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Employment of vehicle to grid technology to decrease the economic-environmental costs equipped with mixed-integer non-linear programming approach

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Highlights

- Programming of thermal power productions by vehicle to grid technology
- Economic factors considered besides environmental factors in programming
- The Non-linear modeling of the proposed problem and using a powerful mathematics method
- Considering charging/discharging of EVs as virtual power plants in the proposed strategy

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Abstract

In the present work, the programming of thermal production units is adopted by vehicle to grid (V2G) technology. The suggested approach solution is made by the mixed-integer non-linear programming (MINLP) method in the GAMS simulation environment. The main objective of this study is to obtain an answer to minimize the considered objective function (OF). Some limitations are also considered in this optimization problem that should be met by the proposed method. The proposed method of this work is evaluated to validate its efficiency. In this regard, this proposed technique is tested on an IEEE 10-unit case study that contains 5000 EVs (electric vehicles). According to the obtained results, the utilized V2G can considerably influence the unit commitment (UC) problem. EVs bring on new loads to the electrical network that grows the expenditure of power production. Nevertheless, the coordinated charging method, along with rational utilization of V2G power, can decrease this expenditure. Also, take into consideration the minimizing operating expenses as the programing goal presents a better overall economic and environmental performance in the thermal unit with V2G cases.

1. Introduction

A GV (gridable vehicle) can act as a small portable power system (S3P) to promote the durability and security of the system. Recently, V2G attracted much attention. The efficiency of V2G is highly dependent on the intelligent programming of gridable vehicles or S3Ps in limited parking lots. This technology can decrease the affiliations to the small high-cost units in current networks that cause to decrease the operating expenditure and emitted pollution. As well, V2G results in durability enhancement of current networks [1]. UC problem is a complex issue that schedules the operation of production units. In this process, committed generators should satisfy the demanded power and reserve the requisites with the lowest possible operational expenditure under some limitations. Moreover, EDP (denoting the economic dispatch problem) assigns the demanded power from the running generators, in addition, to meeting the electrical energy balance relations in an optimum manner under unit operational constraints [2]. Utilized techniques for solving the UC problem are categorized into three main classes: classic, smart, and hybrid. The UC problem consists of even limited parking loss in which smart scheduling can provide significant profit [3]. Many approaches are proposed in the literature for UC problem solutions containing dynamic programming, priority list, Lagrangian [3, 4], internal-

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point method, integer linear programming, and intelligent approaches like tabu optimization [6], annealing method, fuzzy methods, GA algorithm [7], probabilistic method [8] artificial networks (ANNs), shuffled-frog-leaping method [9], information-gap decision theory (IGDT) [10], smart grid data [11], as well as PSO (particle swarm optimization) algorithm [12]. Present work suggested the MINLP method to solve the UC and EDP problems for IEE 10-network case studies. Hence, five different scenarios are considered to optimize the case studies, and their results are compared to select the best scenario to solve the UC and EDP problems. Also, the MINLP method results are compared with the other optimization methods to present the employed optimization method utility. In the proposed MINLP approach, the considered problem contains discrete/continuous parameters in line with the UC problem.

2. Problem statement

Fuel expenditure in thermal generation units is mostly stated in a second-order function form of the produced energy of the generator in that time interval by:

$$FC_i(P_i(t)) = a_i + b_i P_i(t) + c_i P_i(t)^2 \quad (1)$$

In which, a_i, b_i and c_i denote the fuel factors for thermal units. Table 3 lists the considered values for these coefficients. Also, $P_i(t)$ is the produced electricity, and $FC_i(P_i(t))$ denotes the fuel expenditure of this power for the ith unit.

Furthermore, the environmental cost function is presented in the polynomial form. The order of this function relies on the demanded precision. Here, a second-order function is considered as follows:

$$EC_i(P_i(t)) = \alpha_i + \beta_i P_i(t) + \gamma_i P_i(t)^2 \quad (2)$$

In this function, α_i, β_i, and γ_i denote the emission factors, and their considered values are listed in Table 4.

Network power balance: balancing between generation and used power in each period is essential in ISO for short-term programming.

$$\sum_{i=1}^{N} P_i(t)u_i(t) + P_{V2G}(t) = D(t) + loss \quad (3)$$

Here, $u_i(t)$ denotes the condition of the ith unit (off/on) at the interval t. this parameter is one once this unit is committed in a generation. Also, $D(t)$ indicates the demanded power and $P_{V2G}(t)$ determines the exchanged electricity between the grid and V2G.

In production constraints for achieving great effectiveness in long-term operation, units' production must be in the allowable range.

$$P_i^{min} \le P_i(t) \le P_i^{max} \quad (4)$$

where, P_i^{min} and P_i^{max} determine the lower and upper bounds of production by ith unit.

Lower bound of up/down-time: once a unit is started to operate, it should incessantly remain in this status for a certain period (due to some technical reasons). As well, once the unit is turned off, it must stay in this status for a certain period.

$$if\ u_i(t) = 1\ then\ (1 - u_i(t+1))MU_i \le x_i^{on}(t) \quad (5)$$

$$if\ u_i(t) = 0\ then\ u_i(t+1)MD_i \le x_i^{off}(t) \quad (6)$$

where, MU_i and MD_i denote respectively the lower bounds for up and down-time of the ith unit. Also, $x_i^{on}(t)$ and $x_i^{off}(t)$ indicate respectively the on and off-time intervals.

Ramp-rate limitations: by assuming a network as a mechanical system, the variation rate of production can't violate from a specific range.

$$\begin{aligned} &if\ u_i(t) = 1\ and\ u_i(t-1) = 0 \\ &then\ P_i(t) - P_i(t-1) \le RU_i \end{aligned} \quad (7)$$

$$\begin{aligned} &if\ u_i(t) = 0\ and\ u_i(t-1) = 1 \\ &then\ P_i(t-1) - P_i(t) \le RD_i \end{aligned} \quad (8)$$

Here RU_i is the ramp-up of the ith unit, and RD_i denotes the ramp-down of that unit.

Start-up expenditure: for restarting of a non-committed unit, start-up expenditure is computed by:

$$Sc_i(t) = \begin{cases} h - cost_i \\ c - cost_i \end{cases} \quad (9)$$

In which $h - cost_i$ is the hot start expenditure. Also, $c - cost_i$ is the cold start expenditure, where its amount is lower than the hot start expenditure.

Spinning reserve limit: by now, many approaches are suggested in the literature to specify reserve capacity. There is no load on spinning reserve in synchronous generators. So, it can rapidly respond to the load oscillations [6].

$$\sum_{i=1}^{N} P_i^{max}u_i(t) + P_{V2G}(t) = D(t) + R(t) + loss \quad (10)$$

Table 1. Kinds of reserves with their features [6].

Reserve kind	Start time (min)	Synchronization?
TMSR	< 10	Yes
TMNSR	< 10	NO
30 minutes Reserve	[10, 30]	NO
60 minutes Reserve	[30, 60]	NO

CR	> 60	NO

Table 1 presents the reserves' kind and their features. Just spinning reserve is taken into account in the present work.

Estimation of connected EVs count to the power system: The count of gridable vehicles in a real-world power system is estimated as follows:

$$N_{V2G} = Q_{V2G} \times V_{REC} \times N_{REC}$$
$$N_{V2G} = \frac{Q_{V2G} \times V_{REC} \times X_{RL} \times D_{min}}{AV_{HLD}} \quad (11)$$
$$AV_{HLD} = \frac{AV_{MEC}}{30 \times 24}$$

where, D_{min} denotes the lowest possible power demand value in a time interval; X_{RL} indicates the residential demands' share in the grid; V_{REC} denotes the count of gridable vehicles for each household user; Q_{V2G} determines the percentage of the registered car participating in the procedure and AV_{MEC} signifies the mean monthly power usage of a residential user. Also, AV_{HLD} is the mean demanded power by a residential user in each hour.

Exchanged electricity with the grid:

$$P_{V2G}(t) = \sum_{j=1}^{N_{V2G}} \xi P_{Vj}(t)(\psi_{pre} - \psi_{dep}) \quad (12)$$

Here, the battery's performance is determined by ξ, and $P_{Vj}(t)$ denotes the capacity of the jth vehicle. As well, ψ_{pre} *and* ψ_{dep} determine the initializing and ending SOCs (state of charges), respectively.

Emission of vehicles: Here, an approximation in a linear function form is utilized for vehicles' emission computation by [13]:

$$EC_j(L_j, e_j) = L_j \times e_j \quad (13)$$

In this formula, $EC_j(L_j, e_j)$ denotes the emission function, and L_j indicates the covered distance by jth vehicles (miles). Also, e_j determines the emission of this vehicle in each mile.

Objective functions: following functions are the OFs in 3 cases:

$$min\ FC = \sum_i (a_i + b_i P_i(t) + c_i P_i^2(t)) u_i(t) + Sc_i(t)(1 - u_i(t-1)) + (x + yP_{V2G}(t) + zP_{V2G}^2(t)) \quad (14)$$

$$min\ EC = \sum_i (\alpha_i + \beta_i P_i(t) + \gamma_i P_i(t)^2) + EC_j \quad (15)$$

$$Min\ multiFunc = W\left(\sum_i \left(a_i + b_i P_i(t) + c_i P_i^2(t)\right) + Sc_i(t)\left(1 - u_i(t-1)\right) + \left(x + yP_{V2G}(t) + zP_{V2G}^2(t)\right)\right) + (1 - W)\left(\sum_i (\alpha_i + \beta_i P_i(t) + \gamma_i P_i(t)^2) + EC_j\right) \quad (16)$$

Test system: The utilized variables in the present work are presented below:

- The mean capacity of batteries (P_{Vj}) is 25 kWh.
- The entire count of cars in a city is estimated to be 50000.
- The frequency of charging and discharging is considered one each day.
- The programming horizon is one day (24 hours).
- Performance of system (ξ) is 85 percent.
- Also, expenditure factors of EVs are as: $x = 0$, $y = 8.21$, and $z = 0.20$.

Table 2 lists the demanded power. Also, Table 3 and Table 4 represented the operator information and factors of the production unit's emission in the considered test system (IEEE 10-unit network), respectively.

Table 2. Demanded power per hour [14].

Hour	Load $[GW]$	Hour	Load $[Mw]$
1	0.70	13	1.40
2	0.75	14	1.30
3	0.85	15	1.20
4	0.95	16	1.05
5	1.00	17	1.00
6	1.10	18	1.10
7	1.15	19	1.20
8	1.20	20	1.40
9	1.30	21	1.30
10	1.40	22	1.10
11	1.45	23	0.90
12	1.50	24	0.80

Table 3. Operator data of IEEE 10-unit network [14].

Parameters	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
P^{max} $[MW]$	455	455	130	130	162	80	85	55	55	55
P^{min} $[MW]$	150	150	20	20	25	20	25	10	10	10
a $[\$/h]$	1000	970	700	680	450	370	480	660	665	670
b in $\$/MWh$	16.19	17.26	16.6	16.5	19.7	22.26	27.74	25.92	27.27	27.79
c $[\$/MW^2h]$	0.00048	0.0003	0.002	0.00211	0.00398	0.00712	0.00079	0.00413	0.00222	0.00173
MU $[h]$	8	8	5	5	6	3	3	1	1	1
MD $[h]$	8	8	5	5	6	3	3	1	1	1
SCh $[\$]$	4500	5000	550	560	900	170	260	30	30	30
SCc $[\$]$	9000	10000	1100	1120	1800	340	520	60	60	60
CST $[h]$	5	5	4	4	4	2	2	0	0	0
$I.S$ $[h]$	8	8	-5	-5	-6	-3	-3	-1	-1	-1

Table 4. Emission factors of production units [13].

Generator	α_i $[ton/h]$	β_i $[ton/Mwh]$	γ_i $[ton/Mw^2h]$
G1	10.33908	-0.24444	0.00312
G2	10.33908	-0.24444	0.00312
G3	30.03910	-0.40695	0.00509
G4	30.03910	-0.40695	0.00509
G5	32.00006	-0.38132	0.00344
G6	32.00006	-0.38132	0.00344
G7	33.00056	-0.39023	0.00465
G8	33.00056	-0.39023	0.00465
G9	35.00056	-0.39524	0.00465
G10	36.00012	-0.39864	0.00470

3. Numerical results

Present work programmed the generations in 5 cases. Table 5 presents the various cases with OFs. Also, Table 6 provides the results for programming without V2G. As anticipated, expenditures in case C1 and emission amounts in case C2 are reduced

Table 5. Various cases with considered OFs.

Case	Programmed in the presence of	OF
C1	Thermal units	Minimizing operating expenses
C2	Thermal units	Minimizing emissions
C3	Thermal units and V2G	Minimizing operating expenses
C4	Thermal units and V2G	Minimizing emissions
C5	Thermal units and V2G	Multi-Objective Optimization

Table 6. Operating expenses & emissions in C1 and C2.

C1		C2	
Operating expenses [$]	**Emissions** $[ton]$	**Operating expenses** [$]	**Emissions** $[ton]$
564267.356	26485.095	623253.613	18179.054

Table 7. Comparison of operating expenses of MINLP approach with other ones.

Approach	Expenditure [$]	Approach	Expenditure [$]
MINLP	564267.356	LR [4]	568356
GA [15]	565825	BCGA [15]	567367
DP [15]	565825	ICGA [16]	566404
PSO [1]	564743.5	LRGA [17]	564800
HPSO [18]	564772	LS [5]	564970
SFLA [19]	564769	EP [20]	565352
BF [21]	564842	BPSO [22]	565804
LRPSO [23]	565869		

Table 7 compares the suggested approach to others in solving the problem under consideration for a better evaluation. The proposed approach's effectiveness and precision are relatively high, resulting in a remarkable decrement in operating expenses.

Also, Tables 8 and 9 represent the results for UC and EDP problems in the considered test system in the presence of V2G and SOC in case C3. According to these results, operating expenses of G1 and G2 turning on at the starting of the programming are relatively low, and they stay committed in all 24 periods. As well, due to the high price of G9 and G10, they are committed just in hours, and the remaining generators aren't able to satisfy the demanded power and reserve.

Tables 10 and 11 present the UC and EDP problems results in the considered test system in the presence of V2G and SOC in case C4. Regarding obtained results, the G1 and G2, because of lower operating costs stay committed for all 24 hours. Also, G9 and G10 are committed hourly. The comparison of C3 and C4 results reveals that the G9 and G10 are staying committed for the higher hourly time. Also, G3's committed time enhances in the C4 compared to C3, while the G4's committed time in the C3 is higher than in C4.

Two cases of C2 and C4 just concentrated on emissions, and their OFs are aimed to minimize the emitted pollution. The operating expenses and emission amount of the 10-unit network in considered cases are contrasted in Tables12 and Table 13.

Table 8. Programming results of IEEE 10-unit network in the presence of V2G (C3).

Hour	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
1	453	271.107	0	0	0	0	0	0	0	0
2	453	319.831	0	0	0	0	0	0	0	0
3	453	371	0	0	0	0	0	0	0	0
4	453	362	0	128	0	0	0	0	0	0
5	453	356	0	128	0	0	0	0	0	0
6	453	384.925	128	128	24	0	0	0	0	0
7	453	434.974	128	128	24	0	0	0	0	0
8	453	453	128	128	44	0	0	0	0	0
9	453	453	128	128	93	19	0	12	0	0
10	453	453	128	128	161	45.125	24	0	0	12
11	453	453	128	128	161	79	24	12	0	12
12	453	453	128	128	161	79	24	12	12	0
13	453	453	128	128	161	45.125	24	0	0	12
14	453	453	128	128	93	0	24	0	0	0
15	453	453	128	128	44	0	0	0	0	0
16	453	336.037	128	128	24	0	0	0	0	0
17	453	286.016	128	128	24	0	0	0	0	0
18	453	384.852	128	128	24	0	0	0	0	0
19	453	453	128	128	28.924	19	0	0	0	0
20	453	453	128	128	126	19	0	0	12	0
21	453	453	128	128	93	19	0	0	0	0
22	453	342	128	128	0	0	0	0	0	0
23	453	366	0	0	0	0	0	0	0	0
24	453	369.945	0	0	0	0	0	0	0	0

Table 9. V2G power and SOC in C3.

Hour	P_{V2G} $[MW]$	SOC [%]	Hour	P_{V2G} $[MW]$	SOC [%]
1	-25.225	52.3	13	-12.021	49.2
2	-25.185	54.7	14	14	47.9
3	24	52.5	15	-13	49.1
4	6	52.1	16	-24.857	51.4
5	61	46.2	17	-24.936	54
6	-24.980	48.6	18	-24.739	56.2

7	-24.873	50.7	19	-18.835	57.9
8	-11	51.8	20	72	51
9	18	49.8	21	19	50.1
10	-12.137	51.7	22	39	45.8
11	-6	52.7	23	-19	47.5
12	42	48.1	24	-24.947	49.8

Table 10. Programming results of 10-unit network in presence of V2G (C4).

Hour	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
1	301.881	301.881	0	0	0	79	86	0	0	0
2	301.881	301.881	0	0	0	79	86	0	0	0
3	301.881	301.881	0	0	163	79	86	0	0	0
4	301.881	301.881	129	0	163	79	86	0	0	0
5	301.881	301.881	129	0	163	79	86	0	0	0
6	301.881	301.881	129	0	163	79	86	0	0	0
7	301.881	301.881	129	0	163	79	86	0	0	0
8	301.881	301.881	129	0	163	79	86	56	0	0
9	301.881	301.881	129	0	163	79	86	0	56	56
10	301.881	301.881	129	129	163	79	86	56	56	56
11	301.881	301.881	129	129	163	79	86	56	56	56
12	301.881	301.881	129	129	163	79	86	56	56	56
13	301.881	301.881	129	129	163	79	86	56	56	56
14	302.498	302.498	129	129	163	79	86	0	56	56
15	300.024	300.024	129	129	163	79	86	56	56	56
16	300.025	300.025	129	129	163	79	86	0	0	0
17	300.025	300.025	129	129	163	79	86	0	0	0
18	300.025	300.025	129	129	163	79	86	0	0	0
19	300.024	300.024	129	129	163	79	86	56	0	0
20	300.025	300.025	129	129	163	79	86	56	0	0
21	300.025	300.025	129	0	163	79	86	56	0	0
22	300.024	300.024	129	0	163	79	86	56	0	0
23	300.025	300.025	0	0	0	79	86	0	0	0
24	300.024	300.024	0	0	0	79	86	0	0	0

According to a yearly mean traveled distance by car (around 12000 miles) and the mean emitted pollution of a car (around 1.2 lb/mile), the emitted pollution of a car is predicted at 14400 lb (12000*1.2) by Equation (12). So, the total emission of 5000 considered cars is around 720,000,000lb (equivalent to 326678.766 tones) in one year. Therefore, the entire emissions are obtainable via the sum of emitted pollution of thermal units and stated vehicles.

Table 11. V2G power and SOC of C4.

Hour	P_{V2G} $[MW]$	SOC [%]	Hour	P_{V2G} $[MW]$	SOC [%]
1	-70.137	56.4	13	43.364	19.9
2	-20.134	58.5	14	0	19.9
3	-81.647	65.9	15	-150.657	34.3
4	-111.483	76.5	16	-135.657	46.8
5	-61.482	82.5	17	-185.657	64.6
6	38.364	78.6	18	-85.657	72.6
7	88.364	70.3	19	-40.657	76.5
8	83.364	62.5	20	159.443	61.5
9	128.364	50.6	21	59.443	55.9
10	43.364	46.3	22	-10.657	56.9

11	93.364	37.5	23	36.443	53.3
12	143.390	23.9	24	36.443	49.9

Table 12. Comparison of operating expenditure for each case.

Case	Operating expenditure in $
C3	559530.047
C4	672099.154
C5	567399.048

Table 13. Comparison of operating expenditure for each case.

Cases		Emissions (ton)
C3	Thermal units	26562.783
	Vehicles	894.965
	Total	27457.748
C4	Thermal units	15702.586
	Vehicles	894.965
	Total	16597.551
C5	Thermal units	22156.827
	Vehicles	894.965
	Total	23051.516

In the third case, the operating expenses and emitted pollution are optimized simultaneously with equal weights. The Pareto diagram of the third case is captured in Fig. 1, where the optimum values are achieved by optimization with various weights to decrease the emissions and operating expenses. The selection of one point among these optimum points is based on the importance of considered variables. Here, weight coefficients for both variables are considered to be equal. Also, the spinning reserves of various cases are depicted in Fig. 2. According to this figure, spinning reserve values of all cases are higher compared to the basic values. So, it can be inferred that the durability of the system is enhanced.

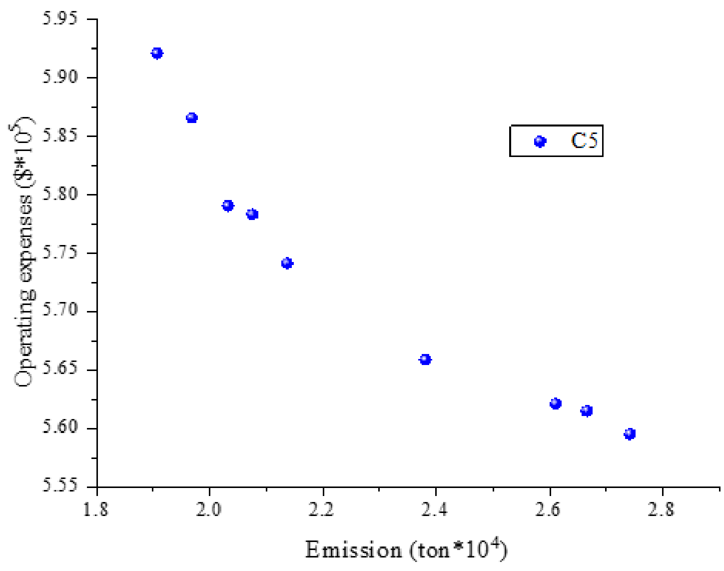

Fig. 1. Pareto chart of C5.

4. Conclusion

Present work solved the UC problem for a case study containing EVs to depict expenditure and emission decrements. The obtained results of this paper demonstrated considerable potential for investment return for production units by utilization of V2G in the network. We considered short-term programming in the IEEE 10-unit network in the presence of V2G technology to evaluate the proposed method. In this regard, the MINLP approach was proposed to solve the UC problem under different limitations, including production constraints, minimum up/down-time, ramp rate limitations, and start-up expenditure. The obtained results demonstrated that the suggested approach could reduce the expenses and the amount of emitted pollution. Also, the proposed method has high efficiency and could enhance the feasible answers considerably. Moreover, the employed MINLP method with the 564267.356 \$ operating cost without the V2G consideration represents the lowest operating expenses among the studied optimization methods. Comparing the considered optimization scenario reveals that the thermal units with V2G by considering the minimizing the operating cost scenario (C3) represents the best performance of about 5.85×10^5 \$ operating expenses and 2.6×10^4 ton emission.

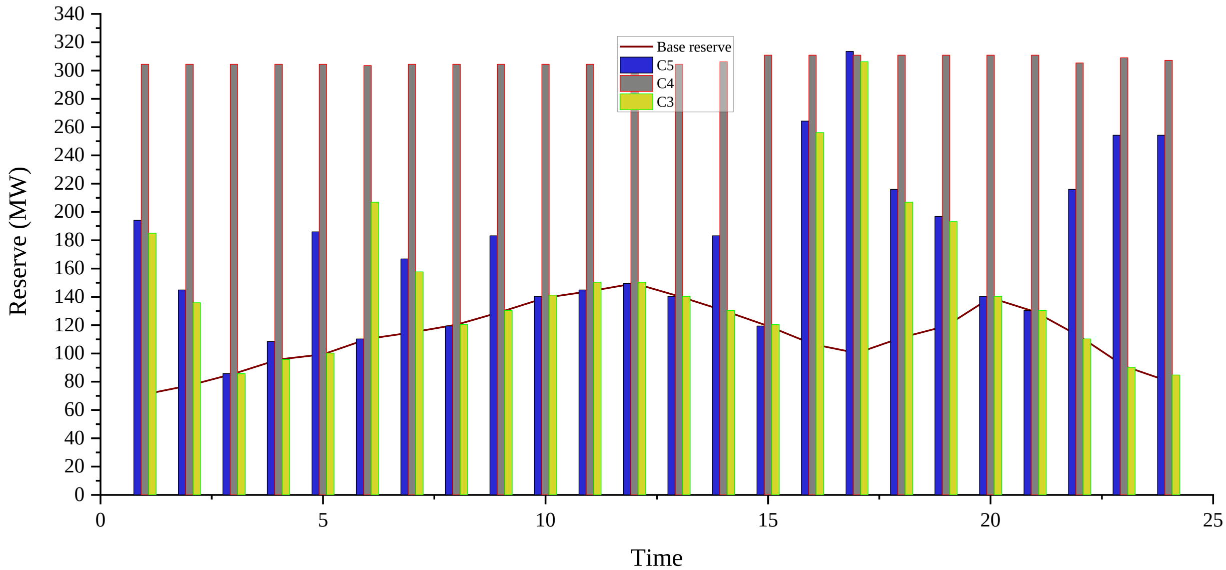

Fig. 2. Comparison of spinning reserve for various cases.

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