An Integrated Rule – Based Approach of Unit Commitment with Economic Load Dispatch Problem

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Abstract: Unit commitment (UC) along with economic load dispatch (ELD) is an integral optimization problem in the power generation industry. UC focuses on scheduling generating units while ELD focuses on how much power each generating unit must dispatch. Current approaches in this problem domain deal with non-convex, non-smooth and non-linear optimization model with a number of constraints. To address the complexity of power generation optimization problem of a peaking power plant, a rule-based algorithm is used to solve the UC with ELD problem under different system constraints. In this paper, an alternative approach in addressing UC and ELD problems is presented. The proposed algorithm attempts to provide flexibility in addressing several desired policies of decision-makers. A case study is conducted in a diesel-fired, power plant in central Philippines to elucidate the proposed approach. Three policies were created and analysed to effectively address the optimization problem: (1) classic unit commitment model, (2) buying and selling strategy, and (3) continuous loading strategy with various issues being considered. The model incorporates the participation of the case firm in a wholesale power market. The paper also shows the adaptability of the approach to any policy a firm might want to adopt. Simulation was conducted using a week's production data of the firm. Results show different cost reductions for different policies the firm could have achieved if it had used the algorithm. Results also indicate that the strategies generated exhibit a significant decrease in total costs and ease of implementation with respect to the current production schedule of the case firm. Furthermore, the second policy provides the least generated cost which implies that generating firms must consider the option to sell power when market prices reach desired levels.

Key Words: Unit Commitment; Economic Load Dispatch; Rule-based approach; Power Generation

1. INTRODUCTION

Common and simple ways to generate electricity is through the use of diesel fired generators. With the emergence of new power sources, diesel generators are now commonly used as auxiliary supply. These units are then utlized only when the demand for power can no longer be met by base-load and itermediary supply. Diesel fired generators are now classified as auxiliary supply units since generating units that are carry low generation costs are present (Jell, 2015). A power system must be able to maintain a steady supply of electricity. Hence the presence of diesel generators is still as important today to ensure the security of the system. Also, to maintain the influx of investors from public and private sectors needs a reliable power system (Trivedi, 2013). More than a decade and a half ago, state laws have turned the power generation industry from a monopoly to a competitive wholesale market. Competition is injected into the industry via a spot market entity that is a pool-based electricity market (EPIRA, 2001).

With the arrival of market competition, power companies need to produce electricity at the least possible cost to compete with other companies. In line with this, the century-old Economic Load Dispatch (ELD) becomes extremely useful (Xia and Elaiw, 2009). ELD is described as a nonlinear optimization problem that has an objective of minimizing generation cost at the same time meeting different system requirements (Barisal and Prusty, 2015).

Due to the extensive reach and limits of the ELD problem, a lot of new parts were introduces to the ELD problem that address several types of concerns. A few of these concerns are minimizing total emissions to allowable limitsas mandated by state regulations, considering the use of renewable energy sources (RES), demand response models that balance out demand against supply, and distributed generation that allocates electricity to entities who are far from the power grids.

The complex characteristics of ELD has challenged a number of domain scholars in approaching the optimization problem. Conventional and meta-heuristic approaches were utilized to answer wide array of characters of the ELD such as MILP model (Wang et al., 2012), deferential evolution model (Storn and Prince, 1995) to name a few. Everyone of these methods exhibits its own pros and cons. So far, there seems to be no dominant method that capable of answering the majority of the ELD problem and its various variations.

Thus, this paper attempts to develop an integrated approach that highlights unit commitment with economic load dispatch problem. This methodology will aid in scheduling of generating units and their corresponding production output by a rule-based algorithm. The developed approach is applied in a diesel-fired, peaking power plant in central Philippines. This firm, the East Asia Utilities Corporation (EAUC), is a diesel fired electric power plant. Due to the characteristics of diesel fired generatoes, it has high generation costs, it is then ideal for EAUC to produce its generating units optimally. Results generated by the algorithm will be compared to the actual generation of the firm and reported in this paper. To determine the actual production cost of the firm, its acutal loading schedule will be fed into the cost rate functions of each generating unit. The contribution of this study is the proposed methodology in addressing both unit commitment and economic load dispatch problem.

2. METHODOLOGY

The method addresses the unit commitment with economic load dispatch problem through a rule-based algorithm. The method is formulated through an algorithm that has rules attached to it that needs to be satisfied. These rules are derived from the decision maker's objectives. The objectives then are translated into the algorithm mathematically. The algorithm can now then identify which units to commit. The last step would have to be the use of optimization software that solves for the ELD problem given the set of units that have been chosen to be committed.

2.1 Policy 1 – Adaptation of Classic Unit Commitment

This study first applies the classic Unit Commitment in generating a production strategy. The Rule-Based approach will be shown in latter policies which were established based on the case. This policy however fails to address different system requirements set by the firm but it is ideal in a way that it could optimize generation costs without looking into certain constraints that is unique to each generating firm. Its objective function has been based on different related literatures that were focused on this study. Start-up and Shutdown costs are neglected since the firm considers this as a negligible cost.

$$\min \sum_{t=1}^{T} \sum_{i=1}^{N} [F_i(P_i^t)]U_i^t + WP^i(B)(U_B) \qquad \text{(Eq. 1)}$$

Where:

WP^t = WESM price for the interval

The different constraints of this study are the energy balance & generator limits. The energy balance shows the equality of the total generated power and the demand of the firm including its internal consumption. Generator limits are the minimum and maximum capacity per unit.

$$D_1 + (0.0339)((U_1 + U_2 + U_3 + U_4)^2) + (0.6229)(U_1 + U_2 + U_3 + U_4) = P_1U_1 + P_2U_2 + P_3U_3 + P_4U_4 + P_5U_5 \qquad \text{(Eq. 2)}$$

$$P_{min,i} \leq P_i \leq P_{max,i} \qquad \text{(Eq. 3)}$$

2.2 Policy 2 – Buying and Selling Strategy by a Rule-Based Algorithm

This second algorithm addresses the policy in the firms' willingness to participate in the spot-market in selling excess capacity. The algorithm gives the decision maker the necessary decision points as to how much to produce to meet their contracted demand at the same time sell to the spot-market. The algorithm decides the when to commit units given specific selling points. The algorithm addresses the UC problem. The policy in the form of an algorithm is shown in Fig. 1.

The steps of the algorithm are as follows:

Step 1: The algorithm determines the demand required of the firm from contracted customers.
Step 2: The available capacity is taken; this is by subtracting the plant capacity with the demand required. The available capacity is then the amount of power that the firm can sell to the power market.
Step 3: The algorithm first determines if the market price is viable for it to participate in the selling of power. The algorithm decides if the market price is greater than Php 1,000.00 compared to the firm's set price. If it is greater, the algorithm opts to sell. If not, the algorithm opts to buy or produce only.
Step 4a: If the algorithm opts to sell, it initiates an optimization problem, ELD, with a new variable. This variable is the sell variable, which determines how much should be sold. This variable is seen as a negative number in the objective function, as the revenues lessen the costs.
Step 4b: If the algorithm opts to buy, then it initiates an optimization problem, ELD, with just a normal model with an option to buy. There is no sell variable included here, only a buy variable.
Step 5: The algorithm reverts back to the beginning for a new interval.

The model now includes a sell, S, variable for an interval t. This sell variable dictates as to how much to sell to the power market. This is expressed as a negative value since it is selling and reduces costs. There is an added constraint for the limits of the sell function. The objective function is,

$$\sum_{i=1}^{N} F_i^t(P_i^t)(U_i^t) + WP^t(B^t)(U_B^t) - WP^t(S^t)(U_S^t) \qquad \text{(Eq. 4)}$$

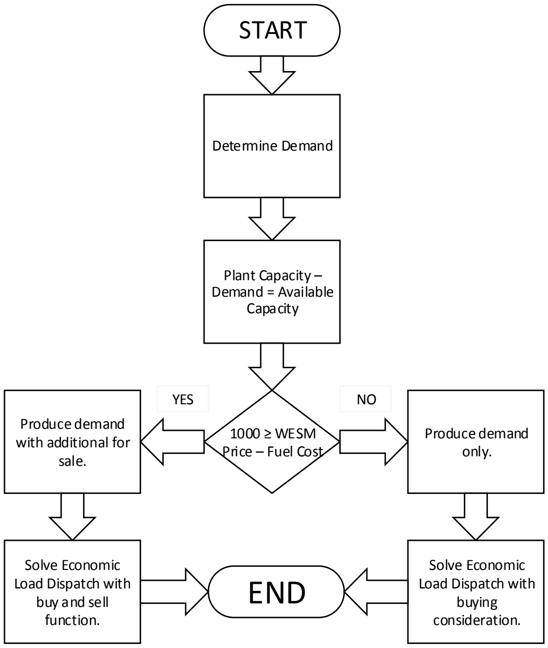

Fig. 1 Buy and Sell Algorithm

WP^t is the current market price for both buying and selling power at time interval t. Price for buying or selling in the spot-market is the same in a given interval t.

$$0 \le S^t \le 43 - D^t \qquad \text{(Eq. 5)}$$

Eq. 5 demonstrates the excess capacity constraint. This constraint makes sure that only the excess capacity is sold to the spot-market. In return this also ensures that the contracted demands from its customers are met first before selling to the market.

The demand D^t is the demand of its customers for interval t. This limits the sell variable to only sell the excess power after addressing the contract.

Eq. 6 shows the power balance constraint. This has been modified to note the additional production schedule brought about by the option to sell.

$$D^t + S^t + P_L = \sum_{i=1}^{N} F_i^t(P_i^t)(U_i^t) + B^t(U_B^t) \qquad \text{(Eq. 6)}$$

The variables on the left side of the Eq. 6 shows the expected output of the firm to meet contracted demand, excess capacity to be sold and internal consumption. On the right side shows the production, internal generation and purchased power, of the firm to meet expected output.

The whole optimization model now is,

$$\min \sum_{t=1}^{T}\sum_{i=1}^{N}[F_i(P_i^t)]U_i^t + WP^t(B)(U_B) - WP^t(S)(U_S) \qquad \text{(Eq. 7)}$$

Subject to

$$6 \le P_1 \le 11.1 \qquad \text{(Eq. 8)}$$
$$6 \le P_2 \le 11 \qquad \text{(Eq. 9)}$$
$$6 \le P_3 \le 11.5 \qquad \text{(Eq. 10)}$$
$$6 \le P_4 \le 11.1 \qquad \text{(Eq. 11)}$$
$$0 \le B \le 43 \qquad \text{(Eq. 12)}$$
$$0 \le S \le 43 - D \qquad \text{(Eq. 13)}$$

$$U_1, U_2, U_3, U_4, U_B, U_S = 1,0 \qquad \text{(Eq. 14)}$$

$$D + S + \left(-0.0339(U_1 + U_2 + U_3 + U_4)^2 + 0.6229(U_1 + U_2 + U_3 + U_4)\right) = P_1(U_1) + P_2(U_2) + P_3(U_3) + P_4(U_4) + B(U_B) \qquad \text{(Eq. 15)}$$

2.3 Policy 3 – Continuous Loading Strategy by a Rule – Based Algorithm

This policy focuses on getting rid of the inconvenience of starting up and shutting down generators. It typically provides a basis if the different generators are to be forced to run or if the firm opts to buy.

Step 1: Determine demand of the given interval.

Step 2: Prioritize units that are online to prevent from starting up and shutting down generators.

Step 3: Assign U=1 for units that are already online for them to be prioritized by the model

Step 4: Solve ELD in order to identify which generators to dispatch, how much to allocate per generator, and to identify total production cost.

Step 5: The decision maker now identifies whether demand for the next interval exceeds the current capacity of the online generators. If yes, decision maker compares current WESM price against price to produce and decide whether it is more economic to purchase rather than produce. If it is better to produce power, online units are prioritized to cater demand. If it is better to purchase power, online units are de-committed and purchases are made. If no, it is ensured that uncommitted units remain offline.

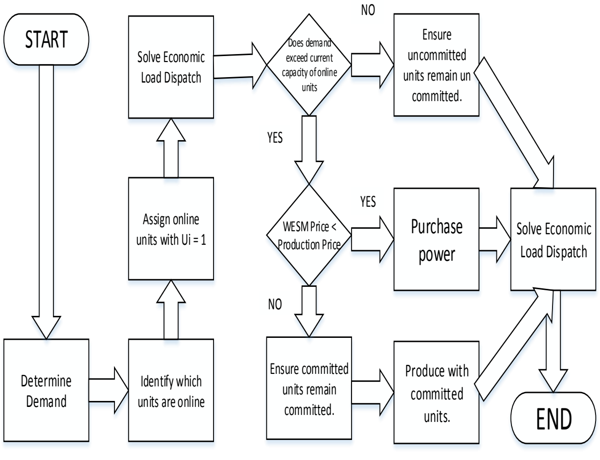

Fig. 2. Continuous Loading Algorithm

3. RESULTS AND DISCUSSION

The studied firm is currently using priority list method combined with merit order loading in their operations of commiting and dispatching units. The firm have internal decisions like the decision maker's arbitrary choice in their operaions that would lead to not having an optimal dispatch. These decisions made may lead to inefficiency.

The lack of optimization in the firm's production is addressed in this study through an established mathematical optimization models. UC and ELD problems are solved through the introduction of a rule-based algorithm. The algorithm provides the firm a proper basin on its decision making. Certain policies introduced in this study like the buy and sell policy and the continuous loading policy were developed through the rule-based algorithm. The buy and sell policy aids the decision makers how much to produce and when to sell excess capacity in the power market. Continuous loading on the other hand ensures that the firm is optimally commiting efficient units for long running hours.

Since the rule-based algorithm is easy to format, it is viable for application compared to other approaches given that the behavior of the generation units of the firm is the same for any policy. The algorithm is applicable to any generating firm and only a few changes will be altered to satisfy the different concerns one would want to address. To add up, the approach is practical for actual operations, quick, easy to understand and use. The presentation of this algorithm would be in a simple flowchart for ease of use and understanding. This simplicity surpasses other methodologies by its ease of use. Its simplicity makes its easily applicable to power generation firms in places that UC or ELD problems are not well known. The minimum knowledge required from the user to utilize this approach is an elementary literacy in optimization specifically in non-linear programming formulation. The users need only be versed in model formulation since a handful of software is capable in solving optimization problems, MATLAB or Lingo to name a few. The lead time of this method to arrive at a solution is also small, unlike other methods as discussed earlier, at the same time satisfying the preferences of the decision maker. This is ideal for those firms who need to satisfy changing requirements at different periods. Also, the decision maker must have full knowledge of the different aspects in the generating firm in order for the method to be effective.

However due to the direct participation of the decision maker to the formulation of the rules used, the algorithm might lead to not a true global optimum solution unlike the search power of soft computing methods such as GA, PSO or DE. But the drawback of these methods in the Philippine setting is that it is not ideal for real-time dispatch since it has long computational time. In addition these approaches are hard to model due to the complexity in programming and implementation. Also, there have been studies that claim that these techniques sometimes get trapped in local optima due to premature convergence.

Since this case firm is a peaking power plant, not all of the unit will be used to produce since this firm mainly runs when there is a surge or high demand for power. This makes the algorithm truly applicable since it is able to identify units to commit when the firm requires it. However for baseload plants, power generators that are always online to serve the general demand for power, this method would seem useless or unpliable. This is because there is no need for unit commitment since all of the generating units are already online and most of the time these plants are utilized to its full capacity. As for intermediary plants that address the demand not met by base load plants, it will only be useful during periods when these plants start up and shut down, which happens occasionally.

Different systems can use this algorithm aside from peaking power plants. Generating systems that use renewable energy sources can utilize of this algorithm. However for this to work, the algorithm needs to be used in conjunction with other soft wares that address the randomness brought about fuel used for these systems. Such software needs to address the probabilities of the amount, presence and quality of the wind or sunlight to power such renewable energy sources. This is where the algorithm lacks in computing power.

This then brings us to the main drawback of this approach. This approach has difficulty in being able to stand on its own. The algorithm needs the help of other computing soft wares to successfully give out solutions to address the ELD problem. For this study, the algorithm was matched with Lingo software, an optimization program to solve for the ELD.

Table 1. 7 – Day Policy Comparison

Interval (Day)	Actual Cost	Total Cost			Difference		
		Classic	Buy And Sell	Continuity	Classic	Buy And Sell	Continuity
1	861,311.36	523,007.83	231,953.12	523,007.83	338,303.53	629,358.24	338,303.53
2	826,157.23	586,451.28	443,496.95	593,853.21	239,705.95	382,660.28	232,304.02
3	799,232.89	577,624.17	284,784.87	584,939.76	221,608.72	514,448.02	214,293.13
4	314,429.24	137,601.94	137,601.86	137,601.94	176,827.30	176,827.38	176,827.30
5	-	-	-	-	-	-	-
6	-	-	(360,451.00)	-	-	360,451.00	-
7	817,308.86	522,137.12	215,165.06	522,137.12	295,171.74	602,143.80	295,171.74

4. CONCLUSIONS

In this paper, a different strategy for power production scheduling is proposed where different issues in generating firms are effectively addressed. The ideal optimal solution is fixed on solving the basic unit commitment problem. Two policies were introduced for the case firm which are the buy and sell strategy and continuous loading strategy. It is shown that the two strategies are considered near-optimal solution since the results are close to the ideal classic unit commitment model.

Case results show that it is beneficial for the firm to use the second policy which is the buying and selling strategy by a rule – based algorithm because it yields with the highest difference from the actual loading schedule among the three policies which means that the firm would be able to save costs using this policy. This shows that if the firm has the chance to sell energy to WESM, it can help in minimizing the total production costs. However, considerations such as the internal decision-making procedures should also be taken into account because these procedures can cause deviation from the results.

For future work, studies might consider different policies to address different issues. Possible policies might be including competitors, load curtailment, running hours, transmission losses, security constraints, and probabilities of failure. The problem is evident that it does not have an optimal strategy and it solely depends on the preferences of the decision-maker. Furthermore there is an option to look for better optimization programs that can handle more requirements.

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