Multi - Area Unit Commitment In The National Electricity Market

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Abstract: The power energy industry has undergone radical transformations determined by a series of reforms implemented in recent years. As a result, the scenario of the unit commitment problem has changed dramatically from a monopolist system to a volatile bidding environment. This paper presents a new model which was developed to solve the multi-area unit commitment problem including the economic dispatch. The model is based on a sequential method and has been applied on a large scale power system with two and three regions in a deregulated power environment. In comparison with many multi-area unit commitment formulations, this model contains important constraints such as: transmission limits, transmission costs and inter-regional transmission losses. The sequential multi - area unit commitment model produces one-day (48 half-hourly trading intervals) schedules of units, including the economic dispatch, within a very low computational time.

Keywords: *Unit commitment; Load demand; Pool price; Electricity modelling*

1. INTRODUCTION

A power system consists of power generation, transmission and distribution sectors. A generation unit converts kinetic, thermal or nuclear energy into electrical energy. The power system operates under continuous and significant variations of customers demand.

The purpose of this study is to develop and implement a new algorithm and solve the multi-area unit commitment problem including the unit dispatch, in a large scale deregulated power system.

The literature contains a variety of optimization methods used to solve the unit commitment problem with different degrees of success.

Most of the approaches use small power systems and ignore important constraints. Larsen et al. (2001) assumed that “Transmission losses and constraints are as usual neglected”. As a consequence, the unit commitment problem is simplified and the search space is reduced considerably. In other research papers a heuristic method (priority list) is used to obtain an initial feasible solution, Lee et al. (1994).

Furthermore, in many cases there is a substantial difference between theoretical and practical applications. It was shown by Nissen (1992) that ”many researchers are concentrate their attention on standard problems to test the quality of their algorithms; but in real life practical applications reveal conflicting objectives and constraints that are not covered by these tests”.

Due to the nature of the optimization process and decision making in a deregulated electricity market, it is essential for the model to obtain an optimal solution within a very low computational time, practically to run in ‘real’ time.

The inclusion of inter-regional losses, auxiliary factor, transmission costs, transmission limits, and spinning reserve, in a large interconnected power system significantly increased the complexity of the multi-area unit commitment problem. Also, the computational time of the model is considerably affected.

The model is applied on two and three interconnected regions of the Australian National Electricity Market and the results are discussed.

2. SEQUENTIAL MULTI-AREA UNIT COMMITMENT MODEL (SQMAUC)

2.1. Introduction

The scheduling of the units together with the allocation of the generation quantities which must be scheduled to meet the demand for a specific period represents the *Unit Commitment problem.*

A *multi-area unit commitment* (MAUC) represents two or more interconnected regions of a power system. A multi-area power system is expected to provide a series of advantages such as:

- Substantial operational cost savings;
- Increased safety of the power system;
- Increased competitiveness;

- Enhanced environmental benefits.

For many techniques, is very difficult to find an 'optimal' solution to the MAUC problem for a large scale power system, within a very low computational time.

2.2. Pool price

The Australian national market is based on a pool market structure where all the electricity produced by the units is traded. In the new environment, the schedule of units, including the quantities of electricity dispatch, is based on *pool price*. As a result, the modelling of *pool price* has become an essential task in order to determine the scheduling of the most bid-efficient units, to meet the demand in all the regions and for each trading interval.

The trading day is a 24-hour period commencing at 4:00 am Eastern Standard Time and contains 48 half-hourly trading intervals. The market customers submit their demand levels and the units compete by offering their available capacity at different price levels. Daily offers must be received by 12:30 pm on the day before the supply is required. For the next 24 hours, any generation unit can offer only one set of 10-band prices for all the quantities offered. The units can only change the quantities offered up to five minutes priory to the trading interval but the prices cannot be changed under any circumstances.

NEMMCO calculates the most cost-efficient supply solution to meet the demand at all times, according to the bid process. As a unique central dispatch, it determines the scheduling of units based on a five minute dispatch cycle and half-hour trading intervals to ensure the equilibrium of supply and electricity demand and to meet all the system constraints.

The *pool price* is an average of the six 5-minutes dispatch prices for each trading interval (30 minutes). As an incentive to bid close to their costs, all the committed units receive the *pool price* irrespective of their bids.

2.3. Sequential method

Sequential Method combines the merits of two powerful methods, Dynamic Programming and Lagrange Relaxation. Consequently, the sequential approach maintains the solution feasibility and takes the benefits of unit commitment dual decomposition.

The multi-area unit commitment model is exclusively developed using the sequential method. Based on pool price, the sequential method employs a bidding procedure to sequentially identify the next most economic unit to be committed.

Lee (1988) and Huang (1997) described the sequential approach which involves two phases: the sequential commitment and the parameters revision. In first phase, based on the half-hourly or hourly bidding prices and function of constraints, the next most economic unit is identified and committed. The second phase updates the multi-area power system parameters.

Thus, the next best unit, as a function of bid price, is sequentially identified at each stage and committed until the demand of each region is met, while all the constraints are satisfied.

2.4. Definitions and assumptions

The regions included in SQM_2 are Queensland (Qld) (referred as Region 1) and New South Wales (NSW) (Region 2). For SQM_3 Victoria is the third region.

The power system for two regions contains 94 generation units and 145 for three regions.

The bids for period one were used for the whole day as result of the computational limitations.

The dynamic loss factor equation for Queensland to New South Wales interconnector is published by NEMMCO and is included in model.

The sent-out demand is the demand remaining after the electricity consumed by auxiliaries is taken out. Auxiliary percentages are estimated and their values are: Queensland = 6.5%, New South Wales = 8% and Victoria = 8.5%.

Transmission limits for two regions model are outlined in Figure 1.

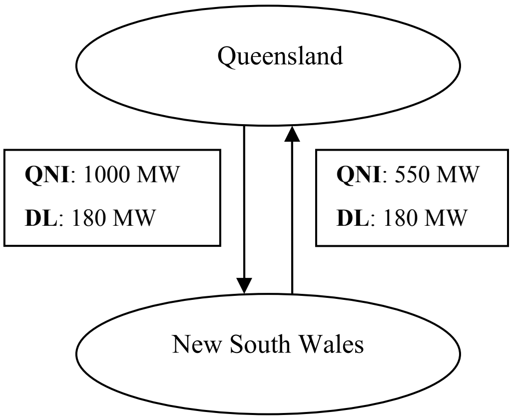

Figure 1 Two regions system design

The limit of the direct flow between New South Wales and Victoria is 850 MW and 1100 MW in the reverse direction.

Information about transmission costs is confidential. The only published material regarding this matter is the DirectLink offer. After analysing their bidding strategy, the costs for the export of electricity Queensland – NSW were estimated at \$2.50/MW and New South Wales - Victoria at \$2.55/MW.

2.5. Objective function

The objective of the MAUC problem is to find an optimal scheduling of units, including the allocation of the generation quantities of each unit, in order to minimize the total cost of dispatched electricity for all regions, during a time horizon, subject to a set of constraints.

$$Minimise \sum_{j=1}^{R} TC_j \tag{1}$$

The total cost for region *j* is defined by equation:

$$TC_j = \sum_{all\ i,\,k} \sum_{b=1}^{10} \delta_{ikdnbj} \times O\,\mathrm{Pr}_{ikdnbj} \times Q_{ikdnbj} \tag{2}$$

where:

- $O\,\mathrm{Pr}_{ikdnbj}$ is the operating price of unit U_{ik} in day *d*, period *n*, with transmission costs to region *j*
- δ_{ikdnbj} is the flag for unit *i* from region *k* exporting to region *j*
- Q_{ikdnbj} is the quantity produced by U_{ik} in day *d*, period *n*, exported to region *j*.

2.6. Model constraints

- Demand

$$\sum_{i=1}^{M} \sum_{k=1}^{R} \sum_{b=1}^{10} \delta_{ikdnbj} \times \square_{ikdnbj} = D_{dnj} \qquad j = \overline{1, R} \tag{3}$$

At any point in time the model has to satisfy the most important condition: the demand in each region has to be met.

- Interconnection transmission limits;

$$\sum_{i=m_{k-1}+1}^{m_k} \sum_{b=1}^{10} \delta_{ikdnbj} \times Q_{ijdnbk} \le TL_{kj}$$

For each day and period, transmission flow has to be only in one direction and less than or equal to the transmission limit.

- Spinning reserve;

The minimum reserve levels must be maintained in order to assure the reliability of the power system. These are: Qld. = 450 MW, NSW = 660 MW and Victoria = 500 MW.

- Capacity limits;

$$\sum_{b=1}^{10} X_{ikdnb} \le C_{ik} \tag{4}$$

The sum of the quantities in each of the 10 bands needs to be less than or equal to the unit capacity.

- Prices offers;

$$\mathrm{Pr}_{ikdn1} < \mathrm{Pr}_{ikdn2} < \cdots < \mathrm{Pr}_{ikdn10} \tag{5}$$

Price offered in ten-band bids need to be in an ascending order:

- Non – negativity conditions:

$$Q_{ikdnbj} \ge 0 \tag{6}$$

$$\delta_{ikdnbj}\ is\ binary \tag{7}$$

2.7. Inputs and outputs for SQMAUC model

The inputs are:

- Forecast of the regional demand;
- Spinning reserve for each region;
- Bid prices and quantities for each unit;
- Transmission costs;
- Inter-regional transmission losses;
- Auxiliary factor;
- Transmission limits of interconnectors.

The outputs are:

- Regional pool prices;
- Total cost of dispatched electricity;
- Schedule of units including the dispatch quantities;
- Interconnector flows.

2.8. Code description

The Sequential model (SQM) calls all the required modules in order to solve the MAUC problem. The model starts by calling the module *Initialisation* which allows the user to select the main specifications of the model. Then, from the first through the last selected day, the model loops until all the periods are solved.

For each individual day, the modules *Create demand* and *Create bid* will create the files for the specified days. These files are used later by *Solve* *the regions* module when loops through each period, by. The model is solved sequentially for each period. The output includes both, daily summaries and period by period data, provided by the modules *Write summary output* and *Write daily output*. The flow chart for the SQM_2 is shown in Figure 2.

Sequential model for three regions (SQM_3) continues until all the three demands are met. After the demand is met in one region, the bids are updated in order to include the relevant transmission costs and inter-regional transmission losses. Then, the bids are calculated and sorted function of the new prices and the allocation process continues.

When the transmission limit is reached for one segment of the system, electricity cannot be sent on that line and all the remaining bids for that segment will be ignored.

The main difference from SQM_2 is due to the third region, because is possible to transfer electricity from region 1 to 3 through 2, and reverse, depending on the transmission constraints and flow directions. This situation appears when the last demand that needs to be met is either 3 or 1. If the transfer of electricity is possible, the quantity allocated will be the minimum of the quantity offered in bid, the difference between demand and the cumulative quantity already allocated to that region, and for each interconnector segment the difference between its limit and the total quantity transferred on it.

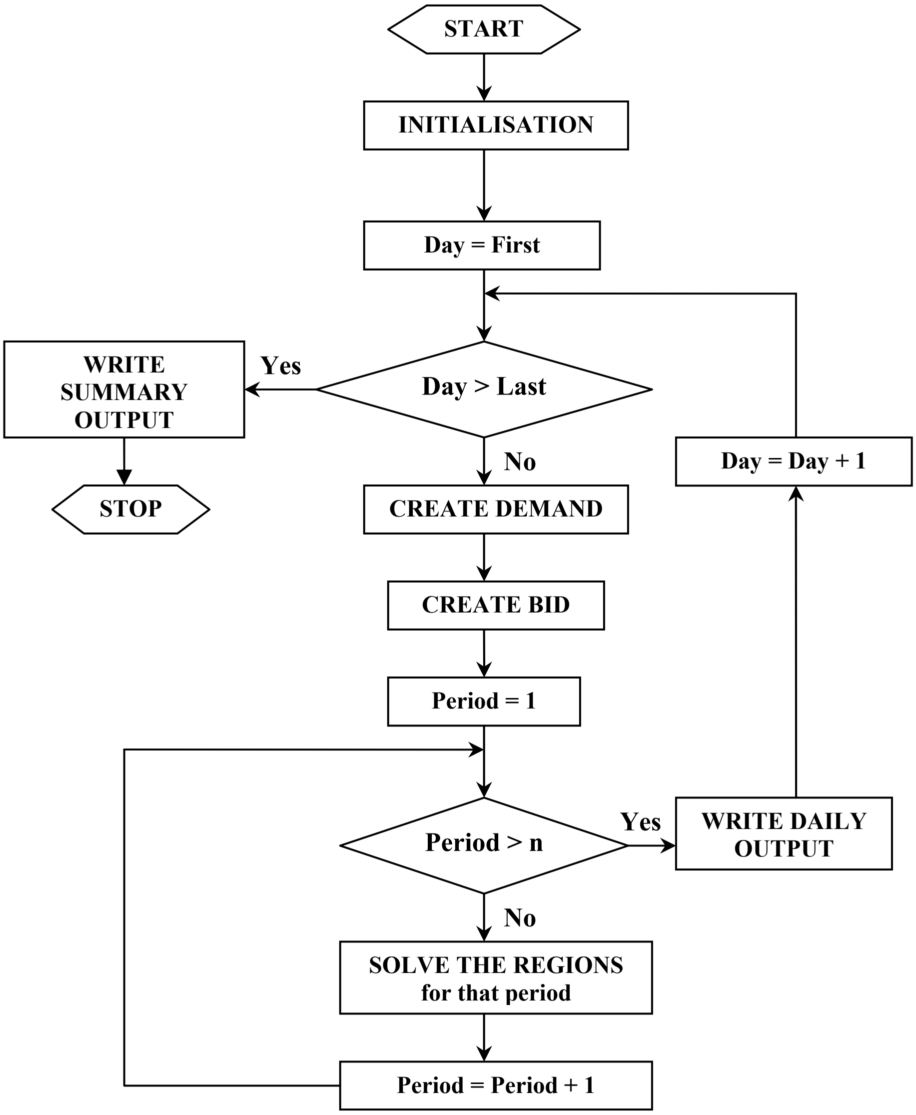

Figure 2 Flow chart of SQM_2

2.9. Running SQMAUC model

Data was mainly obtained from NEMMCO Market Data site.

The model can be run half-hourly or hourly. Thus, 48 and 24 periods respectively, can be set and demand and bid data need to be constructed for the chosen timeframe. In this research, all the model runs were based on 48 half-hourly periods.

The model was run for three representative days, 20 January 2000 (summer), 1 July 1999 (winter) and 9 September 1999 (spring).

2.10. Results - two regions, summer day

Due to outages in the system, pool prices for both regions reached more than $200/MWh, with NSW keeping a high $278/MWh for about four consecutive periods (Figure 3).

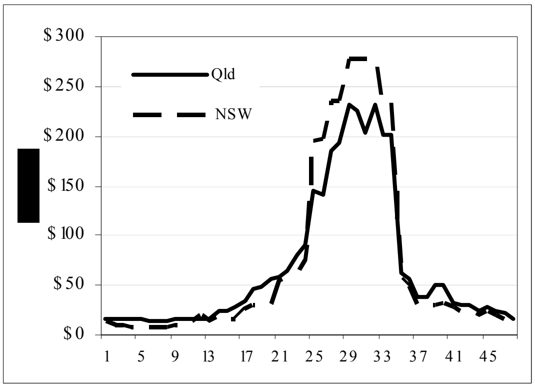

Figure 3 SQM_2 Pool price solutions - 20 January 2000, summer

During those periods, NSW to Queensland flow had a maximum of 730 MW for three periods, the interconnector operating in this direction 77% of the time (Figure 4). The flow from Queensland was at low levels.

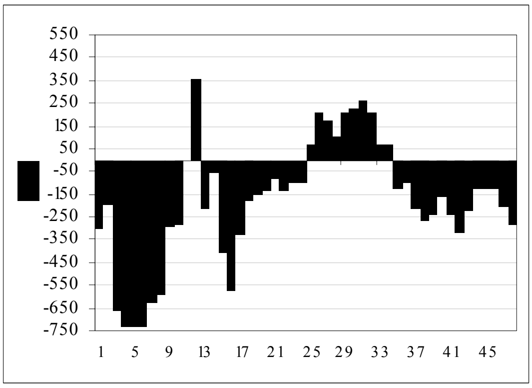

Figure 4 SQM_2 Flows Queensland to NSW, 20 January 2000, Summer

After the sequential model was run, the final optimal solution of the MAUC - two regions, is written period by period to a file. The schedule of units dispatch for one trading period is shown in Table 1.

2.11. Computational time

Generation units have the right to rebid the electricity quantities during the trading day and a short time is available to update the situation and to take dispatch decisions. In order to have a viable and applicable model in this field, it is very important that the calculation of an optimal schedule of units, including the allocation of the generation quantities of each unit, to be performed within a very low computational time.

The model was run in different conditions and the computational time was recorded. For the two and three regions of the national market, the sequential model obtains MAUC solution for one day (48 half - hourly trading periods), in 5 and respectively 17 seconds.

All runs were executed on a Pentium 4, 1.7 GHz with 256 DDR memory. The code is written in Visual Basic for Applications and the interface is through Microsoft EXCEL. Some manipulation of initial data was performed using Access.

3. CONCLUSIONS

The model was developed exclusively using Sequential Method.

In comparison with the old unit commitment approach, this modelling is used in a deregulated market where each generation unit is operating to maximize its own profits. As a result, the modelling of *pool price* has become an essential task in order to determine the scheduling of the most bid-efficient units.

The model includes important constraints which were largely ignored by other research papers.

The model was applied on two and three interconnected regions of the Australian national market for three representative days (hot, cold and mild). It can be extended to include more regions and has no limitation on the number of consecutive days which can be run.

In this modelling exercise, the ‘optimal’ solutions, attained in ‘real’ computational time, proved the effectiveness of this approach to solve MAUC problems in deregulated electricity markets.

Table 1 Scheduling of units for New South Wales and Queensland, period 37, SQM_2

QUEENSLAND			
Unit Name	Dispatch (MW)		
	Winter	Summer	Spring
BARCALDN	52	52	52
BARRON-1	30	30	30
BARRON-2	30	30	30
CALL_A_1	26	22	22
CALL_A_2	26	22	22
CALL_A_3	26	22	22
CALL_A_4	26	22	22
CALL_B_1	350	350	320
CALL_B_2	350	350	320
COLNSV_1	34	34	34
COLNSV_2	30	30	30
COLNSV_3	30	30	30
COLNSV_4	30	30	30
COLNSV_5	65	65	65
GSTONE1	280	280	275
GSTONE2	280	280	275
GSTONE3	280	280	275
GSTONE4	255	235	225
GSTONE5	255	235	205
GSTONE6	285	285	280
KAREEYA1	18	18	18
KAREEYA2	18	18	18
KAREEYA3	18	18	18
KAREEYA4	18	18	18
ROMA_7	36	36	36
ROMA_8	36	36	36
STAN-1	350	350	270
STAN-2	350	350	270
STAN-3	350	350	270
STAN-4	350	310	270
SWAN_A_1	60	45	45
SWAN_A_2	60	45	45
SWAN_A_3	60	45	45
SWAN_A_4	60	45	45
SWAN_A_5	60	45	45
SWAN_A_6	60	45	45
SWAN_B_1	116	85	85
SWAN_B_2	116	85	85
SWAN_B_3	116	85	85
SWAN_B_4	116	85	85
TARONG#1	355	350	350
TARONG#2	355	350	350
TARONG#3	355	350	350
TARONG#4	360	350	350
W/HOE#1	15	15	15

NEW SOUTH WALES			
Unit Name	Dispatch (MW)		
	Winter	Summer	Spring
BW01	660	600	580
BW02	630	600	580
BW03	660	600	580
BW04	660	600	580
ER01	600	600	550
ER02	660	660	630
ER03	660	660	660
ER04	660	660	660
LD02	470	470	470
LD03	500	500	500
LD04	400	400	400
MM3	280	200	200
MM4	200	200	200
MP1	660	660	630
MP2	660	660	630
SHGEN	80	80	0
SHPUMP	240	240	240
SITHE01	160	160	160
VP5	658	540	400
VP6	600	559	338
WW7	430	430	360
WW8	400	400	360

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