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MINIMIZATION OF ENERGY LOSSES IN MID-DELTA ZONE

تقليل مفاقيد الطاقة فى منطقة وسط الدلتا

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الخلاصة:

يتناول هذا البحث تقليل مفاقيد الطاقة فى منطقة وسط الدلتا وترجع أهمية هذا البحث إلى أنه يستنبط طريقه رياضيه عمليه تساعد متخذى القرار على تحديد نظم التشغيل المثلى للإستفاده القصوى من المهمات الكهربائيه القائمه نتيجة لتقليل المفاقيد لتوفير الإستثمارات اللازمه لمواجهة الطلب المستمر على الطاقه، كما أنه يتناول أنواع مفاقيد الطاقه المختلفه والتوصيات اللازمه لتقليل كل منها.

تم تطبيق النموذج الرياضى على شبكة وسط الدلتا وبينت النتائج دقة النموذج مقارنةً بالقيم المنشوره فى أحد تقارير البنك الدولى، كما أن مقارنة النتائج مع القياسات الحقيقيه للمفاقيد خلال عامى ١٩٩٥ ، ١٩٩٦ تؤكد أن هناك فرصة حقيقيه فى إمكانية تقليل المفاقيد 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 asist. the decision making process in an electric utility to optimize the operation procedures to save investements 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 personel.

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:

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

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:

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

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.

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

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.

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

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

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

where:

λ_s = season loss factor.
P_{maxs} = 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 worthmentioning 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 individoal (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 demaad 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 algorithim.

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:

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

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:

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

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

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

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:

$$P_s = 2\% P_{\max_s} \tag{3.6}$$

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

$$P_3 = \frac{\sum_{s=1}^{4} P_s \text{ x } P_{\max_s}}{\sum_{s=1}^{4} P_{\max_s}} \tag{3.7}$$

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 66/11kV substation is calculated as:

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

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.

$$P_y = P_1 + P_2 + P_3 + P_4 \tag{3.9}$$

the percentage demand losses is calculated by:

$$\%\text{Demand Losses} = \frac{\text{Total Demand Losses}}{\text{Peak Load}} \text{ x } 100 \tag{3.10}$$

$$= \frac{P_y}{P_L} \text{ x } 100$$

where

P_k = Average of season maximum loads $= \dfrac{\sum_{s=1}^{4} P_{\max_{SL}}}{4}$ (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:

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

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

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

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:

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

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

$$\lambda_y = 0.44$$

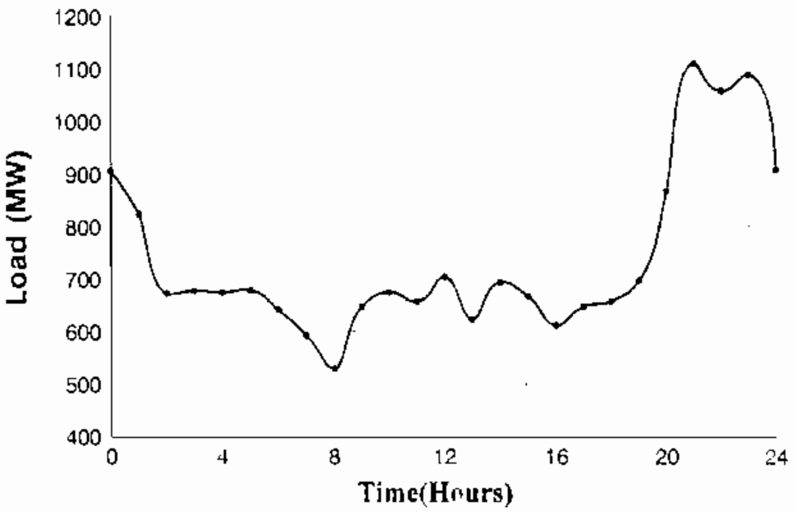

Fig. (4.1): Daily load curve for summer season

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
	$\sum P_i = 17591$	**$\sum P_i^2 = 13464959$**

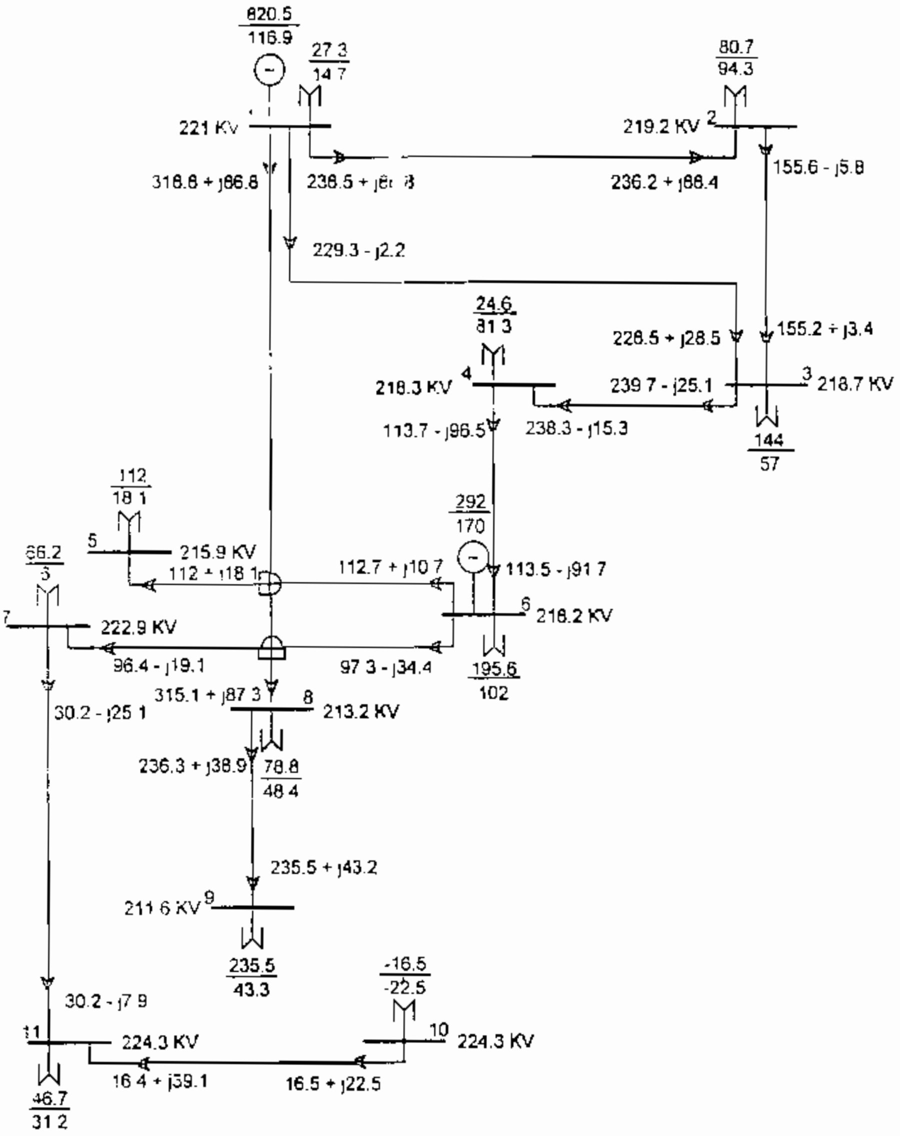

Fig. (4.2): Load Flow Program Results

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

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

P_1 = 7.513 (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 equations (3.4), (3.5).
P_L = 174.00 kW

P_2 = 4.35 MW

4.3 (66 kV) network losses:

According to equation (3.6)
For WINTER season : $P_S = 0.02 \times 1201 = 24.02$ MW
For SPRING season : $P_S = 0.02 \times 1150 = 24$ MW
For SUMMER season : $P_S = 0.02 \times 1107 = 22.1$ MW
For AUTUMN season : $P_S = 0.02 \times 1156 = 23.12$ MW
According to equation (3.7).

P_3 = 23.089 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 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

Yearly energy losses $= \lambda_y \times P_y \times 8760$
$= 407643 \times 0.44 \times 8760$
= 157123.59 MWH

Calculation of Energy during the year.
Energy during WINTER season = 1755285 MWH
Energy during SPRING season = 1549972.5 MWH
Energy during SUMMER season = 1596053.75 MWH
Energy during AUTUMN season = 1590122.5 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 [illegible] accuracy of the mathematical model developed in this paper if compared to the figures [illegible]ned 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 Losses	Calculated = 3.528	2.42
	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) Impolying 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 redнce 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    BUS        PG       QG          PL      QL       QMI      QMAX
NO     TYPE      (MW)    (MVAR)       (MW)   (MVAR)   (MVAR)    (MVAR)
1      SLACK    820.538  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          900      .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    BUS       PT        QT              VMAG          VANG
NO     TYPF     (MW)     (MVAR)            (KV)          (DEG)
 1     SLACK    793.238   102.2489         221.0000        .0000
 2     PQ       -80.700   -94.3000         219.1831       -.3989
 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     PO       -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, RECEIVING. FROM SENDING END. FROM RECEIVING END.
NODE       NODE           (MW)     (MVAR)      (MW)         (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
```