CHAPTER 4 BALANCING ALGORITHM

4.1 INTRODUCTION

Load forecasting used to be a simple procedure and for most utilities the customer consumption remained fairly constant from one year to the next. It appears that the confident load prediction has become more difficult over the past decade. Even with more sophisticated techniques, utilities have been wrong much more than they have been correct.

Latest reviews of industry forecasts questioned the accuracy of the predictions. Working groups have been established to come up with answers about why it is difficult to produce more accurate forecasts. The answer is simple - the results are determined by the behaviour of millions of individual customers and businesses.

The transmission network that becomes larger over the years, fluctuations in the economy and changing customer energy preferences are some important factors that make the transmission load forecasts extremely difficult and complex. [1]

The balancing algorithm takes the different forecasts as inputs and reconciles (balances) the results. The forecasting results are entered as ranges and the balancing is done separately for each year. If consensus exists between the different forecasts, a “feasible” solution has been reached. In case of unfeasibility, reports are provided to identify the reason(s) for unfeasibility.

This chapter describes the mathematical relationships between the different forecasts as required for the balancing algorithm, and the principles of the heuristic solutions.

4.2 MATHEMATICAL RELATIONSHIPS

The electrical load model (Chapter 1) has three phases. Phase 1 describes the inputs into the transmission network. The inputs are the generation pattern (GP) and equal the transmission system load. As mentioned in Chapter 1, the modelling of loads are done at the time when the transmission system load reaches its maximum peak (MSD). All loads are measured in megawatts (MW).

Generation pattern

The private power stations are not included, because the concept has not been finalised.

$$GP = \sum_{q=1} Net_q + \sum_{r=1} NetInt_r \qquad (4.2.1)$$

where:

GP	Generation pattern
Net_q	Eskom power station net power output q
$NetInt_r$	Import r from a neighbouring country

Maximum system load (demand)

$$MSD = GP \qquad (4.2.2)$$

where:

MSD	Annual maximum transmission system load
GP	Generation pattern

Phase 2 describes the transmission system outputs.

Transmission system outputs

$$MSD = PS + INT + TXLOSS + TOTDX \qquad (4.2.3)$$

where:

PS	Total power station load directly supplied from the transmission network

INT	Total international customer load
TXLOSS	Total transmission electrical network losses
TOTDX	Total load to distribution networks ("Total area loads")

Power station loads

$$PS = \sum_{s=1} PS_s \tag{4.2.4}$$

where:

PS_s Power station load s supplied directly from the transmission network

International customer loads

$$INT = \sum_{t=1} INT_t \tag{4.2.5}$$

where:

INT_t International customer load t

Area loads

$$TOTDX = \sum_{h=1} Area_h \tag{4.2.6}$$

where:

$Area_h$ Area load h

Transmission substation loads

$$Area_h = \sum_{j \in I_h} TX_j \tag{4.2.7}$$

where:

TX_j Transmission substation load j

I_h Index set links transmission substations j to area h

Note: A transmission substation is linked to one area only

The transmission load TX is the net load that flows between transmission and distribution at that transmission substation. The next three examples explain the situation. A transmission substation (400/132 kV) supplies an international customer and a number of distribution substations. The load TX is then defined by the distribution substation loads only. In the second example a transmission substation has two voltage transformations connected to the distribution networks, the 220/132 kV import load and the 220/66 kV export load. The load TX is defined as the net load between the exports and imports. In the last example, a power station net power output is connected to a transmission substation's 132 kV bus. A number of distribution substations are fed from the bus. The load at the transmission substation TX equals the distribution substation load minus net power output.

Distribution substation loads

$$TX_j = \sum_{k \in I_j} DX_k \qquad (4.2.8)$$

where:

DX_k Distribution substation load k

I_j Index set links distribution substations k to transmission substation j

Equation (4.2.8) is only true when an end-use customer (in the distribution network) is directly connected to the transmission substation. In most cases the distribution substations are a distance away from the transmission substation and then electrical losses have to be added to equation (4.2.8). Another shortcoming is the exports and imports between transmission substation supply areas.

To modify equation (4.2.8), the following rules:

i) The electrical losses in the distribution networks (supply area of the transmission substation) are added as a single value.

ii) If power is exported from transmission substation A to transmission substation B, then the export and import loads equal the load that is measured on the first distribution substation feeder in the transmission substation B supply area.

iii) The difference between the actual export (given there are no other distribution substations on the feeder) and the modelled import is accounted for in the electrical losses.

Then equation (4.2.8) becomes,

$$TX_j = \sum_{k \in I_j} DX_k + Ex/\mathrm{Im}_j + DXloss_j \qquad (4.2.9)$$

where:

Ex/Im_j	Total exports (+) and imports (-) for transmission substation j
$DXloss_j$	Total distribution electrical losses for transmission substation j

Total distribution electrical losses

$$DXLOSS = \sum_{j=1} DXlossj \qquad (4.2.10)$$

Total export and import loads

$$\sum_{j=1} Ex/\mathrm{Im}\, j = 0 \qquad (4.2.11)$$

Sector loads

$$TOTDX = \sum_{g=1} Sec_g + DXLOSS \qquad (4.2.12)$$

where:

Sec_g	Sector load g

Area per sector loads

$$Area_h = \sum_{g=1} AreaSec_{gh} + DXLOSS_h \qquad (4.2.13)$$

$$Sec_g = \sum_{h=1} AreaSec_{gh} \qquad (4.2.14)$$

where:

$Area_h$	Area load h

Sec_g	Sector load g
$DXLOSS_h$	Total distribution electrical network losses for area h
$AreaSec_{gh}$	Sector load g for area h

4.3 OPERATIONS RESEARCH

The first formally - recorded operations research teams started during World War II. The military management in England called on a team of scientists to study the most effective utilisation of limited military resources. The establishment of this scientific team marked the first formal operations research activity.

The name "operations research" (OR) was apparently derived from the team's research on military operations. This new decision-making field has been characterised by the use of scientific knowledge through interdisciplinary team effort for the purpose of determining the best utilisation of limited resources.

Today OR is no longer used for military activities only, but also in business applications such as financial planning, city planning and even crime investigation studies. Such an OR study consists of building a model of the physical situation and defining it as a simplified representation of a real-life situation.

The most important OR model types are mathematical models. Sometimes the mathematical formulation is quite complex to allow an exact solution. In such cases the computation time could be long and not practical. In such cases heuristic methods can be developed to reduce the computation times, but will still ensure a feasible solution. The heuristic method relies on intuitive or empirical rules to reach a solution. The heuristic method moves from one feasible solution to another and improve the model criterion during each move.

4.4 BALANCING ALGORITHM

The balancing algorithm is based on a heuristic solution and consists of two phases. The feasibility phase checks the different forecasts (enter as ranges) for feasibility. If feasibility exists, then the second phase determines a value for each variable representing a predicted value. Lastly, the range factors are a measure to display the balanced area and sector loads relative to their individual ranges.

Feasibility

The balancing algorithm starts at the lower distribution substations (child nodes) and compares the loads with the transmission substation (parent node). If feasibility exists, then the algorithm narrows the parent node range and continues.

When moved to the next level, the parent node will change to a child node and, similarly, a new grouping of child nodes and a parent node will be formed.

Feasibility exists if the following is true.

$$Range\left|Parent^{Lower}, Parent^{Upper}\right| \cap Range\left|\sum Child^{Lower}, \sum Child^{Upper}\right| \ \# \phi \tag{4.4.1}$$

The next rule narrows the parent node range.

$$NewParent^{Lower} = \max\left(Parent^{Lower}, \sum Child^{Lower}\right) \tag{4.4.2}$$

$$NewParent^{Upper} = \min\left(Parent^{Upper}, \sum Child^{Upper}\right) \tag{4.4.3}$$

If equations (4.4.2) and (4.4.3) are applied and the area load is the parent node, then

$$newArea_h^{Lower} = \max(Area_h^{Lower}, \sum_{j \in I_h} newTX_j^{Lower}) \tag{4.4.4}$$

$$newArea_h^{Upper} = \min(Area_h^{Upper}, \sum_{j \in I_h} newTX_j^{Upper}) \tag{4.4.5}$$

Determining the expected values

The balancing algorithm determines a solution if feasibility exists.

The balancing algorithm starts at the transmission system and then moves down.

The transmission system load is selected as the first parent node (newParent).

$$newMSD = \left(newMSD^{Upper} + newMSD^{Lower}\right)/2 \qquad (4.4.6)$$

From equation (4.2.3) the child nodes are PS, INT, TXLOSS and TOTDX. A child is determined as:

$$newChild = newChild^{Lower} + p(newChild^{Upper} - newChild^{Lower}) \qquad (4.4.7)$$

The value for p is calculated as follows:

$$p = (newParent - \sum newChild^{Lower}) / \left(\sum \left(newChild^{Upper} - newChild^{Lower}\right)\right)$$

If $\left(\sum \left(newChild^{Upper} - newChild^{Lower}\right)\right) > 0$

Else

$$p = 0 \qquad (4.4.8)$$

where:

newParent = newMSD

and the newChild nodes are determined by equation (4.4.7).

The generation pattern (newGP) is determined as:

$$newGP = newMSD \qquad (4.4.9)$$

The rest of the forecast values are determined similarly.

Example

The heuristic method is applied on a system with three areas, area 1 (three substations), area 2 (seven substations), and area 3 (two substations). The results are shown in Table 4.4.1.

Table 4.4.1 Heuristic Solution

	Lower	Upper	New Lower	New Upper	p	Balanced
MSD	3379.0	3388.0	3379.0	3384.0		3381.50
Area 1	389.0	391.0	389.0	391.0	0.77	390.55
Substation 1	297.0	303.0			0.70	301.20
Substation 2	85.0	90.0			0.70	88.50
Substation 3	0.5	1.0			0.70	0.85
Area 2	1977.0	1982.0	1977.0	1982.0	0.77	1980.86
Substation 4	17.0	19.0			0.59	18.17
Substation 5	186.0	192.0			0.59	189.51
Substation 6	94.0	99.0			0.59	96.93
Substation 7	371.0	380.0			0.59	376.27
Substation 8	173.0	180.0			0.59	177.10
Substation 9	330.0	340.0			0.59	335.86
Substation 10	780.0	792.0			0.59	787.03
Area 3	1007.0	1011.0	1007.0	1011.0	0.77	1010.09
Substation 11	95.5	103.0			0.65	100.35
Substation 12	900.1	915.0			0.65	909.74

Range Factors

The range factors are a measure to evaluate the balanced values relative to their own ranges.

$$Range\ \ factor = \frac{2\times Actual-(Upper+Lower)}{(Upper-Lower)} \qquad (4.4.10)$$

1) Given the actual value equals the lower range, then the range factor equals –1.
2) Given the actual value equals the upper range, then the range factor equals 1.
3) Given the actual value equals the average of the lower and the upper range, then the range factor equals 0.

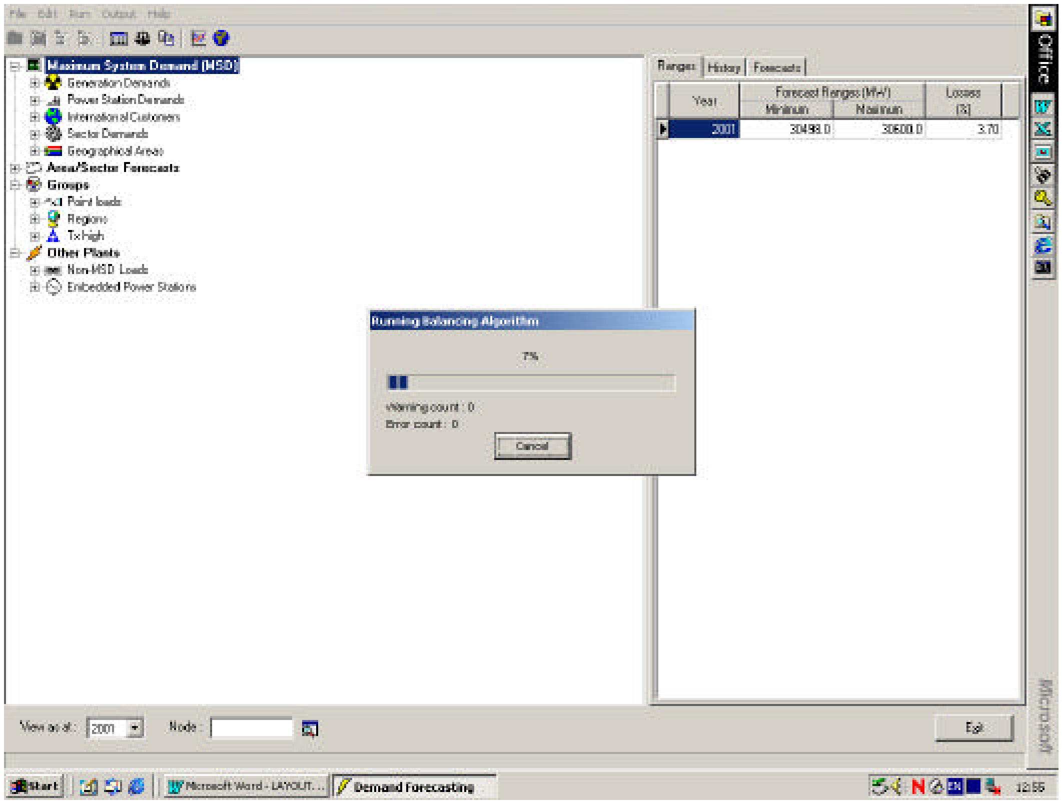

Figure 4.4.1 – Balancing Algorithm

4.5 EVALUATION

The heuristic solution may not find a solution for some feasible conditions. In most cases it is when the range factors are close to –1 or 1. But again, what is important - an optimal solution on expected loads ten or more years from now, or a method that solves in a reasonable time with acceptable results? That is the objective of the balancing algorithm - to solve in reasonable time limits, but to still ensure consensus (feasibility) exists.

In Chapter 1 it was mentioned that, for power flow studies P and Q, values are required for each load bus. The P values are the balanced loads from the balancing algorithm. It is important to check the import-and export balanced figures with the results from the power flow results. Since most of the point loads are distribution substation loads, the load that flows through the transmission substations are compared with the balanced transmission substation loads.

4.6 CONCLUSION

Because of the complexity of the transmission load forecast it is critically important to evaluate a number of different forecasts. The number of expected loads makes a manual process, to check consensus between the different forecasts not feasible. Therefore the research started to develop such an algorithm. The balancing algorithm provides feasible solutions, and within reasonable time limits (less than one minute on PCs with 1.7 GHz CPUs).

It can therefore be concluded that the balancing algorithm makes it possible to evaluate different forecasts and when consensus exists provides feasible solutions for transmission network studies.

4.7 REFERENCE

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