

Lecture Notes in Electrical Engineering 1086

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Y. R. Sood · Atif Iqbal ·
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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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-

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 - Results of ICRP 2023 held in Nuh, India during 28 – 29 March 2023
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Table of contents (68 papers)

Front Matter

Pages i-xix

Editorial: Renewable Power for Sustainable Growth

- Hasmat Malik, Sukumar Mishra, Y. R. Sood, Atif Iqbal, Taha Selim Ustun
-

Pages 1-29

An Efficient Algorithm for Energy Management in Smart Grid for Various Improvements

- Deepa Kumari, Ashish Sharma
-

Pages 31-43

Investigations and Validation of PV-Powered Unified Power Quality Conditioner for Electric Vehicle Smart Charger in Standard AC/DC Hybrid Microgrid Test System

- S. Sumana, R. Dhanalakshmi
-

Pages 45-60

Short-Term Electricity Load Forecasting Using Modified Hidden Markov Model

- Poras Khetarpal, Neelu Nagpal, Mahesh Kumar, D. Lakshmi, Neelam Kassarwani
-

Pages 61-74

Microgrid Systems with Classical Primary Control Techniques—A Review

- Sujit Kumar, H. K. Yashaswini, Naveen Sharma, Mohit Bajaj
-

Pages 75-83

Green Energy Solutions for Indoor Air Quality Improvement

- Saad Javed, Safdar Tanweer, Syed Sibtain Khalid, Naseem Rao, Jawed Ahmad, Bhavya Alankar
-

Pages 85-97

Data Resource Library for Renewable Energy Prediction/Forecasting

-
- Subeyr Bashir Ahmed, Hasmat Malik, Shahrin Md Ayob, Nik Rumzi Nik Idris, Awang Jusoh, Fausto Pedro García Márquez

Pages 99-164

Solar Rooftop On-Grid Connected Net Metering System

-
- Sarfraz, Anju Gupta, Rashmi Agarwal

Pages 165-176

Contemporary Maximum Power Point Tracking Methods of Solar Photovoltaic Modules

-
- Jyothi Tompala, Sravana Kumar Bali

Pages 177-192

Performance Analysis of Perturb & Observe and Incremental Conductance Method of Maximum Power Point Tracking in Solar PV-Based Power Generation

-
- Avdhesh Kumar

Pages 193-204

The Airfoil Design for Small-Scale Wind Turbines in Maximizing Renewable Wind Energy

-
- S. A. H. Roslan, N. Umar, Z. A. Rasid, A. K. Arifin

Pages 205-216

Comparative Study on Solar PV Module Performance with Sun Irradiance Trapping Mechanism: Power Generation Forecasting Using Machine Learning

-
- Rupendra Kumar Pachauri, Ashutosh Shukla, Ahmad Faiz Minai, Aryadhara Pradhan, Vinay Gupta, Mohit Kumar et al.

Pages 217-228

The Geometric Modelling and Linearization of Small-Scale Wind Turbine Blades for Optimized Renewable Energy

-
- S. A. H. Roslan, N. Umar, Z. A. Rasid, A. K. Arifin

Pages 229-243

Performance Analysis of H-Type Vertical Axis Wind Turbine by Using Novelty Numerical Simulink Method

- Muhammad Radhiva, Muhammad Hasya Abdillah, Geordiano Devanaldy Khresna Putra, Muhammad Raihan Wajdi, Putri Wulandari, Wahyu Caesarendra et al.

Pages 245-257

Energy Production from Various Bio-wastes Under Different Electrode and Temperature Conditions: Experimental Study

- Rahul Anand, Rupendra Kumar Pachauri, Ahmad Faiz Minai, Akhlaque Ahmad Khan, Rajesh Singh, Shashikant

Pages 259-270

Simulation and Prototype Design of Hybrid Renewable Energy Harvesting System

- Yanuar Z. Arief, Muhammad Syukri Nurulhak, Hamzah Eteruddin

Pages 271-288

Design and Development of an Inexpensive Intelligent Device for Sag Measurement for Overhead Transmission Lines

- Manoj Kumar, Aman Kumar, Tushar Tomar, Anuj Dixit, Divya Asija, R. K. Viral

Pages 289-303

Gradient Descent Back-Propagation Through Momentum (GDBPM) Endorsed \diamond cos \diamond Control Technique-Based DSTATCOM Intended for Shunt Indemnification

- Mrutyunjaya Mangaraj, Kampara Ravisankar, Majji Satish, Kantubhukta Dinesh, A. Praveena

Pages 305-317

Improvement in Voltage Stability of the System Due to Increased Penetration of Electric Vehicles Using Distributed Solar Photovoltaic Sources

- Sheetal Deshmukh, Shirazul Islam, Atif Iqbal, Md Fahim Ansari

Pages 319-338

An Intelligent System for Furfural Estimation in the Power Transformers

- Md. Manzar Nezami, Hythem Hashem, Md. Danish Equbal, Mohammad Junaid Khan, Md. Fahim Ansari, Elfatih Elmubarak Mustafa

Pages 339-345

Design of PID-Tuned Controller for Automatic Voltage Regulator for Frequency Stability in Thermal Power Plant

- Md. Fahim Ansari, Atif Iqbal, Md. Manzar Nezami

Pages 347-354

Optimization of Distributed Generators in a Virtual Power Plan Using Mixed Integer Linear Programming Method

- Ahmed Abubakar Elwan, Mohd Hafiz Habibuddin, Yanuar Z. Arief, Siti Nur Aisyah Mohd Sharan, Ahmad Safawi Bin Mokhtar, Rasyidah Binti Mohamad Idris

Pages 355-365

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

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

Pages 367-375

Deployment of Renewable Embedded Generation and Unified Power Quality Conditioner in Distribution System using Firefly Algorithm

- Musa Mustapha, Madihah Binti Md. Rasid, Jasrul Jamani Bin Jamian, Ganiyu Ayinde Bakare, Yau Shuaibu Haruna

Pages 377-389

Application of Wind Power in Backwashing Filter Media

- Deepak Juneja, Sushindra Kumar Gupta, Aditya Rana

Pages 391-401

Mixed Reality Accelerates the Designing Process in Automotive Industry

- Mohamad Yahya Fekri Aladin, Ajune Wanis Ismail, Fazliaty Edora Fadzli

Pages 403-415

Design and Implementation of Solar Charging Electric Vehicle

-
- Rahil Imtiyaz, Aman Kumar, Gitanjali Mehta, Ruqaiya Khanam
-

Pages 417-429

Modelling and Analysis of a Permanent Magnet DC Motor Fed Electric Vehicle Drive System

-
- K. Subbaramaiah, Ravisankar Kampara, Majji Satish, Kantubhukta Dinesh, Karthik Tamvada
-

Pages 431-440

An Overview of Electric and Hybrid Vehicle Technology

-
- V. S. Vishwanath Nagarajan, Vinay Kumar Jadoun, N. S. Jayalakshmi, Anubhav Kumar Pandey
-

Pages 441-456

Performance Analysis of Classical Converter Using Different Control Strategies for Switched Reluctance Motor with Dynamic Loading

-
- Ritika Asati, Deepak S. Bankar
-

Pages 457-467

Design and Development Gear-Electric Bike and Performance Testing for Indian Road Conditions

-
- Vinay Gupta, Jitesh Kumawat, Rupendra Kumar Pachauri, Shashikant
-

Pages 469-479

Design and Development of a Solar-Based Wireless Electric Vehicle Charging System

-
- Sanyam Jain, Samyak Jain, Sanjay Kumar, Harsh Kaushik, Neelu Nagpal, Ravi Sharma
-

Pages 481-494

Design, Optimization, and Performance Enhancement of Switched Reluctance Motor for Pollution-Free Electric Vehicle Application

-
- Kesar Ali, Arbaz Sherkhani Shaikh, Kirti Govind, Javid Navaj Shaikh, Yogesh B. Mandake, Deepak S. Bankar
-

Pages 495-512

Using Linear Regression Model to Predict the Wholesale of the Electric Car in Indonesia: What Can Be Learned from the Model?

- Rosyid R. Al-Hakim, Nur F. Soelaiman, Sri Riani, Yanuar Z. Arief

Pages 513-519

Comparison of Thermoelectric Generator with Boost Converter and Single-Ended Primary-Inductance Converter

- Megat Azri Irfan Adzmi, Mohd Zaki Daud, Shahrin Md Ayob, Razman Ayop

Pages 521-533

A Hybrid Maximum Power Point Tracking (MPPT) for Thermoelectric Generator (TEG) System

- Naseem Mohd Arshad, Mohd Zaki Daud, Shahrin Md Ayob, Razman Ayop

Pages 535-551

Thermoelectric Generator (TEG) by Using Indirect Maximum Power Point (MPP) Algorithm

- Ardrine Justin, Mohd Zaki Daud, Shahrin Md Ayob, Razman Ayop

Pages 553-568

Comprehensive Review on AC-DC, DC-DC, DC-AC-DC Converters Used for Electric Vehicles and Charging Stations

- Utkarsh Shukla, Shekhar Yadav, Nitesh Tiwari, Aayushi Priyadarshini

Pages 569-588

Control and Performance Analysis for Active Islanding Detection Using q-Axis Control in Renewable Energy Sources Based Microgrid: A Review

- Avdhesh Kumar

Pages 589-599

Harmonics Analysis of Triple-Phase Induction Motor Drive

- Mohd. Rizwan Khan, Md. Nasim Akhter, Mohd. Sartaj

Pages 601-618

Development of Witricity Based Wireless Power Transmission System

- Kanhaiya Mishra, Arjun Kushawaha, Neetigya Chaurasia, Sudhanshu Kumar, Gautam Kr. Singh, Mohammad Shahid

Pages 619-634

Analysis of Three-Winding Transformer Configurations for Energy Storageless Dynamic Voltage Restorer

- Muhammad M. Roomi, S. M. Suhail Hussain, Mohd Tariq, Taha Selim Ustun

Pages 635-648

Data Reliability Analysis for Early Fault Diagnosis of Air Handling Unit (AHU)

- Hasmat Malik, Shahrin Md Ayob, Nik Rumzi Nik Idris, Awang Jusoh, Fausto Pedro García Márquez, Abdulaziz Almutairi

Pages 649-674

Use of Solar Energy in Treatment of Pulp and Paper Industry Effluent with Hemp: An Experimental Study

- Ambika Thakur, Deepak Juneja, Yogyendra Narayan

Pages 675-687

Design of Radar-Based Portable System for Monitoring of Human Vital Signs with Renewable Energy Resources

- Pushparaj, Amod Kumar, Garima Saini

Pages 689-716

Controlling Methods of Brushless DC Motor in Electrical Vehicle Drives

- Megha Sharma, Shailly Sharma, Jayashri Vajpai

Pages 717-726

Effect of Number of Poles on IPMSM Performance for Electric Vehicle Drivetrain

- Vinod Kumar Kuttey, Sravana Kumar Bali

Pages 727-736

Offline Power Quality Management and Control Using Neural Networks

- Papia Ray, Surender Reddy Salkuti, R. Aditya Kumar

Pages 737-749

Optimized Integral Sliding Mode Load Frequency Control of an Isolated Power System

- Neelam Kassarwani, Neelu Nagpal, Jagrat Sehgal, Pierluigi Siano

Pages 751-762

Implementation of Supercapacitor-Battery-Based Energy Storage System in Hybrid Power System Incorporating Renewable Energy Resources

- Jahid, Manauallah, Sheeraz Kirmani

Pages 763-772

Hybrid Waste to Energy Electricity Generation and Battery Storage System: The Economics and Environmental Emission in a Low-Income Community

- Ahmed Abubakar Elwan, Mohd Hafiz Habibuddin, Yanuar Z. Arief, Ahmad Safawi Bin Mokhtar, Rasyidah Binti Mohamad Idris

Pages 773-783

Application of Solar Power in the Loopholes and Coverages of Buses in the Bus Rapid Transit System in Bhopal

- Rajeev Kumar, Deepak Juneja, Yogendra Narayan

Pages 785-797

Forecasting of Carbon Emissions in India Using (ARIMA) Time Series Predicting Approach

- Somesh Sharma, Amit Mittal, Manmohan Bansal, Bhagawati Prasad Joshi, Ashish Rayal

Pages 799-811

Peak Shaving Through Battery Storage for Photovoltaic Integrated Building Considering the Time of Day Pricing

- A. Sharma, P. Mahajan, R. Garg

Pages 813-825

Economic Analysis of Renewable Energy Systems for Rural Electrification

- Nikita Yadav, Rahul Sharma, Yashwant Sawle

Pages 827-836

Improved Voltage Regulation in Hybrid Photovoltaic/Wind Using Modified Dynamic Voltage Restorer with Hybrid Control Scheme

- Preeti Rani, Ved Parkash, Naveen Kumar Sharma

Pages 837-852

Contingency Analysis for a Solar Energy Generation System Using Real-Time Data Analysis

- Vishal V. Mehtre, Shivani Jitendra Khare, Swapnil Namekar, D. S. Bankar

Pages 853-866

Digital Twin in Extended Reality Applications for Industry 4.0

- Ajune Wanis Ismail, Mohamad Yahya Fekri Aladin, Nur Ameerah Abdul Halim

Pages 867-880

Deep Image Coding in the Fractional Wavelet Transform Domain based on High-Frequency Sub-bands Prediction

- Nadeem Ahmad, Zainul Abdin Jaffery, Irshad, Shaheen Khan

Pages 881-898

QIVIFS: Quaternion Approach of Interval-Valued Intuitionistic Fuzzy Sets with Applications in Renewable Energy System

- Bhagawati Prasad Joshi, Madan Mohan Sati, Sanjay Oli, Deepak Kumar, Ashish Rayal, Abhay Kumar

Pages 899-910

Feminine Protection Wearable System Based on IoT

- Shubham Kumar Verma, Udai Raj Tiwari, Utkarsh Rau, Khadim Moin Siddiqui, Sandhya Srivastava, Jayati Vaish

Pages 911-922

Marine Predictors Algorithm Optimization Technique to Estimate GMPP of PV Array Under Partial Shadowing Conditions

- Rupendra Kumar Pachauri, Rajesh Singh, Ahmad Faiz Minai, Shashikant

Pages 923-932

Artificial Intelligence-Based Bearing Fault Diagnosis of Rotating Machine to Improve the Safety of Power System

-
- Mohmad Iqbal, A. K. Madan

Pages 933-942

Stability Enhancement of AC Microgrid Using Discrete Mode Controllers with Optimum Sampling Frequency

-
- Amit Arora, Mahendra Bhadu, Arvind Kumar

Pages 943-962

Performance Analysis of Grid-Integrated Solar System Through Interlinking Converter with Control Schemes

-
- Preeti Rani, Ved Parkash, Naveen Kumar Sharma

Pages 963-980

Towards Achieving Net Zero Emissions in India by 2070

-
- Akash Midha, Anuradha Tomar

Pages 981-991

IOT-Based Monitoring and Controlling of Substation Parameters

-
- P. Sai Kiran, B. Venkateswara Rao, G. Satyamohan Sarveswar, P. Manikanta

Pages 993-1002

Effectiveness of Resilience Index in Assessing Power System Performance

-
- Hasna Satya Dini, Jasrul Jamani Jamian

Pages 1003-1019

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 mixed 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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367

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).

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

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

$$\hat{U}(t) - \hat{U}(t-1) \leq \hat{U}(t + T_{up}) \quad (2)$$

$$\hat{U}(t-1) - \hat{U}(t) \leq \hat{U}(t + T_d) \quad (3)$$

where

$$TU_i = T_{on} \text{ if } T_{op,i} < MT_{up} \quad (4)$$

$$TD_i = T_{off} \text{ if } T_{id,i} < MT_{dwn} \quad (5)$$

For any operating unit OPU,

$$MT_{up} \geq \varphi / \delta \text{ (h)} \quad (6)$$

$$MT_{dwn} \leq \gamma / \mu \text{ (h)} \quad (7)$$

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].

$$I_{i,t} = I_o + \sum_s P_{s,t} - \mu_t \quad \forall t \in T : t = 1 \quad (8)$$

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

And the inventory limits are given as follows

$$\gamma \leq I_{i,t} \leq \varphi \quad (10)$$

where

$I_{i,t}$ 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) .

$$P_{itmax} \geq P_{dit} \geq P_{itmin} \quad (11)$$

$$P_d = U(t) * P_{op} + h * P_{id} \quad (12)$$

where

$P_{di,t}$ Total demand power
 P_{itmax} Maximum power demand for each unit at a time (t)
 P_{itmin} 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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