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Hasmat Malik · Sukumar Mishra ·
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Renewable Power for Sustainable Growth

Proceedings of ICRP 2023

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About this book

The proceedings is a collection of papers presented at International Conference on Renewal Power (ICRP 2023), held during 28 – 29 March 2023 in Mewat Engineering College, Nuh, India. The book covers different topics of renewal energy sources in modern power systems. The volume focusses on smart grid technologies and applications, renewable power systems including solar PV, solar thermal, wind, power generation, transmission and distribution, transportation electrification and automotive technologies, power electronics and applications in renewable power system, energy management and control system, energy storage in modern power system, active distribution network, artificial intelligence in renewable power systems, and cyber physical systems and internet of things in smart grid and renewable power.

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- Hasmat Malik,
- Sukumar Mishra,
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- Presents research works in the field of renewable power sources
- Results of ICRP 2023 held in Nuh, India during 28 – 29 March 2023
- Serves as a reference for researchers and practitioners in academia and industry

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Solving Unit Commitment Problem Using Mixed Integer Linear Programming for Demand Side Management

Ahmed Abubakar Elwan, Mohd Hafiz Habibuddin, and Yanuar Z. Arief

Abstract The implementation of demand side management (DSM) for an industrial plant by solving a unit commitment problem (UCP) is hoped to solve imbalances between electricity supply limitations and demand requirements which many times lead to a partial or total shutdown of production plants because of trips due to under voltage or high frequency when the supply is overloaded or a unit is suddenly stopped, while there is a need to maintain production. For this study, the cement industry was divided into operating units, simulated under two scenarios, and solved using mix integer linear programming (MILP) in an Excel solver. The result shows that there is a reduction in cost by 30% from $1203 to $880 for the same production requirement.

Keywords Unit commitment problem · Mixed integer linear programming · Demand side management · Electricity supply · Production plants

1 Introduction

Manufacturing plants are energy intensive, consuming about 54% of the world's total delivered energy [1]. The cement sub-sector alone is consuming approximately 12–15% of total industrial energy use (electrical energy) [2, 3]. According to [3] energy cost constitutes about 60–75% of the direct manufacturing cost of cement. To sustain profitability and balance demand and supply that guarantee cost-effective manufacturing and availability of products to consumers, a detailed review of energy

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use to identify improvement in areas of demand/supply balance and cost optimization becomes necessary.

Due to the increasing demand for cement production [4] and the epileptic source of supply in Nigeria, most cement manufacturing industries hardly meet up with customer demands. To boost the electricity supply for the industries, various distributed generations (DGs) were integrated into the electrical system either as self-generation or purchased power. However, this action increases the cost of production because of the return on the investment required and usually takes a long time to implement. A short-term but sustainable solution is required by harnessing available opportunities to balance demand and supply as well as reduce costs through adequate production planning, taking advantage of having storage facilities for inventory in the cement plants.

Several energy management strategies have been adopted by manufacturing plant operators, the most common strategies in practice include (1) the use of energy-efficient machines [5] and (2) applying scheduling strategies [6, 7]. While the use of an energy-efficient machine approach requires an extra investment that imposes huge pressure on companies for early return on investment (ROI), the application of scheduling strategies helps in reducing energy consumption as well as reducing financial costs and attracts less or no investments to execute. The most commonly practiced scheduling strategy in the Nigerian cement industries is load shedding or power-down. The power-down strategy means that a machine cannot be idle for a certain amount of time between two consecutive processing tasks [8], it has to be shut down immediately after use. Therefore, when a machine is shut down energy may be saved based on the assumption that not all jobs are available at the same time. However; this may not be applicable in a high-demand continuous manufacturing plant like cement industries, where continuous operation is desirable or at least to have all storage facilities filled up. Another strategy used is the speed-scaling technique [9], this technique has to do with the selection of the right processing speed for an operating machine. But this technique also requires some level of equipment investment and will increase the cost burden on the production plant.

The dynamic management of electricity demand, also referred to as demand side management (DSM), emerges as an effective approach to energy management. Industrial DSM helps to improve power supply performance and optimize production to meet up with customer demands [6]. Related studies [10, 11] considered electrical energy cost minimization through classical deadlines and pre-emptive schedules to reduce consumption. The authors in [12] use mathematical models to minimize costs in a variable electricity price. While [11] deals with different consumption at different machine states, [12] was concerned with job ordering and processing and optimal scheduling of machine states, respectively, by using heuristics and genetic algorithms.

Authors in [13] applied the model from [12] to a real-time plant and a 20% improvement in profit was recorded after the implementation to a CHP plant. Using discrete time representation in a continuous power-intensive non-dispatchable demand response program, [9] developed a MILP model for inter-operating modes transition and [14] developed a general discrete time model for the scheduling of power-intensive process networks with various power contracts. A two-step integer/constraint programming approach was used to solve an industrial case study involving energy constraints and objectives linked to electric power consumption [15].

Industrial DSM needs flexibility in production and energy management, to explore this authors in [7] made schedules based on sequencing and timing of production tasks, giving particular attention to waiting for time constraints between consecutive production stages. Scheduling considering the inventory of a plant was studied by [16]. The emphasis was on the impact of storage in industrial DSM. For the same purpose state-task network (STN) and resource-task network (RTN) was used by [17] using a well-known concept from [18], where state nodes were used to represent features of the operations (final product, intermediates, and feeds). Modeling of industrial schedules by considering both production and power consumption was first proposed by [19], where the production and consumption characteristics vary within the same process depending on the state in which the process is operating [20].

The objective of this paper is to propose a demand side energy management (DSM) technique by solving a unit commitment problem for an industrial case study. The unit commitment problem aims at the scheduling of units to achieve optimal production to satisfy the inventory needs and also balance power supply/demand at a minimum cost, while other studies focused on minimizing cost by scheduling waiting time optimization, reduction in consumption, sequencing of production, and constraints between stages and electricity prices. A mix integer linear programming approach is used to solve the unit commitment problem (UCP). This approach tends to solve the difficulty of integrating energy constraints (DSM) into production scheduling.

2 Research Method

The industrial plant to be addressed is a cement manufacturing plant and the problem to be addressed is optimizing the available power supply for production to satisfy demand at a minimized cost. The plant is divided into four main operating units' codes named OPU1…4. The properties for each unit are displayed in Table 1.

Each operating unit requires a large amount of electricity to turn huge machinery into production. Each unit is equipped with storage facilities, maximum and minimum storage levels are identified in Table 2. The plant operation is expected to be updated in real-time depending on the frequency. The peak supply demand for the operating units is 25 MW.

Table 1 Plant properties

Properties	OPU1	OPU2	OPU3	OPU4
Operating cost	30	25	45	60
Idling cost	20	30	50	10
Start-up cost	800	650	200	80
Min cons level	4	2	5	5
Max cons level	9	3	10	10
Minimum up time	46	5	150	71
Minimum down time	86	3	43	13
Power allocation (%)	35	5	25	30

Table 2 Plant inventory parameters

Parameter	OPU1	OPU2	OPU3	OPU4
Production rate	260	20	80	140
Consumption rate	70	16	140	240
Maximum capacity	13,000	100	14,000	12,000
Minimum capacity	4000	40	5000	3000
Min Inv. to start	6000	40	6000	3000
Max Inv. to stop	12,000	90	12,000	10,000
Variance to stop	1000	10	2000	2000
Variance to start	6000	60	8000	7000
Min up time	46	5	150	71
Min down time	86	3	43	13

2.1 Model Description

Each unit is expected to be in any of the three states, the ON state, the OFF state, and the IDLE state. The duration of the ON state is $\geq$ minimum operating time and the duration for OFF $\leq$ minimum downtime the idle time is when the unit is kept running without any output and should be minimized. Both minimum operating time and minimum down time are evaluated based on inventory stock level and restocking requirements. Each stage of operation consumes power referred to as operational power (P_{op}) which depends on the state of the units whether the unit is ON or OFF and idle power when the overall unit is not active but some amount of power is required to run some critical equipment for cooling and other related functions. The shortest ON duration has to be met before a unit is shut down and the shortest OFF duration is also required before a unit is restarted up.

2.2 Equations

The objective function is made of two cost components. The first cost component is determined by real-time status decisions termed as the operation cost, i.e., if a unit is in operation or not at the time of the decision. The second cost component comes when the units are not in active operation. This idling cost is usually incurred when the units are turned off and there must be some residual elements that will be allowed to continue operating for cooling and other non-productive activities. The objective function is formulated as in (1).

$$\min[e(n)]\left\{\sum_{n=t}^{N-1} e^{\mathrm{o}}(n)P_{\mathrm{op}}.\hat{U}(t)+\sum_{n=t}^{N-1} e^{\mathrm{id}}[P_{\mathrm{id}}](n)\right\} \tag{1}$$

where

e^{o}	Operating cost for the units after start-up and before shutdown
e^{id}	Cost incurred from non-operation activities when units are idling
P_{op}	Operating power
P_{id}	Idling power.

The following constraints apply.

(a) **Operating Time Constraints**

$$\hat{U}(t)-\hat{U}(t-1)\leq\hat{U}\left(t+T_{\mathrm{up}}\right) \tag{2}$$

$$\hat{U}(t-1)-\hat{U}(t)\leq\hat{U}(t+Td) \tag{3}$$

where

$$\mathrm{TU}_i=T_{\mathrm{on}}\ \mathrm{if}\ T_{op,i}<\mathrm{MT}_{\mathrm{up}} \tag{4}$$

$$\mathrm{TD}_i=T_{\mathrm{off}}\ \mathrm{if}\ T_{id,i}<\mathrm{MT}_{\mathrm{dwn}} \tag{5}$$

For any operating unit OPU,

$$\mathrm{MT}_{\mathrm{up}}\geq\varphi/\delta\ (\mathrm{h}) \tag{6}$$

$$\mathrm{MT}_{\mathrm{dwn}}\leq\gamma/\mu\ (\mathrm{h}) \tag{7}$$

where

δ	Rate of production
μ	Rate of consumption

γ	Minimum stock
φ	Maximum stock
$U(t-1), U(t)$	status of a unit at a time $(t-1)$ and time (t).

(b) Mass Balance Constraints (Inventory Constraints)

We define the variable $I_{i,t}$ which represents the product stored at each time period t as a balance of consumption from the amount produced by each unit *i*. By mass balance, the following relationships hold [21].

$$I_{i,t} = I_{\mathrm{o}} + \sum_{s} P_{s,t} - \mu_t \quad \forall t \in T : t = 1 \tag{8}$$

$$I_{i,t} = I_{t-1} + \sum_{s} P_{s,t} - \mu_t \quad \forall t \in T : t > 1 \tag{9}$$

And the inventory limits are given as follows

$$\gamma \leq I_{i,t} \leq \varphi \tag{10}$$

where

$I_{\mathrm{i},t}$	Product stored at each time period *t*
I_{o}	Initial inventory position
$P_{s,t}$	Production at time *t*
μ_t	Consumption rate.

(c) Energy Balance (Demand/Supply) Constraints

The demand limit of each operating unit is between the maximum and minimum power levels of each unit as given in (11) a period of time (*t*).

$$P_{\mathrm{itmax}} \geq P_{\mathrm{dit}} \geq P_{\mathrm{itmin}} \tag{11}$$

$$P_{\mathrm{d}} = U(t) * P_{\mathrm{op}} + h * P_{\mathrm{id}} \tag{12}$$

where

$P_{\mathrm{di,t}}$	Total demand power
P_{itmax}	Maximum power demand for each unit at a time (*t*)
P_{imin}	Minimum power demand for each unit at a time (*t*)
P_{op}	Operation power
P_{d}	Demand power
P_{id}	Idling power
$U(t)$	Operating status of the plant
h	Hours of operation to produce.

3 Results and Analysis

Results from the simulation are presented in two scenarios: the business as usual (BAU) and the constraints. In the business-as-usual scenario, the restriction is just on the power limits, hence a unit can be started or kept down as long as the power required is within the limits. After modeling and simulation, Table 3 gives the cost objective and Table 4 is the power for the BAU.

From the result in Table 3, idling cost is about 33% of the total cost, this is because some equipment was running even when the plant is not in production. Operating cost is the actual cost incurred from power used during production and this accounts for 67% of the overall cost of production.

From Table 4, the total idling power consumed by all the units is 15 MW, while the power used in the actual production (operating power) is 19.1 MW representing 44% and 56%, respectively. An almost equal amount of power is required by the units during idling and when the plant is in normal operations. There is a huge need to be controlled for good optimization.

In the constraint scenario, the restriction is on both power and utilization status limits. A unit can only consume power within its limit and only when it is in operation. When the unit is not in operation, then it incurs additional costs for idling as seen in the outcome of the simulation results. After modeling and simulation, Table 5 gives the cost values, and Table 6 gives the power values required by the respective units.

In the constraint scenario, power is only consumed when the unit is in production mode, hence the reduction in the total cost from $1203 in the BAU to a total cost of $880.00. To achieve this, unit 2 has to be down while other units 1, 3, and 4 are onboard as given in Table 7.

Table 3 BAU cost distribution values

Name	Original value	Actual value	Contribution (%)
Total cost ($)	0	1203.94	100
Operation cost ($)	0	797.74	67
Idling cost ($)	0	406.20	33

Table 4 BAU power distribution values

Name	Original value	Actual value
The total power consumed (MW)	0	34.1
Operating power (MW)	0	19.1
Idling power (MW)	0	15

Table 5 Constraints scenario cost distribution values

Name	Original value	Actual value
Cost ($)	1230	880

Table 6 Constraints scenario power values

Name	Actual value
Power OPU1 (MW)	8
Power OPU2 (MW)	0
Power OPU3 (MW)	8
Power OPU4 (MW)	6

Table 7 Operating status of the units in the constraint scenario

Name	Actual value
Operating status OPU1	1
Operating status OPU2	0
Operating status OPU3	1
Operating status OPU4	1

The total power consumed in the constraint scenario is 32 MW compared with the 34.1 MW of the BAU scenario under the same period and condition of operation. This resulted in the reduction of the total power cost for the process.

4 Conclusion

This study presents a mixed-integer linear programming formulation (MILP) to solve unit commitment (UC) for energy management while considering the production and power constraints in an industrial plant. It is shown that this is possible by modeling the operating parameters based on the amount of inventory required to be produced at any time. The study also shows that by committing the units following some constraints, the cost has been reduced by **27%** from the BAU scenario maintaining all other limits. Application of the method of this study is expected to reduce electricity demand and allow prompt response to supply/demand mismatch. By incorporating DSM in production planning and unit scheduling for maintenance and other intervention purposes in a manufacturing plant, it is possible to control power cost and energy efficiency throughout the process.

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References

1. Conti J, Holtberg P, Diefenderfer J, LaRose A, Turnure JT, Westfall L (2016) International energy outlook 2016 with projections to 2040. USDOE Energy Information Administration (EIA), Washington, DC (United States). Office of Energy Analysis
2. Madlool NA, Saidur R, Hossain MS, Rahim NA (2011) A critical review on energy use and savings in the cement industries. Renew Sustain Energy Rev 15(4):2042–2060
3. Fadayini OM, Madu C, Oshin TT, Obisanya AA, Ajiboye GO, Ipaye TO, Rabiu TO, Akintola JT, Ajayi SJ, Kingsley NA (2021) Energy and economic comparison of different fuels in cement production. Cem Ind Optim Charact Sustain Appl 3:105
4. Unachukwu GO (2003) Energy efficiency measures investigation in cement company: BCC case study. Niger J Renew Energy. 10(1–2):85–92
5. Menghi R, Papetti A, Germani M, Marconi M (2019) Energy efficiency of manufacturing systems: a review of energy assessment methods and tools. J Clean Prod 10(240):118276
6. Yin Y, Wang Y, Cheng TC, Liu W, Li J (2017) Parallel-machine scheduling of deteriorating jobs with potential machine disruptions. Omega 1(69):17–28
7. Wang DJ, Liu F, Jin Y (2017) A multi-objective evolutionary algorithm guided by directed search for dynamic scheduling. Comput Oper Res 1(79):279–290
8. Liang P, Yang HD, Liu GS, Guo JH (2015) An ant optimization model for unrelated parallel machine scheduling with energy consumption and total tardiness. Math Probl Eng 1:2015
9. Zhang Q, Grossmann IE (2016) Planning and scheduling for industrial demand side management: advances and challenges. Altern Energy Sources Technol 383–414
10. Zhang X, Hug G, Kolter JZ, Harjunkoski I. Model predictive control of industrial loads and energy storage for demand response. In: 2016 IEEE power and energy society general meeting (PESGM) 2016 Jul 17. IEEE, pp 1–5
11. Weckmann S, Kuhlmann T, Sauer A (2017) Decentral energy control in a flexible production to balance energy supply and demand. Procedia Cirp. 1(61):428–433
12. Xu W, Tang L, Pistikopoulos EN (2018) Modeling and solution for steelmaking scheduling with batching decisions and energy constraints. Comput Chem Eng 4(116):368–384
13. Mitra S, Sun L, Grossmann IE (2013) Optimal scheduling of industrial combined heat and power plants under time-sensitive electricity prices. Energy 1(54):194–211
14. Harjunkoski I, Maravelias CT, Bongers P, Castro PM, Engell S, Grossmann IE, Hooker J, Méndez C, Sand G, Wassick J (2014) Scope for industrial applications of production scheduling models and solution methods. Comput Chem Eng 5(62):161–193
15. Pattison RC, Touretzky CR, Johansson T, Harjunkoski I, Baldea M (2016) Optimal process operations in fast-changing electricity markets: framework for scheduling with low-order dynamic models and an air separation application. Ind Eng Chem Res 55(16):4562–4584
16. Uddin M, Romlie MF, Abdullah MF, Abd Halim S, Kwang TC (2018) A review on peak load shaving strategies. Renew Sustain Energy Rev 1(82):3323–3332
17. Castro PM, Dalle Ave G, Engell S, Grossmann IE, Harjunkoski I (2020) Industrial demand side management of a steel plant considering alternative power modes and electrode replacement. Ind Eng Chem Res 59(30):13642–13656
18. Melouk S, Damodaran P, Chang PY (2004) Minimizing makespan for single machine batch processing with non-identical job sizes using simulated annealing. Int J Prod Econ 87(2):141–147
19. Artigues C, Lopez P, Hait A (2013) The energy scheduling problem: industrial case-study and constraint propagation techniques. Int J Prod Econ 143(1):13–23
20. Tomar A et al (eds) (2022) Proceedings of 3rd international conference on machine learning, advances in computing, renewable energy and communication: MARC 2021, vol 915. ISBN: 978-981-19-2830-7. Springer, pp 15, 781. https://doi.org/10.1007/978-981-19-2828-4
21. Ierapetritou MG, Wu D, Vin J, Sweeney P, Chigirinskiy M (2002) Cost minimization in an energy-intensive plant using mathematical programming approaches. Ind Eng Chem Res 41(21):5262–5277