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OPTIMIZED ECONOMIC DISPATCH OF ELECTRICITY IN NIGERIA

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Abstract

Power system operational planning is required to make the greatest use of available energy resources to meet variable load demand while maintaining the highest level of safety for all equipment and workers involved at the lowest possible cost and without breaching any system limits. Proper planning of power systems entails that, optimal unit commitment (UC) is achieved, and this could result to significant cost savings for electric utilities. The non-storable nature of electric power, on the other hand, makes meeting load demand at any time a difficulty. In order to fulfill the expected load demand, Unit commitment, also known as start-up and shut-down schedules, is used to determine when generating units should be switched ON/OFF. This paper suggested an algorithm were involving mixed integer linear program for optimal economic dispatch. The method was tested on a Nigerian national grid that runs at 130 kV and has 14 buses, using MATLAB. The findings showed that the strategy is an efficient optimization tool that demonstrates that optimal unit scheduling saves power providers a lot of money. However, as the size and complexity of the test system grows, the approach's efficiency diminishes. The total fuel consumption for all the generators at peak time is $402,547.20, unit price for running a unit is $2,848.00 and the total cost optimized is $16,150.00.

Keywords: Economic dispatch, Thermal power generator, Hydro power generator, Unit commitment, Nigeria

1. Introduction

Electricity expanded rapidly throughout the world after invention. Electrical power systems in the world have grown larger and more geographically expansive with many interconnections between neighboring systems. Nigeria has also grown in production of electricity. Nigeria has recorded impressive rates of economic growth in recent years. Electrical power sectors play an important role in national economy [1]. The power interest in Nigeria far overwhelms the stock and the stockpile is epileptic in nature. This is blocking its turn of events, despite the accessibility of huge normal assets in the country. Consistent power supply is the sign of a created economy. Any country whose energy need is epileptic in supply drags out her turn of events and dangers losing expected financial backers. The proficiency of producing unit, the transmission loses and the working expenses are significant elements to be considered for the monetary activity of the framework [2]. As of late, the Power Holding Company of Nigeria (PHCN) has been encountering difficult issue in age, transmission, circulation, upkeep, monetary imperatives and expansion in power interest, taking into account the age/power request issues, a few units were on crisis/constrained blackouts, which prompted framework aggravation, for example, halfway and all out-framework breakdown [3]. These issues were credited to over focusing on the units to create outside their typical working circumstances. This will along these lines lead to producing electric power at misfortune. Considering the above issue, it becomes important for one to concentrate on the expense elements of the accessible warm units, their power limits and the greatest power interest of the entire country at a specific time in order to do the economic load dispatch (ELD) issue [4]

Economic load dispatch is an important optimization task in power system operation for allocating generation among the committed units such that the constraints imposed are satisfied and the energy requirements in terms of British thermal units per hour (Btu/h) or dollar per hour ($/h) or Naira per hour (N/h) are minimized" [5,6]. Enhancements in booking the unit results can prompt massive expense reserve funds. The proficient and ideal monetary activity of electric power frameworks has consistently involved a significant situation in electric power industry. In late many years, it is turning out to be vital for utilities to run their power frameworks with least expense while fulfilling their client's interest constantly and attempting to create gain. Since the demand is very large and the power generation is limited so it is required to fulfill the load demand using committed generating units in minimum fuel cost [7].

The ideal arrangement of the pragmatic monetary burden dispatch issue is one of the most generally talked about and investigated issues of force framework arranging and activity. The advanced power framework all over the planet has developed such a great amount in intricacy of interconnection and power interest. The center has moved towards improved execution, expanded client concentrate, minimal expense, solid and climate agreeable/contamination free power age [2]. As of now, shortage of energy assets, expanding power age cost and ecological concern requires ideal financial dispatch. Enhancement is the demonstration of acquiring the best outcome under given conditions [4].

In the effort to improve the economic dispatch so as to minimize the cost of fuel used in the operation of the power system as well as minimize the emission that a plant produces in the bid to enhance the environmental conditions and reduce the adverse effect of technology on the ozone layer, several works have been done.

Methods like dynamic programming (DP), genetic algorithm (GA), evolutionary programming (EP), artificial intelligence (AI), and particle swarm optimization (PSO) solve nonconvex optimization problems efficiently and often achieve a fast and near global optimal solution [8]. In [9] Ismail, Nur, Mohd, Muhammad, Titik and Mohd, (2008) introduced the monetary power dispatch issues utilizing subterranean insect settlement improvement (ACO) strategy which is a meta-heuristic methodology for taking care of hard combinatorial streamlining issues. This strategy was tried utilizing the standard IEEE 26-Bus RTS and the outcomes uncovered that the proposed method has the legitimacy in accomplishing ideal answer for resolving the issues. Near examinations with counterfeit resistant framework (AIS) were additionally directed to feature the strength of the proposed strategy. In the year 2012, Hardiansyah, Junaidi and Yohannes introduced a successful and dependable molecule swarm streamlining (PSO) method for the monetary burden dispatch issue utilizing the standard 3-generator and 6-generator frameworks with and without thought of transmission misfortunes. The end-product acquired utilizing PSO are contrasted and ordinary quadratic programming and viewed as empowering [10].

The problem of economic dispatch was also solved in [11]. solves the economic dispatch problem in two layers. It uses GA to solve the unit commitment problem and then uses Lagrangian relaxation to perform the economic dispatch. In this method the optimality of solution cannot be guaranteed and also in some instances uses a high computation time, nonetheless it is an advantageous method for large systems. An improved Genetic lgorithm to solve the economic load dispatch problem was also proposed in [12]. The paper introduces new selection and cross over processes into the GA. In comparison to other previously invented GA's it has better solution in terms of convergence rate, reliability and operation cost.

In [113], genetic algorithm based economic dispatch based on arithmetic cross over was also introduces. This makes use of "real value representation scheme, arithmetic cross over mutation and elitism to generate successive sets of possible operating policies." In comparison with "Fuzzy Logic Controlled GA and Advanced Hopfield Neural Network and Advanced Engineering Conditioning GA it shows better results in terms of operation cost for the 20-unit test system." However, it is noted that the proposed technique shows no obvious improvement in contrast with different calculations on the 6-unit test systems.

[14] proposes the use of Particle swarm Optimization in solving of the economic dispatch problem. In the larger systems it has marked superiority in comparison with other heuristic methods. But in smaller systems its advantage is of no effect. [15] uses biogeography in solving the economic dispatch problem. Here the geographical behavior of nature in distributing species is employed to solve the Economic dispatch problem. It uses migration and mutation to operate successfully. In comparison with PSO, GA and simulated annealing it has a better convergence, computational efficiency and better quality of solution. It is however complex in comparison with PSO and also its behavior can be very dismal if parameters are not successfully chosen.

[16] applies a PSO to the economic dispatch problem with non-smoothing functions. Primarily the difference between this and the classical PSO is how the equality and inequality constraints are handled in the modification of each individual's search point. Also, in a bid "to accelerate the convergence speed, a dynamic search space reduction method is devised." Simply put this method is efficient.

[17] proposed a strategy for taking care of monetary dispatch issue utilizing Particle Swarm Optimization (PSO) Algorithm and Simulated Annealing (SA) for the three creating units as a contextual investigation. PSO and SA were applied to figure out the base expense for various power interest. They contrasted their outcomes and the customary procedure, where PSO showed improved outcome and better combination trademark.

By and large the heuristic strategies like Genetic calculation, Simulated strengthening, Particle Swarm Optimization, Ant Colony and Artificial Bee Colony (ABC) procedures and their different alterations have shown stamped improvement in the tending to of the monetary dispatch issue as well as the joined financial and emanation dispatch issue. From the above writing there shows a need in as yet working on the nature of answers for the consolidated financial and discharge dispatch issues, as far as better union, lower misfortunes, quicker calculation times, diminished fuel costs and decreased outflows. It deserves notice that crossover techniques yield unrivaled arrangements, either a heuristic and a conventional strategy or two heuristics. So far, the hybrids existing in open literature do not include the hybrid of PSO and ABC despite the fact that the two techniques yield great arrangements separately.

2. Models of economic dispatch

The Unit Commitment (UC) optimization problems in power systems can be solved using a number of optimization principles including the Mixed Integer Linear Programming (MILP). The MILP formulation adopted in this paper is based on a single binary variable to describe the UC status and the corresponding hourly transition of generating units. The Minimize operational cost (OC) is given as:

$$OC = \sum_{t=1}^{N} \sum_{t=1}^{T} FC_{it}\left(P_{it}\right) I_{it} + NL_i + SD_{it} + SD_{it} \qquad (1)$$

where OC is the operating cost, N is the number of generating units, T is the time horizon, which is 24 hour, and is a binary variable modelling UC decision of unit i at hour t. (P_{It}) is the fuel cost, is the no-load cost of unit i, and are respectively the start-up and shutdown costs of unit i at hour t. $FC_{it}(P_{it})$ is "the input/output curve that is modelled with a quadratic function of the power output in (2).

$$FC_{it}\left(P_{it}\right) = a_i P_{it}^{\ 2} + b_{it} P_{it} + C_i \qquad (2)$$

a_i , b_i and c_i are the cost coefficients

Practically, this cost is modelled as a piecewise-linear function. A tight formulation for this piecewise-linear approximation is given in the equation above. is the cost for restarting a de-committed thermal unit, which is depended to the temperature of the boiler. The number of the start-up and shutdown and their type (hot or cold) changes in function of the ON/OFF status of the units. It is expressed as follows:

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$$ST_{it} = \begin{Bmatrix} HSN_{i,} if MDT_i \le T_{off,i}(t) \le MDT_i + T_{cold,i} \\ CSN_{i,} if T_{off,i}(t) > MDT_i \_ T_{cold,i} \end{Bmatrix} \tag{3}$$

For a plant to be brought into service, an additional expenditure C_{si} has to be incurred in addition to the running cost (i.e., start-up cost of the i^{th} unit), the cost of starting 'x' number of units during any sub-interval *t* is given by:

$$F_{SC} = \sum_x C_{si} \delta_{it} \tag{4}$$

where

$\delta_{it} = 1$, If the i^{th} unit started in sub-interval 't', and otherwise $\delta_{it} = 0$

Similarly, if a plant is taken out of service during the scheduling period, it is necessary to consider the shut-down cost. If 'y' number of units are to be shut down during the sun-interval't', the shut-down cost may be presented as

$$F_{sd} = \sum_{i=1}^{y} C_{sd} \tag{5}$$

where

$\delta_{it} = 1$, when the i^{th} unit is thrown out of service in sub-interval 't', and otherwise $\delta_{it} = 0$

Over the complete scheduling period of 't' sub-intervals, the start-up cost is given by

$$F_{SCT} = \sum_{t=1}^{T} \sum_{i=1}^{x} C_{st} \delta_{it} \tag{6}$$

And the shut-down cost is

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$$F_{SCT} = \sum_{t=1}^{T} \sum_{i=1}^{x} C_{sd} \delta_{it} \tag{7}$$

The total expression for the cost function including the running cost, the start-up cost, and the shut-down cost can then be written in the form:

$$F_r = \sum_{t=1} \left\{ \sum_{i=1} \sum_{j=1} C_{pi} G_{pi} + \sum_{i=1} C_{sci} \delta_{it} + \sum_{t=1} C_{sdi} \delta_{it} \right\} \tag{9}$$

For each sub-interval of time t, the number of generating units to be committed to service, the generators to be shut down, and the quantized power loading levels that minimize the total cost have to be determined.

The proposed flowchart for the optimization of the Unit Commitment problem is illustrated in Figure 1, while the studied bus bar is depicted in Figure 2. The system is a 132 kV, 14-bus power system, which is made up of six units, two of which are hydro and four of which are thermal.

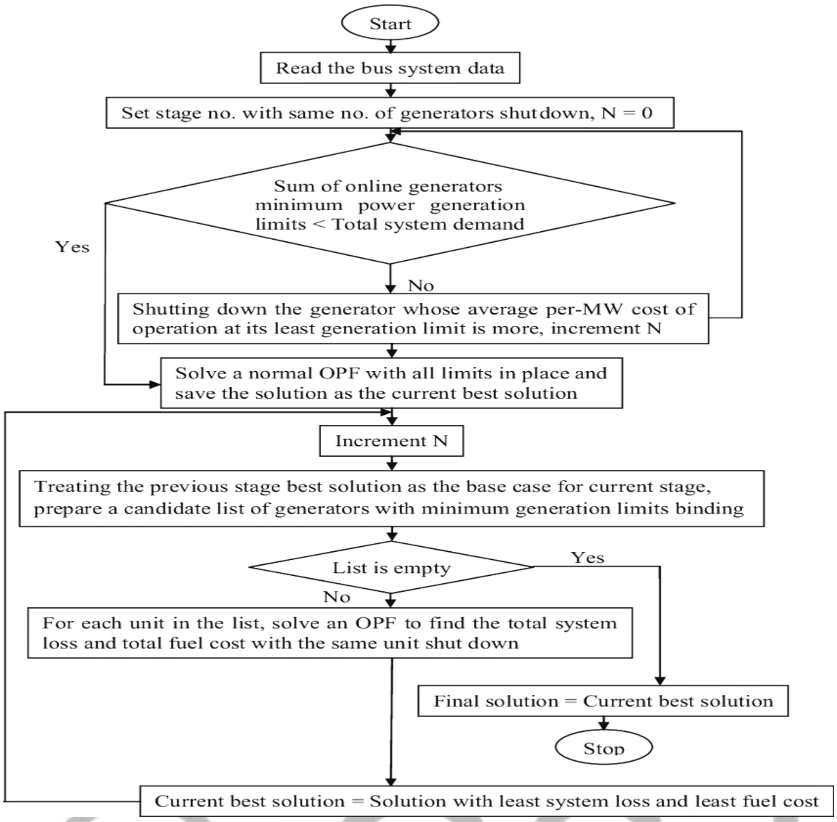

Figure 1: The proposed unit commitment flowchart

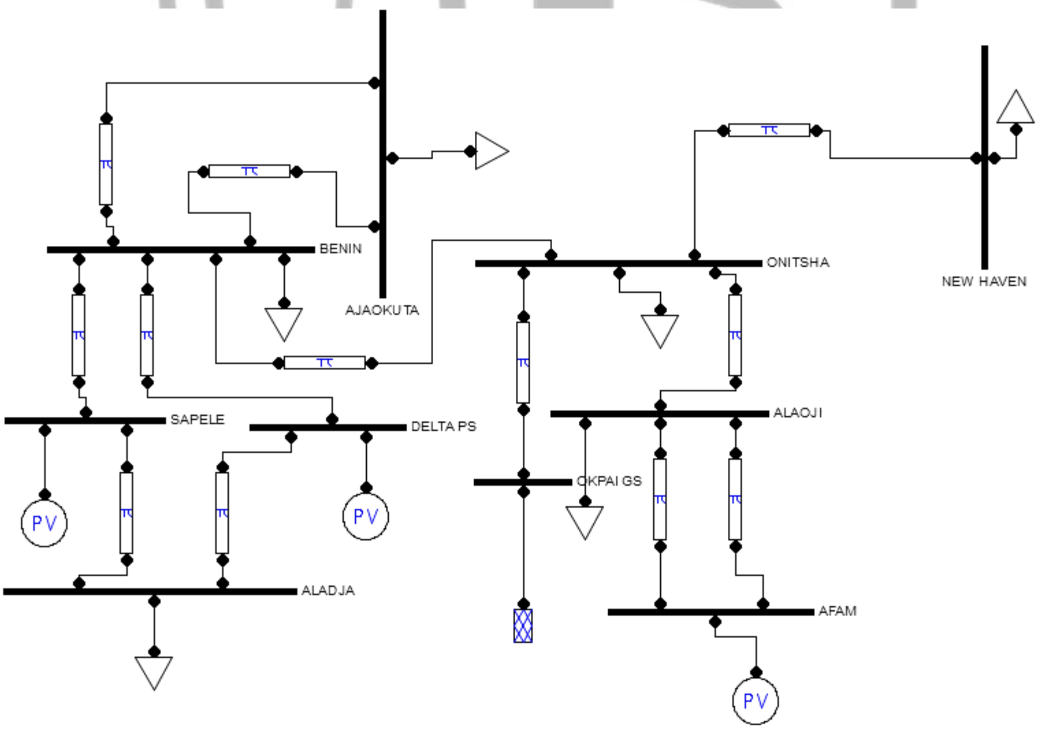

Figure 2 A 14-bus system 132KVA for ELSD and UC study

Two cases were considered. CASE I involves a scenario were the thermal units remained operational throughout the study period, but hydro units were committed at “the sixth hour, when the committed thermal units (units 4 and 5) could no longer provide the needed load demand.” From the tenth to the fifteenth hour, the committed thermal units provided the same amount of electricity. Because all other available thermal units have lost their operational temperature, starting another thermal unit at that time will result in higher costs owing to chilly startup. CASE II involves a situation where the must-run units 4 and 5 covers the load requirement at this time. The hydro units were committed from the first hour.” To put it another way, the must-run condition was broken. Table 1 shows the relevant data for Case I, while Table 2 shows the data for CASE II. The daily load demand for the Cases is illustrated in Figure 3. The uneven pattern in the image, which does not reflect the load demand curve, is once again noticeable. This is due to the fact that unit 5, a must-run unit, was not committed at the right moment, resulting in a high beginning cost, despite the fact that the cost spent during the peak period was lowered.

Table 1:

Hour(hr)	1(MW)	2(MW)	3(MW)	4(MW)	5(MW)	6(MW)	Load	Fuel cost	Startup cost	Prod cost
1	0	0	0	415	425	0	850	14,960		14,950
2	0	0	0	415	325	0	750	13,200		13,400
3	0	0	0	415	305	0	730	12,848		12,800
4	0	0	0	415	275	0	700	17,300		12,500
5	120	0	0	415	425	0	850	19,450		11,400
6	120	0	0	415	445	120	950	20,702	1,100	18,600
7	120	0	0	415	445	120	1150	20,100	1,800	17,550
8	120	0	100	415	445	120	1300	21,200		20,400
9	120	0	188	415	445	120	1400	20,400		18,200
10	120	0	238	415	445	120	1500	22,500		20,210
11	120	0	338	415	445	120	1550	23,780		16,540
12	120	0	430	415	445	120	1600	20,600		15,508

13	120	38	430	415	445	120	1700	19,500		12,700
14	120	88	430	415	445	120	1850	18,750		16,250
15	120	240	430	415	445	120	1900	20,800		20,310
16	120	240	430	415	445	120	1950	13,600		10,502
17	120	240	430	415	445	120	2000	14,670		8,600
18		240	430	415	445	70	2010	9,600		9,500
19		240	430	415	315	0	1950	12,500		10,200
20	0	240	430	415	295	0	1800	17,900		11,400
21	0	240	430	220	220	0	1450	20,850		12,400
22	0	240	430	100	100	0	1310	12,500		3,500

Table 2:

Hour(hr)	1(MW)	2(MW)	3(MW)	4(MW)	5(MW)	6(MW)	Load	Fuel cost	Startup cost	Prod cost
1	125	0	0	425	425	125	850	12,960	3,100	14,950
2	25	0	0	425	325	125	750	15,200		13,400
3	10	0	0	425	305	125	730	14,848		12,800
4	0	0	0	425	275	125	700	14,300		12,500
5	125	0	0	425	425	125	850	16,450		11,400
6	125	217	0	445	445	125	950	16,702	-	18,600
7	130	250	0	445	445	125	1,150	22,100	1,900	17,550
8	130	250	440	445	445	125	1300	19,200		20,400
9	130	250	440	445	445	125	1400	22,400		18,200

10	130	250	440	445	445	125	1500	18,500		20,210
11	120	250	425	445	445	125	1550	16,780		16,540
12	120	0	425	445	445	0	1600	21,500		15,508
13	130	0	440	445	445	0	1700	16,500		12,700
14	130	0	440	445	445	0	1850	19,750	1,900	16,250
15	130	260	425	445	445	0	1900	21,500		20,310
16	125	260	440	445	445	0	1950	15,700		10,502
17	120	260	440	445	445	0	2000	13,870		8,600
18	125	0	425	445	445	125	2010	9,600		9,500
19	130	0	425	445	315	125	1950	16,500		10,200
20	125	0	425	445	295	125	1800	14,900		11,400
21	125	0	440	220	220	125	1450	19,850	650	12,400
22	130	208	420	100	100	0	1310	14,100		3,500

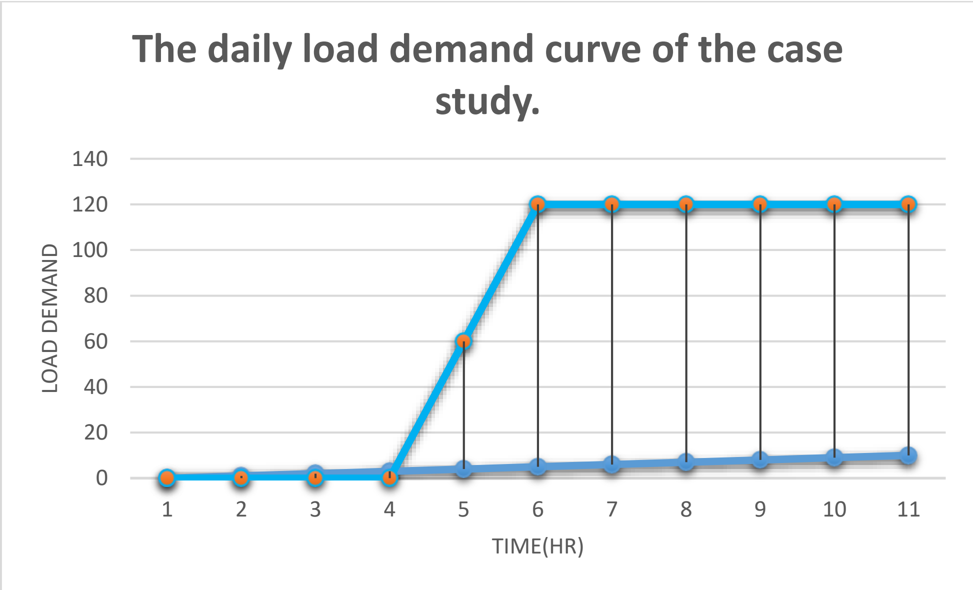

Figure 3: The daily load demand curve of the case study.

5. Results and discussion

The thermal unit was modelled using a quadratic cost function, "but the water transport and other hydro variables were left out because the hydro units are only used during peak demand periods." Table 3.1 shows the operating data that summarizes the attributes of the units. The cost functions that were employed in this investigation were taken from [18]. The adopted method is put to the test on the previously mentioned case study system with a 24-hour horizon. During peak demand, the hydro unit is activated to meet the demand. The result of the EEA solution for the hydrothermal system is contrasted to another approach for developing a system to deliver the same load. Cases I–II deal with three alternative methods that fulfill the power requirement. The total daily energy production is projected to be 33,600 MWh in all scenarios.

Table 3:

UNIT	1(Hy)	2(Hy)	3(Hy)	4(Th)	5(Th)	6(Th)
P_{max} (MW)	130	240	410	315	432	120
P_{min} (MW)	9	25	115	125	140	10
A	0	0	0	1,000	970	700
B	0	0	0	16.19	17.26	16.60
Y	0	0	0	0.00048	0.00031	0.002
On time	15	14	15	8	7	5
Off Time	3	3	3	8	8	5
Hot starts(s)	0	0	0	3,500	4,000	550
Cold starts	0	0	0	8,000	10,000	1,100
Initial state	0	0	0	8	8	-4

5.1.1. Results discussion for CASE I

CASE I is the optimal plan that matched the load demand at the lowest cost, without breaking any constraints, and with the fewest number of transitions from ON to OFF and vice versa. While adhering to the minimal up and down timings, the unit's combination displays the must-run feature of units 4 and 5. The thermal units, on the other hand, had a tiny beginning cost, and the hydro units simply had a staff cost because they do not use any fuel. The units pledged and the load allocation for CASE I are shown in Table 3.2. "As the load demand rises, the total output from the units rises as well, either by increasing the power output of previously committed units or by committing more units." "The total number of transitions from OFF to ON and vice versa for all of the units is only eight. As a result, there were less start-up and shut-down expenditures. This single fact supports the conclusion that CASE I is the most cost-effective combination."

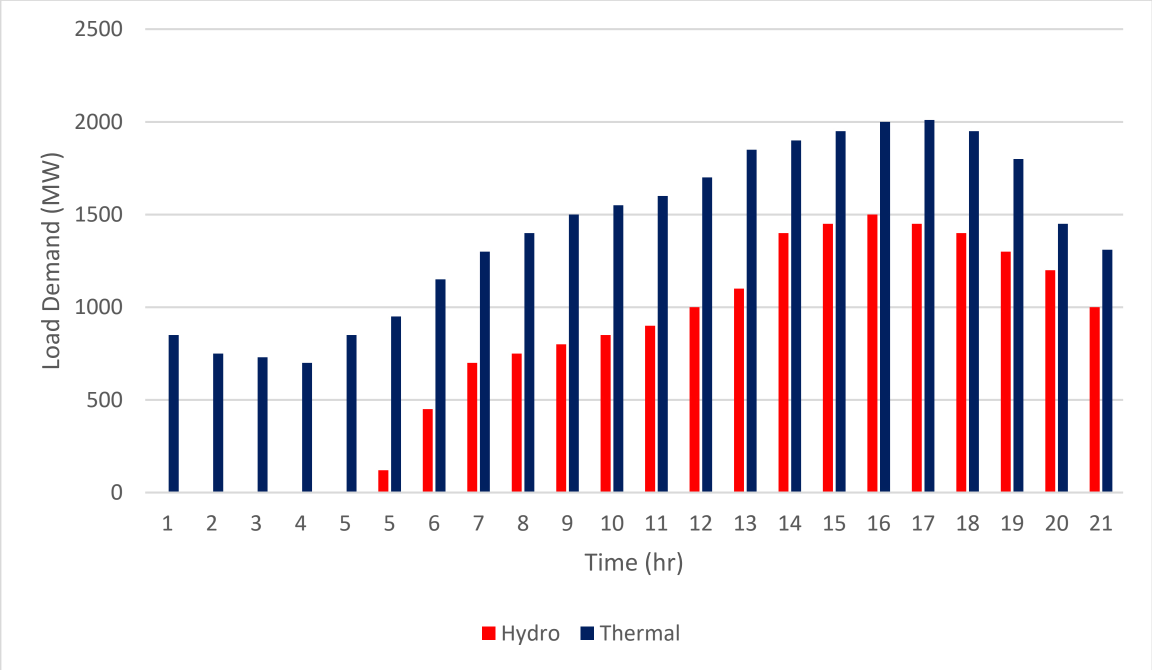

Figure 4: Contribution of hydro and thermal units which met the total load demand

5.1.2. Results discussion for CASE II

The units planned in this scenario, which is shown in Table 3.3, can provide the necessary electricity at a cheaper cost than in Case I. Here, it is presumed that no units were produced in excess of the set minimum or maximum. However, a lot of additional restrictions were broken. There are now more transitions of units from ON to OFF and vice versa, occurring 26 times total, and the must-run feature of unit 5 has been reduced. As with units 1, 2, 6, and 7, this results in the units' failure to comply with the minimum up and minimum down time requirements. The quantity of transitions results in a high beginning cost. The region shown in red indicates where the minimum up time or minimum down time restrictions were broken, while the area highlighted in blue shows where the must-run requirements were broken.

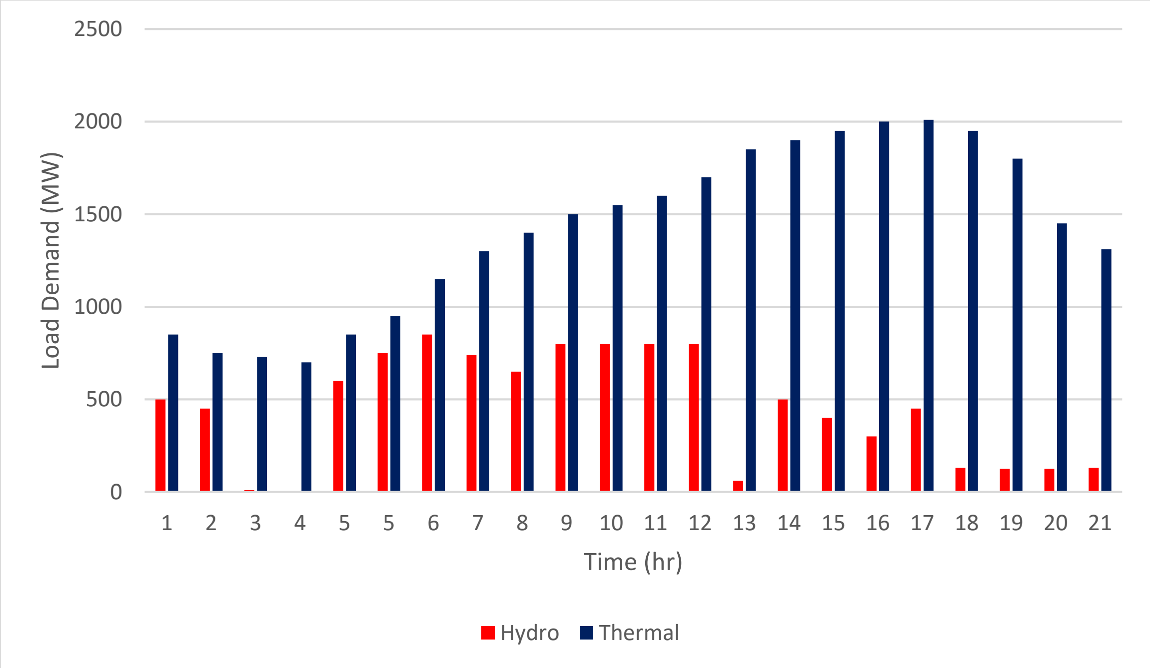

Figure 4: Contributions of hydro and thermal units for Case II

3. Conclusion

This paper has presented optimized economic dispatch of electricity in Nigeria. Based on Unit commitment hypothesis, optimization problem was formulated and solved using mixed integer linear program algorithm. The analysis was carried out for a Nigerian 132 kV, 14-bus power system, and validated in MATLAB using typical line data and parameters. Two cases involving a scenario where, two of the bus unit are hydro and four are thermal were considered. The thermal unit was modelled using a quadratic cost function, "but the water transport and other hydro variables were left out because the hydro units are only used during peak demand period. Results shows that hydro units have no significant cost impact on the generation of electric power; as a result, they are used to control peak system demand, lowering the fuel costs associated with running thermal units. However, the thermal power plant is committed as the load increases and shutdown as the load reduces to increase their life span and reduce the cost of power generation.

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