Dynamic Programming Approach to Unit Commitment Problem for Kuwait Power Generations

Nadine Awadah, Rawan AlShikh Ali, Shaikha AlBaijan, Ghalia Al-Qallaf, Muneerah Al-Hassawi, and Suat Kasap
Industrial Engineering Department
College of Engineering and Technology
American University of the Middle East - AUM
Egaila, Kuwait
Suat.kasap@aum.edu.kw

Abstract

Optimization techniques are becoming essential in the field of power systems. In this paper, two Dynamic Programming (DP) optimization methods were used to solve a large-scale problem which is known as the unit commitment problem (UCP). A sample of ten generating units that forms one power station in Kuwait was chosen to be tested. This paper aims to have a schedule with the least possible electricity production cost while meeting the hourly demand in addition to other system constraints and this is what is known as UCP. A MATLAB code was used to generate solutions for the ten-unit system. The results showed that the conventional DP method reduced the cost by 36.1% while priority DP method reduced the cost by 35%. Since the future NEWKUWAIT vision is introducing renewable energy resources to the power system, solving the UCP will be the first step towards reaching the vision.

Keywords

Unit Commitment Problem, Optimization Methods, Dynamic programming, Priority Dynamic Programming, Conventional Dynamic Programming, Unit Generation Optimization

1. Introduction

The electricity consumption worldwide is increasing with the continuous increase of the population. This huge consumption creates threats on the power systems. Speaking locally, Kuwait's electrical systems are under risk in terms of electricity shortages and blackouts (Ansari, 2013). A new investment of buying more generators to supply the current demand would be expensive. Consequently, we need to search what problems the current grid is facing and how these problems can be solved. When studying an electrical grid, the first component is the generator. The most studied problem related to generators is the unit commitment problem (UCP) (Hobbs, Rothkopf, O'eill, & Chao, 2002). Therefore, the problem addressed in this paper is the UCP which is the scheduling of generators to produce enough electricity to meet the increasing power demands with the least possible production operating cost. The current system will be modeled and solved by knowing the inputs and the costs of the generation, and by adding the amount of consumption over time to balance the input and output. There are many techniques that can be used to solve the UCP. One of the disadvantages of the methods of solution is that the optimum solution is not guaranteed 100 percent; however, the optimality percentage varies from one method to the other (Tung, Bhadoria, Kaur, Bhadauria & Pg, 2012). Dynamic programming (DP) approach was considered in this paper. The advantage behind using DP is the easy implementation of the problem. DP includes various features that deal with controlling the size of the problem effectively (Alshareef & Saber, 2012). It was proven to be a successful technique in solving a medium size power plant. Solving unit commitment problem is an important issue which is targeted by most electrical companies and ministries. Solving such problem will help in reducing the total operating cost, as well as the emissions that are given off by fuel combustion (Taha, 2010). The main objectives of this paper are to formulate and optimize the problem, create a 24 hour schedule for ten generators that are located in Sabiya- Kuwait power system, and finally specifying when to turn them on/off to reduce the generating cost while meeting the daily demand and the operational constraints. Reaching the objectives will show the impact of this paper towards engineering solution economically in Kuwait as well as meet future environmental needs.

2. Background of the Problem

The unit commitment schedule can be daily, weekly or monthly prepared to optimize the amount of electricity generated with least cost possible (Sivanagaraju & Sreenivasan, 2010). Therefore, the problem is to generate daily electricity schedules and introduce them to Kuwait for the first time that will help in reaching the future NEWKUWAIT vision.

The directly related facility to the paper is the ministry of the electricity and water (MEW) and specifically the National Control Center (NCC) as it manages electricity and water production to fulfill Kuwait's daily demand. It was found that the generating units in all power stations are committed to be online 24/7 as it is easier to keep up with the hourly changing electricity demand. Consequently, extremely high costs are spent on excess electricity that is higher than the required demand in some hours throughout the day.

Throughout the years the electricity consumption in Kuwait has been increasing tremendously. Figure 1 illustrates the development of power stations installed capacity from 1965 up until 2015. It proves that the consumption is increasing enormously which led the country to add more generating units to satisfy the needs.

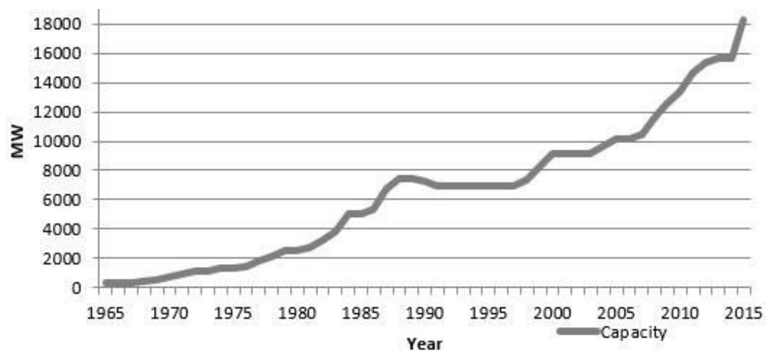

Figure 1: Development of power station installed capacity through 1965 to 2015

Figure 2 supports the information by showing the clear increase in the maximum consumption of electricity during 1996-2016 with the average increase of 4.8% per year. To keep up with this rapid increase, the government is increasing the number of units and their capacities each year which is very costly (Statistics Dept. & Information Center, 2015). When comparing figure 1 and 2, it is easily noticed that the total capacity installed by the ministry of electricity exceeds the demand needed. From here arises the importance of optimizing the generators' behavior to decrease the extra production and therefore the total cost. Kuwait's electrical grid consists of 8 power stations distributed throughout the country. The power stations are composed of different units, stream turbines, gas turbines and combined cycles with a total number of 90 units. The 8 power stations are in Shuwaikh, Shuaiba North, Shuaiba South, Doha East, Doha West, Al-Zour South, Al-Zour North, and Sabiya. To keep up with the increasing demand, the ministry kept increasing the capacity and the number of stations each year. The new introduced Unit Commitment schedule will limit the increase in generating units and reduce operation costs as well.

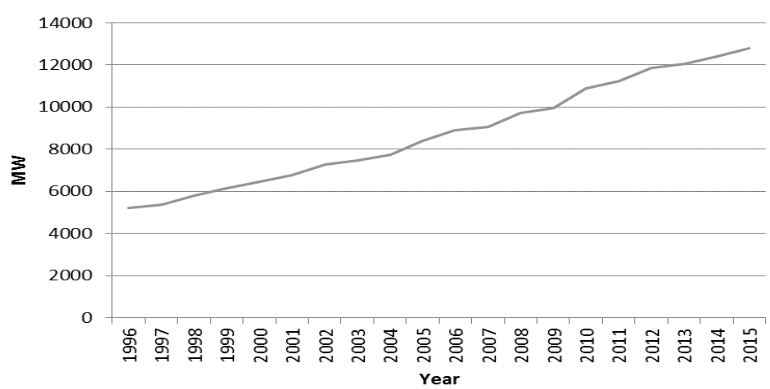

Figure 2: Maximum electricity consumption during (1996-2016)

3. Dynamic Programming Approach

Dynamic programming (DP), also known as dynamic optimization, is a method used to solve complex problems by breaking it into steps (stages). The searching process could be either in a forward direction or backward direction, meaning that the search for a solution can start at the very beginning of the system or at the very end of the system (Sen & Kothari, 1998). A study by Thakur and Titare, (2016) shows the mechanism of dynamic approach step by step. The first step is to consider two units randomly. Then, the output of the two units should be found as discrete load levels and the best combination for all levels of those units. After that, construct a cost curve for the two units and add an additional unit. Finally, calculate the cost curve for the three. This process of adding units will keep repeating until all units are taken into consideration.

3.1 Conventional Dynamic Programming

The conventional dynamic programming obtains the optimum (close to the best) solution but it requires huge memory and consumes a lot of time to get the desired solution (Moores, 1988). The total number of paths tested depends on the number of processed units and the time horizon. Since a sample of 10 units will be processes for 24 hours, paths can be calculated according to Singhal and Sharma (2011) as follows where i represents number of generating units and t is the hours needed to create the schedule:

$Total\ number\ of$ combinations computed: $(2^i - 1)\ x$ t = $(2^{10} - 1)\ x$ 24 = 1.72589 x 10^{72} combinations

Since the number of paths or combinations is high, another alternative method was considered to find schedules in much less time, which is the Priority Dynamic Programming.

3.2 Priority Dynamic Programming

This method is also called sequential dynamic programming since it works step by step to the final solution. This technique starts with the first unit and compares it to the next one in a strict method, and then it prioritizes the best one and continues until reaching the best schedule hourly (Singhal & Sharma, 2011). The main advantage behind using priority dynamic programing is that it reduces the dimensionality of the problem (number of paths used), as well it produces a schedule for the units at given certain time (Snyder, Powell, & Rayburn, 1987).The expected number of paths for the same previous sample size is “ i ” combinations hourly. As a result, only 240 combinations are tested for 10 units. Finally, this method is tested as a second scenario and the least-cost method is chosen. By that, it is guaranteed that the design is good.

4. Formulation of the Problem

Since our problem is optimization, the variables along with the objective function and constraints must be decided at the beginning in order to make sure that the problem is ready to be optimized (Salam, 2007). The objective function is minimizing the operating costs by reducing fuel costs, units starting up costs as well as shutting down costs (Wood & Wollenberg, 1996). The objective function can be represented in equation (1): where TPC is the total production cost, FC is the fuel cost, SUC is the startup cost and SDC is the total shut down cost

$$min\ TPC = FC + SUC + SDC \quad (1)$$

- **The Fuel cost (FC):** Fuel consumption increases in a quadratic (non-linear) form depending on the amount of power produced. FC_i is the fuel cost of unit i, Pit is the amount of power (MW) generated form unit i at time t and the coefficients a, b and c are cost coefficients for generator I in equation (2).

$$FC_i\ (P_{it}) = a_i + b_i P_{it} + c_i (P_{it})^2 \quad (2)$$

- **Start-up cost (SUC):** is the cost of turning on the offline units (Dhifaoui, Guesmi, & Abdallah, 2014). The units must be online for a minimum time before it can be turned off (minimum up time). How to calculate it is seen in equation (3).

$$SUC = Sum\ of\ startup\ costs\ for\ all\ units \times status\ of\ the\ units\ (on/off)$$

$$SUC = \sum_{t=1}^{T} \sum_{i=1}^{N} SUC_{it} \times U_{it} \quad (3)$$

- **Shutdown cost (SDC):** is the cost of turning off the online units. The minimum time required for the unit to stay online before it is switched off (minimum up time) should be considered as well.

$$\boldsymbol{SDC} = \sum_{t=1}^{T} \sum_{i=1}^{N} SDC_{it} \times U_{it} \quad (4)$$

Two different types of variables are considered in the unit commitment problem: binary and continuous. The binary variable is the status of the unit and it can either be 0 (off) or 1 (on). The continuous variable is the amount of power produced at a certain time (Yang, 2007. Both variables can be expressed as follows:

- U_{it}: $The\ status\ of\ unit\ i\ at\ time\ t.$
- P_{it}: $The\ power\ produced\ in\ MW\ from\ unit\ i\ at\ time\ t.$

To solve the unit commitment problem, many constraints should be considered such as:
Load/Generation Balance: It is the total demand of electricity (D) when equal to the total generators' electricity production. Equation (5) satisfies the generation balance constraint.

$$D = \sum_{i=1}^{N}(P_{it} \cdot u(t)) \quad (5)$$

- **Spinning Reserve:** is defined as the extra capacity of all units in power generators that can be generated to meet the demand and keep frequency from dropping in case of emergencies as shown in equation (6).

$$\sum(Max\ P_{it} \cdot U_{it})) \geq (D_t + R_t) \quad (6)$$

- **Ramp rate:** Ramp rate is the increase or decrease in the output over time (electricity generated). It provides the power system with flexibility by ramping up and down the output, given the needed demand. (Datta, 2013)
- **Minimum up time and Minimum down time:** means that whenever a unit is online, it cannot be turned off and whenever a unit is offline it cannot be started immediately until a certain time has passed.

If the minimum up time constraint is violated, the unit stays online for the next time-period shown in equation (7).

$$if\ U_{it} = 1\ (online)\ and\ t_{i,up} < t_{up,min}$$
$$then \quad U_{i,t+1} = 1\ (stays\ online) \quad (7)$$

If the minimum down time constraint is violated, the unit stays offline for next time-period as shown in equation (8).

$$if\ U_{it} = 0\ (offline)\ and\ t_{i,down} < t_{down,min}$$
$$then,\ U_{i,t+1} = 1\ (stays\ offline) \quad (8)$$

5. Results and Discussion

The results of the conventional dynamic programing are illustrated and tested using a prewritten MATLAB code. To solve the problem and form an hourly schedule, the first step was to collect the data required for the ten generators. Table 1 shows the data collected related to the ten generating units which include the maximum/minimum production limits in megawatts, the cold/hot startup status with their corresponding costs in Kuwaiti Dinar, and the online/offline states in hours. Each generator has its own cost coefficients which are a, b, and c.

Table 1: Data for 10-unit system

	Parameter	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
1	Pmin (MW)	100	130	130	30	30	10	10	80	100	100
2	Pmax (MW)	220	300	300	62	62	41	41	215	250	250
3	Cold start cost ($)	100	8000	8000	100	100	100	100	6500	100	100
4	Min up (hr)	1	5	5	1	1	1	1	4	1	1
5	Min down (hr)	1	6	6	1	1	1	1	5	1	1
6	Initial Status (hr)	-1	7	7	-1	-1	-1	-1	-3	-1	-1
7	Hot start cost ($)	50	4000	4000	50	50	50	50	3000	50	50
8	Cold start Hours (hr)	0	5	5	0	0	0	0	3	0	0
9	a (kd/hr)	3242.255	1877.95	1877.95	3299.22	3299.22	3299.22	3299.22	3305.165	3299.22	3299.22
10	b (kd/MW)	48.087	36.043	36.043	51.269	51.269	51.269	51.269	27.675	51.269	51.269
11	c (kd/MW^2)	0.03326	0.02592	0.02592	0.27143	0.27143	0.27143	0.27143	0.10974	0.27143	0.27143

To satisfy the demand, table 2 illustrates the demands in megawatts with their corresponding hours. The hourly demand was in July 15, 2015 as it is the peak month in consuming electricity in Kuwait (Statistics Dept. & Information Center, 2015). As mentioned before, the demand is satisfied by Sabiya power station but the problem occurs in the excess electricity wasted and extra money spent, therefore, optimization is required.

Table 2: hourly demand relative to 10-units

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Demand	1221	1212	1199	1191	1187	1170	1201	1250	1276	1320	1370	1430
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Demand	1567	1591	1574	1546	1496	1468	1432	1389	1343	1307	1291	1258

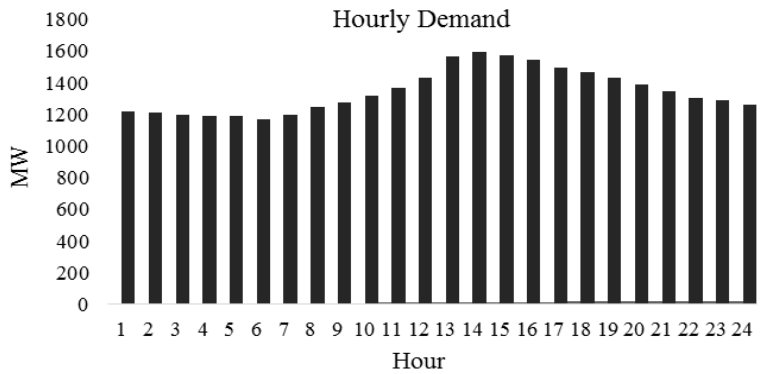

Figure 3: Hourly demand

As noticed from Figure 3, the demand is varying during the day with a peak in hours 13, 14 and 15 so it is predicted in these hours to have all the generating units on (or most of them).

5.1 Baseline Results

Before generating the solutions and alternatives for the problem, the current situation in Kuwait should be tested as a baseline to compare further results and check whether the system has improved or not. Kuwait's ministry of electricity and water doesn't turn off the generating units at all. To calculate the baseline all of the units should be on for the whole time interval (24 hours). The calculated baseline cost was \$ 3,642,310 (1,100,489 KWD).

5.2 Conventional Dynamic Programing Results

The first alternative solution used in this paper was the conventional dynamic programming method. After inserting the data and the equations of the UCP, a MATLAB code was used to test the program and give the results. Table 3 shows the generated hourly schedule of the ten generating units using this method. It shows that unit 1 must stay online for 24 hours without shutting it down in order to meet the demand. On the other hand, unit 6 must be turned on in hours 13:00, 14:00 and 15:00 only. This table took 946 seconds which is approximately 15.7 minutes to be constructed by the MATLAB software. The results also show that the total production cost of the generated schedule during the 24 hours is \$2,326,723 (702,947 KWD) which is much less in comparison with the baseline cost of the current state (\$3,642,310 (1,100,489 KWD)).

Table 3: Unit commitment schedule for conventional DP

	Hours																							
Units	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Unit 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Unit 2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Unit 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Unit 4	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0
Unit 5	1	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Unit 6	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
Unit 7	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0
Unit 8	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Unit 9	1	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Unit 10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 4 demonstrates the production cost of the total online generators for each hour. Adding all these costs will give us the total production cost for the 24 hours. This table was made to compare the total production cost of the scheduled units using both the conventional DP and priority DP methods.

Table 4: Fuel cost for each hour

Hours	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
P-Cost	92234	90607	88936	8545	85212	84198	86057	89104	90858	94024	983047	105308
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
P-Cost	86070	127732	125284	121291	114138	110248	105559	1000419	95806	93064	91911	89631

Consequently, Figure 4 shows the total amount of online units in each hour during the 24 hours when using conventional dynamic programming method (Snyder, Powell & Rayburn, 1987).

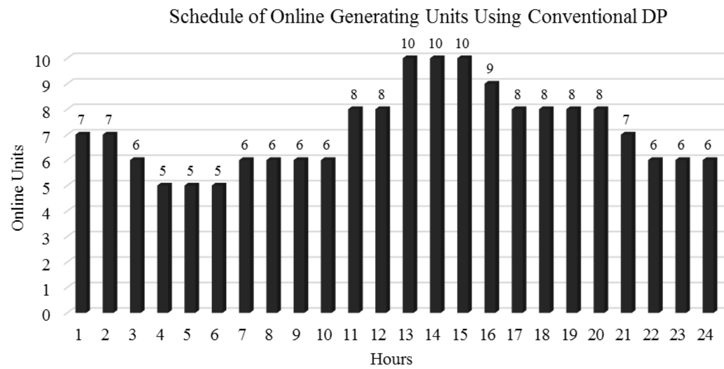

Figure 4: Conventional DP units scheduled

5.3 Priority Dynamic Programming Results

In the second alternative scenario, priority dynamic programming was used where the incremental heat rate of the generators is required. When defining the incremental heat rate, it is the total hourly change in the heat rate. The heat rate in a certain hour is the amount of fuel needed to produce I MW of electricity. Therefore, as the incremental heat rate increase, the unit will have least priority to be online (Bello, Akorede, Pouresmaeil, Ibrahim, & Ai, 2016). Prioritization of the generators is based on the incremental heat rate of each. The following Table 5 declares the heat rates used to get the results. The importance of this rate is that it is needed to be inserted as data to run the priority method on MATLAB. (Alsaffar & El-Sayed, 2014)

Table 5: Incremental heat rate for 10-units

Units	1	2	3	4	5	6	7	8	9	10
Incremental Heat Rate (BTU/KwH)	22	23	21	26	29	31	35	25	20	21

Accordingly, Table 6 shows the required state of each unit for 24 hours. It is clearly noticed that more units are staying online for longer duration when comparing it to conventional DP method which satisfies the working process of Priority method.

Table 6: Schedule 10-units using priority DP

	Hours																							
Units	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Unit 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Unit 2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Unit 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Unit 4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Unit 5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Unit 6	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
Unit 7	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
Unit 8	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Unit 9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Unit 10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

The detailed production cost of each hour was listed in Table 7. When comparing the table of total production cost we got from the priority method, it is clearly noticed that the conventional method gives lower production cost compared to the priority method.

Table 7: Hourly production cost using priority DP

Hours	1	2	3	4	5	6	7	8	9	10	11	12
P-Cost	92234	90607	81680	77709	77170	74974	78995	8380	86643	92040	98137	105408
Hours	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
P-Cost	124499	127732	125284	121291	114138	110248	105559	1000419	94751	90391	88424	84587

Furthermore, Figure 5 shows the overall sequence and amount of online units hourly. As a result, the total production cost resulted when applying priority dynamic programming is $ 2,338,674 (706,588 KWD) and it took an average of 1.45 seconds to generate the schedule which is much less than the conventional method. The detailed production cost of each hour was listed in Table 7.

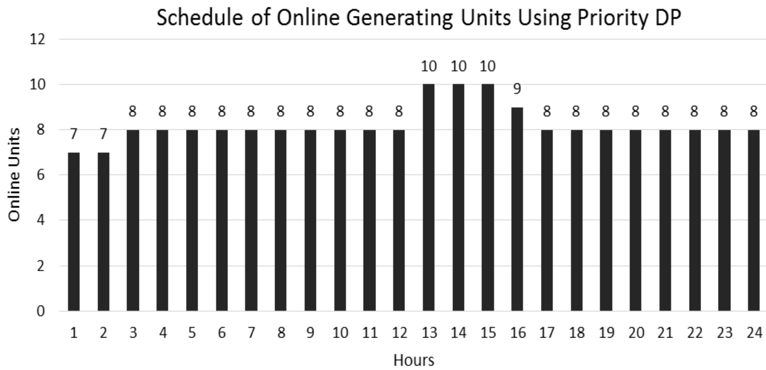

Figure 5: Schedule using Priority DP method

After testing the system and comparing the results, it was found that the best method to implement for scheduling the problem is the Conventional Dynamic Programming, since it can generate a final hourly schedule with the least possible cost compared to the baseline cost. On the other hand, this method took much longer time than the priority dynamic programming method when testing the system. This might cause some inconvenience, but since the main focus was to minimize the total cost, the time is not a big issue if there was no big time variation between the two methods. Comparing the three scenarios together, we can get the following results:

Table 8: Comparison between results

Scenario	Total production cost ($)	% of reduction compared to baseline	Time elapsed (sec)
Baseline	3,642,310	-	-
Conventional DP	2,326,723	36.10%	946
Priority DP	2,338,674	35.70%	1.45

As noticed from Table 8, conventional method reduces the operating cost of the generations by 36.1% which is a very high percentage. Putting into consideration that when the problem is solved as large scale problem (the whole power system), the cost reduction would be critical. The disadvantage of the conventional DP method is that it might consume a huge amount of time to solve such a large problem (Souroudi, 2017). For instance, 12 units were solved using conventional DP in it took more than 45 minutes to get the final schedule. In this case, the other alternative solution can be considered since the number of combinations is low. It would generate schedules fast but with higher costs than the conventional. Since the ministry of electricity and water at the current time do not pay attention that much on the costs, they might go to the priority method. However, with the continuous increase in the fuel costs, they might go to the conventional method regardless time elapsed. Finally, both methods are applicable and depending on the need of the customer (Matousek & Gärtner, 2007).

6. Conclusion

The aim of this paper is to apply optimization methods to a real-life problem which is the power system in this case. The focus was based on optimizing the generators by reducing the total production cost. Different methods were explained with their advantages and disadvantages; the discussion part of the paper included both theoretical and numerical considerations to optimize the problem. The results were translated into tables and graphs to compare the applied methods and reach the optimum solution. These tables and graphs were then explained in detail in the discussion section where economic goals were satisfied through minimizing the total production operating cost. Dynamic programming was proven to be an efficient way to solve the unit commitment problem and such a method will make a huge difference when implementing it in Gulf Cooperation Council countries in general and in Kuwait in specific. It was verified that solving the unit commitment problem is an effective, innovative and creative way in the power systems field and this paper is concluded to be successful and is able to be implemented.

References

Alsaffar, M. A., and El-Sayed, M. A., Emission constrained unit commitment of Kuwait power generation system using genetic algorithm. Journal of Engineering Research, Vol.2, no.2, pp. 101 – 121, 2014.

Alshareef, A., and Saber, A., An Application of Particle Swarm Optimization (PSO) to Dynamic Unit Commitment Problem for the Western Area. Journal of King Abdulaziz University: Engineering Sciences, Vol. 23, no.1, pp. 21-37, 2012.

Ansari, M. J., Kuwait Utilities Sector, technical report by Capital Standards (CSR). Available: http://www.infomercatiesteri.it/public/images/paesi/107/files/Kuwait%20Utilities%20Sector%20Report_pdf%206_13.pdf, March 11, 2018.

Bello, S., Akorede, M., Pouresmaeil, E., and Ibrahim, O., Unit commitment optimisation of hydro-thermal power systems in the day-ahead electricity market, Cogent Engineering, Vol.3, no.1, p.1251009, 2016.

Datta, D., Unit commitment problem with ramp rate constraint using a binary-real-coded genetic algorithm, Applied Soft Computing, Vol.13, no.9, pp.3873-3883, 2013.

Dhifaoui, C., Guesmi, T., and Abdallah, H., Application of multi-objective PSO algorithm for Economic Dispatch (ED) through Unit Commitment Problems (UCP). In Sciences and Techniques of Automatic Control and Computer Engineering (STA), 2014 15th International Conference on, pp. 704-710, Hammamet, Tunisia, 2014.

Hobbs, B., Rothkopf, M., O'eill, R., and Chao, H., The next generation of electric power unit commitment models, Kluwer Academic Publishers, New York, 2002.

Matousek, J., and Gärtner, B., Understanding and using linear programming, Springer Science & Business Media, 2007.

Moores, B., Dynamic Programming versus Conventional Optimization: Response, Journal of the Operational Research Society, Vol.*39*, no.3, pp.322-322, 1988.

Salam, S., Unit Commitment Solution Methods, International Jornal of Energy and Power Engineering, Vol. 1, no.11, 2007.

Sen, S., and Kothari, D. P., Optimal thermal generating unit commitment: a review, International Journal of Electrical Power & Energy Systems, Vol. 20, no.7, pp. 443-451, 1998.

Sivanagaraju, S., and Sreenivasan, G., Power System Operation and Control, Dorling Kindersley, Chennai/ India, 2010.

Singhal, P., and Sharma, R., Dynamic programming approach for large scale unit commitment problem, In Communication Systems and Network Technologies (CSNT), 2011 International Conference, pp. 714-717, Katra, JaIndia, 2011.

Snyder, W., Powell, H., and Rayburn, J., Dynamic programming approach to unit commitment, IEEE Transactions on Power Systems, Vol.2, no.2, pp.339-348, 1987.

Souroudi, A., Power System Optimization Modeling in GAMS, Springer International Publishing, 2017.

Statistics Dept. & Information Center, Electrical Energy, Ministry of Electricity and Water, Kuwait, 2015.

Taha, H., Operations Research: An Introduction, 9th edition, Pearson, 2010.

Thakur, N., and Titare, L., Determination of Unit Commitment Problem, Novelty Journals, pp.24-28, 2016.

Tung, N., Bhadoria, A., Kaur, K., Bhadauria, S., and Pg, P., Dynamic programming model based on cost minimization algorithms for thermal generating units, International Journal of Enhanced Research in Science Technology & Engineering, Vol.1, no.3, pp.2319-7463, 2012.

Wood, A., and Wollenberg, F., Power Generation Operation and Control. John Wiley & Sons, New York, 1996.

Yang, X., Introduction to mathematical optimization: from linear programming to metaheuristics, Cambridge International Science Publishing, 2007.

Biographies

Nadine Awadah was born in Kuwait, in 1994. She received her Bachelor degree in Industrial Engineering from the American University of the Middle East, Eqaila, Kuwait, in 2018. She had continuous AUM honor scholarship 2014-2018. She won the 1st place for the Best Capstone Project in Industrial Engineering Competition- 2018. She joined as an official candidate for AUM's elections-2016. She won the 3rd place in International Day Expo Competition at AUM-2017. Her main interest areas are researching in topics related to renewable energy resources, optimization, and safety. She had worked with many softwares during her undergraduate study period such as Minitab, MATLAB, SCILAB, AutoCAD, Arena, Jack, Visual Studio, and MS office programs. She was a participant for AUM Academic Activities Day, 2014-2018. She won the 2nd place for both Calculas 2 and CS-programming Competitions.

Rawan AlShikh Ali was born in 1995, Kuwait. She got her Bachelor degree of Science in Industrial Engineering from American University of the Middle East- AUM/ Kuwait in 2018. She studied at AUM with an honor scholarship during 2014-2018. Her senior project won the 1st place as the best Capstone undergraduate Industrial Engineering project. She achieved the 1st place in Calculus 2 competition during academic activities - 2014. Her project "Reducing human back pain during heavy lifting using JACK software" was honored as the best work analysis project during academic activities day - 2016.

Shaikha AlBaijan was born in Kuwait, in 1995. She received her Bachelor degree of Science in Industrial Engineering from American University of the Middle East, Kuwait, in 2018. Her senior project won the 1st place as the best Capstone undergraduate Industrial Engineering project. She won the 1st place in Calculus 2 competition during the academic activities-2014. Her main areas of research interest are operation research, and lean six-sigma.

Ghalia Al-Qallaf born in Kuwait, October 1996, holds a degree in Bachelor of Science in Industrial Engineering in American University of the Middle East- AUM in 2018, 1st place Capstone Senior project "Smart Grid and Optimization".

Muneerah Al-Hasawi born 26th April 1995, entered American university of the Middle East (AUM) in 2013, got a bachelor degree of science in industrial engineering in 2018. 1st place Capstone Senior project "Smart Grid and Optimization"- 2017-2018.

Suat Kasap has degrees in electrical-electronics engineering and industrial engineering. He received his Ph.D. in Industrial Engineering from the University of Oklahoma. His research interests are in human factors and ergonomics, occupational safety and health, work and process analysis, technology and innovation management, multi-criteria decision making, financial engineering, data mining, and modeling, analysis, and optimization of complex engineering problems. He worked in four different Industrial Engineering Departments of the American University of Middle East, University of Turkish Aeronautics Association, Hacettepe University, and Çankaya University as an assistant professor. He has taught courses on Work Analysis and Design, Ergonomic Work Analysis, Cognitive Ergonomics Work Analysis, Technology and Innovation Management, Management of Information Systems, Introduction to Optimization and Modeling, Deterministic Models of Operation Research, Project Management, Multi-criteria Decision Making.