220,1,0,0,0,-16.5,-22.5  
'PQ',220,1,0,0,0,46.7,31.2

**Branch Data:**

1,2,0.0412,0.302,3.72,10,0,2,1000  
1,3,0.0412,0.302,3.72,33,0,2,1000  
1,8,0.0412,0.302,3.72,75,2,2,1000  
2,3,0.0412,0.302,3.72,33,0,2,800  
3,4,0.0412,0.302,3.72,56,8,2,800  
4,6,0.0412,0.302,3.72,17,0,2,800  
6,5,0.0825,0.918,2.72,60,0,2,1000  
6,7,0.0825,0.918,2.72,95,0,2,1000  
7,11,0.0412,0.302,3.72,47,0,2,600  
8,9,0.0412,0.302,3.72,30,0,2,1200  
10,11,0.0412,0.302,3.72,45,0,2,800

**Load Flow Output Results For SUMMER Season.****BUS DATA OF BASE CASE**

BUS NO	BUS TYPE	PG (MW)	QG (MVAR)	PL (MW)	QL (MVAR)	QMI (MVAR)	QMAX (MVAR)
1	SLACK	220.538	116.949	27.300	14.700		
2	PQ	.000	.000	80.700	94.300		
3	PQ	.000	.000	144.000	57.000		
4	PQ	.000	.000	124.600	81.300		
5	PQ	.000	.000	112.000	18.100		
6	PV	292.000	170.000	195.600	102.000	.000	170.000
7	PQ	.000	.000	66.200	6.000		
8	PQ	.000	.000	78.800	48.400		
9	PQ	.000	.000	235.500	43.300		
10	PQ	.000	.000	-16.500	-22.500		
11	PQ	.000	.000	-46.700	31.200		

**RESULT FOR BASE CASE****Load Flow Results Of Network Bus**

BUS NO	BUS TYPE	PT (MW)	QT (MVAR)	VMAG (KV)	VANG (DEG)
1	SLACK	793.238	102.2489	221.0000	.0000
2	PQ	-80.700	-94.3000	219.1831	-3.989
3	PQ	-144.000	-57.0000	218.7280	-1.3250
4	PQ	-124.600	-81.3000	218.2395	-3.8139
5	PQ	-112.000	-18.1000	215.9577	-8.0088
6	PV	96.400	68.0000	216.1740	-4.2027
7	PQ	-66.200	-6.0000	222.8662	-9.4276
8	PQ	-78.800	-48.4000	213.2072	-4.1932
9	PQ	-235.500	-43.3000	211.6428	-5.5173
10	PQ	16.500	22.5000	224.2657	-9.5975
11	PQ	-46.700	-31.2000	223.2609	-9.6930

**POWER FLOW THROUGH LINES**

SENDING NODE	RECEIVING NODE	FROM SENDING END. (MW)	FROM RECEIVING END. (MVAR)	FROM SENDING END. (MW)	FROM RECEIVING END. (MVAR)
1	2	236.341	86.801	-236.271	-88.449
1	3	229.250	22.005	-228.507	-28.486
1	8	318.626	86.840	-315.085	-87.384
2	3	155.572	-5.848	-155.230	-3.412
3	4	239.740	-25.103	-238.328	15.274
4	6	113.732	-96.573	-113.573	91.693
6	5	112.685	10.751	-111.995	-18.100
6	7	97.277	-34.396	-96.441	19.129
7	11	30.244	-25.129	-30.221	7.899
8	9	236.285	38.984	-235.500	-43.299
10	11	16.500	22.501	-16.477	-39.099

**TOTAL ACTIVE AND REACTIVE LOSSES IN THE NETWORK****ACTIVE POWER LOSS : 8.822 MW**

Reactive Power Loss : -93.400 MVAR

Solution Of Load Flow Program Achieved In 4 Iteration