Multi Excelon

by Irwan Gani

Multi Echelon Distribution Model for Electric Market Deregulation Collaboration Strategy in East Kalimantan

View the article online for updates and enhancements.

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Multi Echelon Distribution Model for Electric Market Deregulation Collaboration Strategy in East Kalimantan

Irwan Gani[1], Wahyuda[2], Budi Santosa[3] and Muliati[1]

[1]Economics Faculty, Universitas Mulawarman, Samarinda, Indonesia
[2]Industrial Engineering, Universitas Mulawarman, Samarinda, Indonesia
[3]Industrial Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
irwan.gani@feb.unmul.ac.id, wahyuda@gmail.com, muliati@feb.unmul.ac.id

Abstract. Electric market deregulation aims to provide flexibility for customers to have many suppliers and low prices. However, market deregulation also provides opportunity for certain parties to manipulate supply, so there is a scarcity of products that result in price increases. Therefore, this research proposes a collaborative strategy for electricity market deregulation using the Multi Echelon distribution model applied in East Kalimantan with dummy data. Collaboration strategy made based on optimization of mathematical models in two stages and three scenarios. The simulation was carried out using Excel Solver covering three regions, dynamic time and estimated price fluctuations over three periods. As a result, Gencos gets the biggest profit when serving basic load. Whereas wheeling occurs, the D4 region is a strategic area that generates the largest profit compared to the D1 and D6 regions.
Keywords: Supply Chain, Optimization, Electricity, Transportation Model, Deregulation Market, Multi Echelon Distribution

1. Introduction

Electricity market deregulation has changed the vertical integration of electric power production systems into three separate systems namely Gencos, Transcos and Discos. Gencos are companies that have power plant to produce electricity, while Transcos are those that own transmission network to send electricity from producers to consumers. The last part of this system is Discos, which consist of companies that are responsible in distributing the electricity to end customer. The separation of these three systems are aimed to create competition among Genco companies so that electricity can be produced at low cost, and ensure continuity of electric supply.

Based on literature electricity rates are influenced by three factors, i.e., fuel costs, losses and transmission costs [1], while the continuity of supply depends on the amount of production reserves at the power plant [2]. Fuel costs depend on the characteristics of the power plant [3]. The difference in power plant characteristics among Gencos companies causes the allocation of loads needs to be integrated. This integration can be done by using Economic Dispatch process as in [1]–[3].

Electricity produced by the power plant is sent to customers through Transcos. Gencos should achieve cost minimization in order to avoid additional cost in the form of losses. System integration between Gencos and Discos can be done with Price Based Dynamic Economic Dispatch (PBDED) [7], [8]. PBDED has succeeded in creating integration between the two with low cost, even though the results are still lacking in detail [9]. More detailed PBDED obtained by combining PBDED models with multi

echelon [1]. Merging these two models successfully integrates Gencos and Transcos to deliver electricity to customers (DISCOS). The result of application of this model is very dependent on the characteristics of supply and demand in respective area.

This paper applied a combined PBDED model with multi echelon in the East Kalimantan electricity system. The electricity system in respective area consists of interconnected power plants through 150 kv and 20 kv transmission networks. Each power plants are situated in sparsely area as well as serving wide range location of end customer. The result of this research is providing infomation of optimal allocation of power plants with parameters of costs and emissions using Excel Solver.

2.   Methods

This research was conducted using 5 stages: Problem formulation, Literature review, modeling, Simulation, and Analysis (Figure 1).
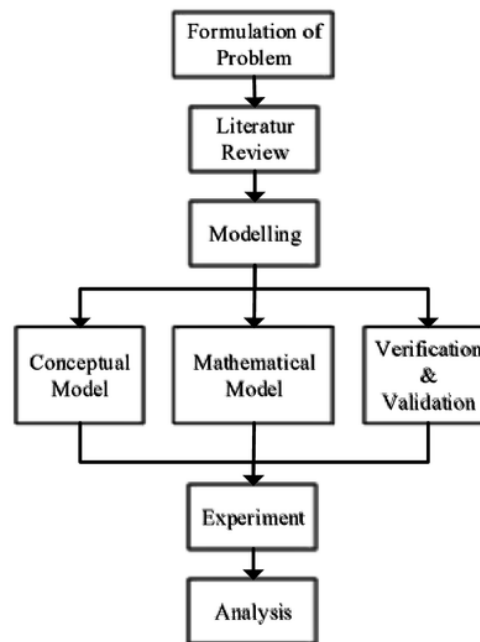

Figure 1. Research methodology

Formulation of the problem. What is the best collaboration of power suppliers in East Kalimantan to get the smallest total cost and emission?

Literature study. All of journals used as literatur in this research published by Elsevier on Economic Dispatch, optimization, and collaboration topics.

Modeling. There are three stages of modeling. First, build the conceptual model to facilitate in designing details of mathematical models; Second, provide mathematical model to illustrate supplier collaboration. Third, Verification and validation. So, there are four mathematical models in this research: SEC + RE, SEC + IPP + RE, SEC + Rent + RE, and SEC + EC + RE.

PBDED Model and Multi Echelon Distribution

The PBDED model as in[4] is aimed to maximize profit with the following objective functions:

$$maximize\ PF = RV - TC \tag{1}$$

In this case,

$$TC = \sum_{t=1}^{T} \sum_{i=1}^{N} \left[C_i \left(P_{(i,t)} + ST_t \right) \right] \tag{2}$$

$$RV = \sum_{t=1}^{T} \sum_{i=1}^{N} \left[\sigma_g(t) \left(P_{(i,t)} I_{(i,t)} \right) \right] \tag{3}$$

C_i: production cost of unit i, $P_{(i,t)}$: Output of generator i at time t. $I_{(i,t)}$ commit or not commit at time t. ST_t start-up cost at time t. t: time of dispatch. i: index generator. N is the number of generating units. $\sigma_g(t)$ load forecasting at time t. $C_i(P_{(i,t)})$ generation cost of unit i

   1.   Demand Constraint

$$\sum P_{(i,t)} I_{(i,t)} \leq D_t \quad t = 1, \dots, Tm \tag{4}$$

   2.   Generator Constraint

$$P_{i,min} \leq P_{(i,t)} I_{(i,t)} \leq P_{i,max} \tag{5}$$

$$-DR_i \leq P_i - P_i^0 \leq UR_i \tag{6}$$

$$\max\{P_i^0 - DR_i, P_{i,min}\} \leq P_i \leq \min\{P_i^0 + UR_i, P_{i,max}\} \tag{7}$$

The purpose of the PBDED model is to maximize profit not just minimizing fuel costs as in (Columbus & Simon, 2013)

$$maximize\ PF = RV - TC \tag{7}$$

In this case,

$$TC = \sum_{t=1}^{T} \sum_{i=1}^{N} \left[C_i \left(P_{(i,t)} + ST_t \right) \right] \tag{8}$$

$$RV = \sum_{t=1}^{T} \sum_{i=1}^{N} \left[\sigma_g(t) \left(P_{(i,t)} I_{(i,t)} \right) \right] \tag{9}$$

C_i: production cost of unit i, $P_{(i,t)}$: Output of generator i at time t. $I_{(i,t)}$ commit or not commit at time t. ST_t start-up cost at time t. t: time of dispatch. i: index generator. N is the number of generating units. $\sigma_g(t)$ load forecasting at time t. $C_i(P_{(i,t)})$ generation cost of unit i

   1.   Demand Constraint

$$\sum P_{(i,t)} I_{(i,t)} \leq D_t \quad t = 1, \dots, Tm \tag{10}$$

   2.   Generator Constraint

$$P_{i,min} \leq P_{(i,t)} I_{(i,t)} \leq P_{i,max} \tag{11}$$

$$-DR_i \leq P_i - P_i^0 \leq UR_i \tag{12}$$

$$\max\{P_i^0 - DR_i, P_{i,min}\} \leq P_i \leq \min\{P_i^0 + UR_i, P_{i,max}\} \tag{7}$$

While additional constraints are as in [5]:

$$F = \sum_{t=1}^{T} \sum_{i=1}^{I} F_{it}(P_{it}) \tag{13}$$

$$F_w = \sum_{t=1}^{T} \sum_{i=1}^{I} F_{it}(P_{it})_w \tag{14}$$

$$C_w = F_w - F + C_{ijt}^y + C_{jkt}^y \tag{15}$$

$$F_{it}(P_{it}) = a_i P_{it}^2 + b_i P_{it} + c_i \tag{16}$$

$$C_{ijt}^y = \frac{P_{ijt}^y}{P_{ijt}} z_{ij} \tag{17}$$

$$C_{jkt}^y = \frac{P_{jkt}^y}{P_{jkt}} z_{jk} \tag{18}$$

$$E_{it}(P_{it}) = \alpha_i P_{it}^2 + \beta_i P_{it} + \delta_i \tag{19}$$

   Equation (7) is used to model the cost of fuel with a regular load, whilst equation (8) applied to accomodate the cost of fuel when wheeling occurs. The 9th equation is aimed to calculate the transmission cost. In order to model the fuel cost we used a quadratic function in equation (10). Whereas the last two equation i.e. equation (11) and (12) were MW-mile method to calculate the transmission of 150 KV and 20 KV

Simulation. Simulation in this research is divided into two stages. In the first stage we did two calculation, which is allocation and distribution of electricity using basic loads, and calculation of

allocation and distribution of electricity with additional demand loads. The second stages consist of collaborative scenarios. Scenario 1, we put additional demand of power in D1 region; Scenario 2, additional demand in the D4 region; and Scenario 3, additional demand in D6 region.

Analysis. This section contains Results and Discussion. In Results section we provide data and computational process whilst in Discussion various finding will be presenter.

3.   Results and Discussion

3.1. Results

In the calculation we used dummy data (as shown in Table 1). Simulation carried out dynamically using three periods by dividing demand into two scenarios namely regular and wheeling. The estimated selling price of electricity varies over three periods.

Table 1. Dummy data for 3 periods

Period	Demand Regular	Demand Wheeling	R+W	Forecasted price	Revenue
1	9,000	200	9,200	1,000	200,000
2	9,400	150	9,550	1,300	195,000
3	9,900	100	10,000	1,250	125,000
Total	28,300	450	28,750	3,550	520,000

Table 2. Results of electricity market collaboration simulation

| | | WHEELING D1 | | | WHEELING D4 | | | WHEELING D6 | | |
	Regular Load	Min. Cost	Min. Emission	Min. Losses	Min. Cost	Min. Emission	Min. Losses	Min. Cost	Min. Emission	Min. Losses
Fuel Cost	16,986,879	28,440,769	49,419,721	38,544,976	17,748,035	41,149,713	50,309,190	17,748,035	41,528,235	43,354,120
Fuel Cost Wheeling		11,453,890	32,432,842	21,558,098	761,156	24,162,834	33,322,311	761,156	24,541,356	26,367,241
Transmission cost	1,406,095	186,168	262,960	178,323	4,688	240,035	290,727	4,688	245,837	251,747
Distribution cost	544,628	106,249	136,674	85,889	15,420	159,612	204,929	31,941	171,227	171,662
Total cost wheeling		11,746,307	32,832,476	21,822,310	781,264	24,562,482	33,817,968	797,785	24,958,421	26,790,650
Revenue	33,595,000	34,115,000	34,115,000	34,115,000	34,115,000	34,115,000	34,115,000	34,115,000	34,115,000	34,115,000
Profit	14,657,398	5,381,815	15,704,355	4,694,189	16,346,857	7,434,360	16,689,846	16,330,337	7,830,299	9,662,529
Emission		6,431,270	3,405,086	3,810,006	6,381,379	2,627,183	2,725,668	6,381,379	2,567,821	2,651,158
Losses		10,425	8,443	6,921	6,954	6,412	6,358	6,954	6,415	6,358

Regular load defined as routine load which is usually served by the electrical system in East Kalimantan. With this particular load the cost of fuel Rp. 16,986,879, the cost of transmission were Rp. 1,406,095, and the cost of distribution Rp. 544,628. Revenue generated from this scheme were 33,595,000 with profit of 14,657,398 (as shown in Table 2).

When an additional contract occurs in the D1 area, there are three objectives considered:

1. Cost Minimization. Power plant allocation were aimed to minimize costs required cost of fuel as much as Rp. 28,440,769, transmission costs Rp. 186,168 and distribution costs Rp. 106,249. The profit gained from this scheme was Rp. 5,381,815.
2. Emission Minimization. Within this scheme we found that power plant requires a fuel cost of Rp. 49,419,721, transmission costs of Rp. 186,168, and distribution costs Rp. 106,249. Profit generated from this simulation was Rp. -15,704,355.
3. Loss Minimization. The allocation of a power plant with this purpose generates total cost as much as Rp. 38,544,976, transmission costs Rp. 178,323, and distribution costs Rp. 85,889. The profit generated from this scheme was Rp. -4,694,189

Similar to our treatment to D1 area we set three objectives in D4 area:
1. Cost Minimization. In achieving this goal we should allocated costs of fuel as much as Rp. 17,748,035, set transmission costs in Rp. 4,688 and distribution costs Rp. 15,420. Profit expected from this allocation was Rp. 16,346,857.
2. Emission Minimization. Power plant required fuel cost of Rp. 41,149,713, transmission costs of Rp. 240,035, and distribution costs Rp. 159,612 for this purpose. With this scheme profit gained was Rp. -7,434,360.
3. Loss Minimization. profit generation expected from this scheme was Rp. -16,689,846 with total cost Rp. 50,309,190, transmission costs Rp. 290,727, and distribution costs Rp. 204,929.

The last treatment for D6 area were the same as the previous area. The result were:
1. Cost Minimization. Power plant allocation with the aim of minimizing costs requires a fuel cost of Rp. 17,748,035, transmission costs Rp. 4,688 and distribution costs Rp. 31,941. Profit gained in this scheme was Rp. 16,330,337.
2. Minimize emissions. Power plant allocation with this purpose requires a fuel cost of Rp. 41,528,235, transmission costs of Rp. 245,837, and distribution costs Rp. 171,227. Profit expected was Rp. -7,830,299.
3. Loss Minimization. The allocation of a power plant with this purpose generates a total cost of Rp. 43,354,120, transmission costs Rp. 251,747, and distribution costs Rp. 171,662. Profit generated was Rp. -9,662,529

3.2. Discussion

Collaboration between power plants to service basic loads requires a total fuel cost of Rp. 16,986,879. This cost required to produce 35,152 MW of electricity to meet the demand of 28,300 MW for three periods. It can be seen that that the amount of production is greater than demand due to losses occured in transmission and distribution networks (Equations 4 and 10). Under this skenario revenue gained was Rp. 33,595,000 and profit generated as much as Rp. 14,657,398. This basic load scheme is used as basis reference when we set additional demand in D1, D4, and D6 regions.

Additional demand in D1 of 450 MW affected revenue to increase by Rp. 520,000. However, along with increasing in production, the cost of fuel was also rising in Rp. 11,453,890, from Rp. 16,986,879 to Rp. 28,440,769. The imbalance between increasing in fuel costs and revenue caused a decreasing in profit as much as Rp. 9,275,583. Revenue increases that are not proportional to the increase in profit are due to the equation of fuel costs (Equation 13) and the improper determination of selling prices of products. As a result tariffs for additional products must be distinguished from product rates for basic loads.

Additional demand for D4 of 450 MW caused an increasing in revenue of Rp. 520,000. The consequence was increasing in cost of production which is caused by increasing in fuel from Rp. 16,986,879 to Rp. 17,748,035 (Rp. 761,156). Compare to the first scheme, revenue gained from this area was smaller than the increase in fuel costs. However, there was an increase in profit of Rp. 1,689,459 due to additional demand in D4 region has changed the allocation structure of the power plant

production. The nearer distance of power plant within this scheme production has caused the decreasing in cost of transmission and distribution.

Additional demand for D6 of 450 MW caused revenue to increase by Rp. 520,000, but increased production also increased fuel costs from Rp. 16,986,879 to Rp. 17,748,035 (Rp. 761,156 difference). In this scheme the increasing of revenue generated was smaller than the increasing of fuel costs. However, we found significant increase in profit as much as of Rp. 1,672,939,- duet o additional demand in the D4 region has changed the allocation structure of the power plant production. The closer location of power plant in the production has caused significant decreasing in cost of transmission and distribution.

3.2.1.   Wheeling in the D1 region

Table 3. Scenario for cost minimization, emission minimization, and losses minimization in region D1

Per.	Minimize of cost			Minimize of Emission			Minimize of losses		
	Cost (Rp)	Demand (MW)	Production (MW)	Cost (Rp)	Demand (MW)	Production (MW)	Cost (Rp)	Demand (MW)	Production (MW)
1	6,936,256	9,200	12,540	12,871,474	9,200	11,607	10,999,378	9,200	11,607
2	9,306,439	9,550	13,673	17,130,549	9,550	13,507	14,895,975	9,550	13,507
3	12,198,075	10,000	14,750	19,417,698	10,000	13,788	12,649,623	10,000	12,266
Tot.	28,440,769	28,750	40,963	49,419,721	28,750	38,901	38,544,976	28,750	37,379

The first scenario, minimizing costs. This scenario requires a total cost of Rp. 28,440,769 to produce electricity as much as 40,963 MW. Scenario 2, emission minimization. This scenario requires a fuel cost of Rp. 49,419,721 to produce electricity 38,901 MW. Scenario 3, Minimizing losses. This scenario requires a fuel cost of Rp. 38,544,976 to produce electricity as much as 37,379 MW, according to Table 3.

Additional demand causes an increase in the amount of production, and transmission / distribution costs. The first scenario requires an additional fuel cost of Rp. 11,453,890. The cost of wheeling 500 kv is Rp. 186,168, while the wheeling cost of 150 kv is Rp. 106,249. So that the total additional costs if there is wheeling in the D1 area of Rp. 11,746,307, detailed results in Table 4.

Table 4. Additional wheeling costs for region D1

	Minimize of cost	Minimize of Emission	Minimize of losses
Fw - F (Rp)	11,453,890	32,432,842	21,558,098
wheeling 500 KV (Rp)	186,168	262,960	178,323
wheeling 150 KV (Rp)	106,249	136,674	85,889
Additional cost (Rp)	11,746,307	32,832,476	21,822,310

3.2.2.   Wheeling in the D4 region

Table 5. Scenario for cost minimization, emission minimization, and losses minimization in region D4

Per	Minimize of cost			Minimize of Emission			Minimize of losses		
	Cost (Rp)	Demand (MW)	Production (MW)	Cost (Rp)	Demand (MW)	Production (MW)	Cost (Rp)	Demand (MW)	Production (MW)
1	5,136,670	9,200	11,351	12,446,306	9,200	11,152	15,061,762	9,200	11,097
2	5,892,102	9,550	11,905	13,293,906	9,550	11,737	16,089,169	9,550	11,737
3	6,719,263	10,000	12,447	15,409,501	10,000	12,273	19,158,259	10,000	12,273
Tot	17,748,035	28,750	35,704	41,149,713	28,750	35,162	50,309,190	28,750	35,108

Table 5 present simulation in three different scenarios. The first scenario, minimizing costs requires total cost of Rp. 17,748,035 to produce electricity as much as 35,704 MW whist the scenario 2, i.e. emission minimization need fuel cost of Rp. 41,149,713 to produce electricity 35,162 MW. In the last scenario, minimizing losses, the cost required to produce as much as 35,108 MW electricity was Rp. 50,309,190.

It is known that additional demand has caused an increase in amount of production, and transmission / distribution costs. The first scenario requires an additional fuel cost of Rp. 761,156. The cost of wheeling 500 kv is Rp. 4,688, while in 150 kv the cost increased to Rp. 15,420. So that the total additional costs if there is wheeling in the D4 area was Rp. 781,264 (detail calculation provided in Table 6).

Table 6. Additional wheeling costs for region D4

	Minimize of cost	Minimize of Emission	Minimize of losses
Fw - F (Rp)	761,156	24,162,834	33,322,311
wheeling 500 KV (Rp)	4,688	240,035	290,727
wheeling 150 KV (Rp)	15,420	159,612	204,929
Additional cost (Rp)	781,264	24,562,482	33,817,968

3.2.3.   Wheeling in the D6 region

Table 7. Scenario for cost minimization, emission minimization, and losses minimization in region D4

Per	Minimize of cost			Minimize of Emission			Minimize of losses		
	Cost (Rp)	Demand (MW)	Production (MW)	Cost (Rp)	Demand (MW)	Production (MW)	Cost (Rp)	Demand (MW)	Production (MW)
1	5,136,670	9,200	11,351	12,763,635	9,200	11,155	13,634,872	9,200	11,097
2	5,892,102	9,550	11,905	13,774,139	9,550	11,737	13,527,739	9,550	11,737
3	6,719,263	10,000	12,447	14,990,461	10,000	12,273	16,191,509	10,000	12,273
Tot	17,748,035	28,750	35,704	41,528,235	28,750	35,165	43,354,120	28,750	35,108

The first scenario is cost minimization. This scenario required total cost of Rp. 17,748,035 to produce electricity as much as 35,704 MW. In scenario 2, emission minimization, the fuel cost expected was Rp. 41,528,235 in order to produce 35,165 MW electricity. In scenario 3, minimizing losses, we found that the system requires the fuel cost of Rp. 43,354,120 to produce electricity as much as 35,108 MW (detail calculation in Table 6).

Additional demand causes an increase in amount of production, and transmission / distribution costs. The first scenario requires an additional fuel cost of Rp. 761,156 with cost of wheeling 500 kv as much as Rp. 31,941. So that the total additional costs if there is wheeling in the D6 area of Rp. Rp. 797,785 (see Table 8)

Table 8. Additional wheeling costs for region D6

	Minimize of cost	Minimize of Emission	Minimize of losses
Fw - F (Rp)	761,156	24,541,356	26,367,241
wheeling 500 KV (Rp)	4,688	245,837	251,747
wheeling 150 KV (Rp)	31,941	171,227	171,662
Additional cost (Rp)	797,785	24,958,421	26,790,650

4. Conclusion

Gencos gets the highest profit when serving basic load. Additional demand resulted additional revenue, however it caused decreasing in profit. This happens because additional revenue is not proportional to

the increased additional production costs. The current price level should be evaluated considering the fluctuations in demand in the electricity market deregulation. Region 4 (D4) can be used as a distribution center for electricity customers outside the basic load. This region can generate the biggest profit with the smallest transmission and distribution costs.

Environmentally friendly electricity production is more expensive because low-emission plants require fuel-powered plants, which is more expensive than conventional power plant. Nevertheless, this high cost production can also be reduced by reducing losses, even though the smaller losses do not automatically lead to the cheaper total cost cheaper since it depend on the characteristics of the generator involved.

5.   References

[1]   Wahyuda, Santosa B and Rusdiansyah A 2018 Cost analysis of an electricity supply chain using modification of price based dynamic economic dispatch in wheeling transaction scheme. *IOP Conf. Ser. Mater. Sci. Eng.*

[2]   Wahyuda and Santosa B 2015 Dynamic Pricing in Electricity: Research Potential in Indonesia. *Procedia Manuf.* **4** pp 300–306

[3]   Bhattacharjee V and Khan I 2018 A non-linear convex cost model for economic dispatch in microgrids. *Appl. Energy* **222** (January) pp 637–648

[4]   Zhou J, Wang C, Li Y, Wang P, Li C, Lu P and Mo L 2017 A multi-objective multi-population ant colony optimization for economic emission dispatch considering power system security. **45** pp 684–704

[5]   Mahdi F P, Vasant P, Kallimani V, Watada J, Fai P Y S and Abdullah-Al-Wadud M 2018 A holistic review on optimization strategies for combined economic emission dispatch problem. *Renew. Sustain. Energy Rev.* **81**(March) pp 3006–3020

[6]   Zhou J, Wang C, Li Y, Wang P, Li C, Lu P and Mo L 2017 A multi-objective multi-population ant colony optimization for economic emission dispatch considering power system security. *Appl. Math. Model.* **45** pp 684–704

[7]   Liao G 2012 Integrated Isolation Niche and Immune Genetic Algorithm for solving Bid-Based Dynamic Economic Dispatch. *Electr. Power Energy* **42** pp 264–275

[8]   Columbus C C and Simon S P 2012 Profit based unit commitment : A parallel ABC approach using a workstation cluster q. *Comput. Electr. Eng.* **38**(3) pp 724–745

[9]   Wahyuda, Santosa B and Rusdiansyah A 2017 Load allocation of power plant using multi echelon economic dispatch. *AIP Conf. Proc.* 020007

[10]   Columbus C C and Simon S P 2013 Profit based unit commitment for GENCOs using parallel NACO in a distributed cluster. *Swarm Evol. Comput.* **10** pp 41–58

Multi Excelon