Hourly scheduling of thermal units utilizing an innovative hybrid approach

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ABSTRACT

The producing unit must be turned on at a time that meets the power system network's needs. It also determines the order of unit shutdowns based on cost. Unit commitment includes computation and turning units on and off. Committed units are planned to join the power system network. The combinatorial character of unit commitment makes it a crucial research issue and optimization job in contemporary power system. In order to effectively use the available resources and equalize the load demand on an hourly basis, unit commitment might be used. In order to solve an optimization issue involving unit commitment, this work introduces a new hybrid approach that combines a whale optimization algorithm (WOA) with a self-organizing migration algorithm (SOMA). An important part of any migration loop is the WOA technique, which is used to evaluate the optimum strength population from the populations that are created stochastically. The suggested hybrid approach is evaluated using two test systems. Before moving on to the IEEE 39 bus system, a four-unit system is implemented. The efficiency of the suggested hybrid WAOSOMA is addressed by comparing the generated simulation results with approaches found in the literature.

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1. INTRODUCTION

In modern society, electrical energy is associated with all walks of life. Thermal units are one of the sources for the generation of electrical energy. Keeping away from misdirect fuel consumption necessitates effective utilization for the generation of power through the thermal units. This intention leads to an effective goal of minimizing fuel consumption as a consequence the objective of reducing the total cost and meeting the system constraints has become a great task for many researchers. Running all the thermal units for a specified load demand leads to an expensive.

To minimize cost, the management of active power generation among the thermal units needs more attention. Planning and scheduling of thermal units result in optimization problems which are commonly termed unit commitment (UC) in power systems [1]. Evaluation of shutdown and startup schedule of power generating unit is incorporated in unit commitment. UC is associated with two recommendations namely economic dispatch and unit scheduling. The prediction of on/off generating units is represented by unit scheduling and the dispatching of generation among the thermal units is evaluated by economic dispatch [2]. UC optimization problem is a non-convex, non-linear and mixed integer combinatorial optimization problem [3].

UC finds the status of power units in meeting the load demand. As the load varies feasible combinations generating units are to be evaluated for achieving the optimal solution for the UC optimization problem. The main intent of solving the UC problem is to assess the optimal solution of cost which is consolidated with many constraints. The objective cost function is indicated in a quadratic form which is convex [4]. With the addition of constraints, the objective function will be refashioned into non-convex nature. Some of the constraints are spinning reserve, ramp rate limits, crew constraints, and power capability constraints [5].

Many techniques applied to resolve the problem of UC relating to depreciation of cost. Dynamic programming [6] which requires more computational time for achieving an optimal solution. The priority list method [7] requires less time but generates local optimal solutions randomly. The commonly used method is the Lagrange relaxation [8] method but suffers from the quality of the solution and convergence; the above methods are concerned with conventional methods. As the complexity of the UC problem increases due to nonlinearity traditional methods cannot be applied.

To handle complex nonlinear optimization problems meta-heuristic techniques are adopted like particle swarm optimization [9], genetic algorithm [10], ant colony optimization [11], simulated annealing [12], bacterial foraging [13], and evolutionary programming [4]. Meta-heuristic methods provide better optimal solutions but suffer based on the dimensionality; this drawback can be compensated using hybrid methods. The combination of two or more algorithms is termed as hybrid technique, such as Lagrange relaxation with a genetic algorithm [14], genetic-based artificial neural network [15], simulated annealing genetic algorithm [16], non-dominated sorting genetic algorithm-II in combination with population variant differential evolution algorithm [17]. In order to lessen the negative effects on the environment, save money, and ensure reliable supply from thermal producing systems, this study presents a two-stage multi-objective unit commitment model for the next day [18]-[23]. In this work, by applying genetic algorithms (GA), a short-term thermal unit commitment issue was addressed, and an inexpensive producing unit schedule was constructed. Taking into consideration the negative consequences of emissions owing to the usage of fossil fuels, emission costs were included to the goal function coupled with fuel and start-up costs [24]-[27]. The methodologies used in the literature to address the UC problem have evolved from conventional optimization techniques to heuristic and hybrid approaches. Each approach exhibits distinct strengths and limitations that impact the validity, scalability, and practical application of the solutions. Everyone has to know the correctness and speed of the following mathematical programming approaches for the hierarchical unit commitment (HUC) problem: Linearizing the hydropower model yields a mixed-integer linear programming (MILP) approach, Lagrangian relaxation decomposes the HUC model, and the MINLP solution solves large-scale, non-concavity issues [28]-[31].

In this paper, a novel hybrid WOA-SOMA is applied, which the combination of a whale optimization algorithm and self is organizing migrating algorithm. The proposed technique is implemented on two test systems and simulations are compared with the literature methods. The paper is organized as follows: Section 2 deals with mathematical formulation concern optimization problem of UC. Section 3 represents the method to resolve the UC problem. Section 4 discusses the simulation outcomes and finally, section 5 presents the conclusion.

2. MATHEMATICAL FORMULATION

The main objective function is scheduling of generating units for minimization of fuel cost maintaining all the constraints i.e. equality and inequality constraints. The minimization of the cost function is presented in (1).

$$min \sum_{o=1}^{M} \sum_{t=1}^{T} F_u\big(P_u(t)\big)U_u(t) + SUC_u\big(1 - U_u(t-1)\big)U_u(t) \quad (1)$$

The above objective function comprises the cost function, startup cost of the power units. $F_u\big(P_u(t)\big)$ is the cost function of u^{th} thermal unit with real power generation at 't' hour. $U_u(t)$ indicates the on/off state of the u^{th} generating unit at 't' hour. SUC_u is the start-up cost of the u^{th} thermal unit. M is the total number of thermal units and T is the time period. The cost function is formulated in quadratic form which is represented in (2).

$$F_u\big(P_u(t)\big) = a_u + b_u P_u(t) + c_u P_u^2(t) \quad (2)$$

Where a_u, b_u, c_u are the cost coefficients of u^{th} generating unit. $P_u(t)$ represents the active power production of u^{th} unit at 't' hour. The startup cost is defined as (3) and (4).

$$SUC = \begin{cases} HSC(t), & if\ T_{u,down} \leq T_{u,off} \leq H_{u,off} \\ CSC(t), & if\ T_{u.off} > H_{u,off} \end{cases} \quad (3)$$

$$H_{u,off} = T_{u,down} + T_{u,cold} \quad (4)$$

Where HSC(t), CSC(t) is the hot start cost, cold start cost at hour 't'. $T_{u,down}$ is the minimum downtime of unit 'u'. $T_{u,cold}$ is the cold start time of unit 'u'. Constraints are subjected to cost function.

2.1. Constraints

2.1.1. Power balance

The real power that is generated from thermal units must equate to the load demand over a period of time. As the load varies the generation of real power has to be varied. The summation of real power generated by all thermal units must be equalizing to the total load demand of that period. This constraint is termed an equality constraint.

$$\sum_{u=1}^{M} P_u(t) * U_u(t) = D(t) \quad (5)$$

2.1.2. Spinning reserve (SR)

SR is the reserve forecasted load demand to maintain desired reliability. The spinning reserve constraints are represented as (6).

$$\sum_{u=1}^{M} P_u(t). U_u(t) \geq D(t) + SR(t) \quad (6)$$

D(t) indicates the load demand at time 't' hour.

2.1.3. Power limits

The real power generated from generating units has to keep within the limits. The limits are associated with minimum power generation limits and maximum generation limits. The generated real power has to exist between the minimum and maximum power limits.

$$P_u^{min} \leq P_u \leq P_u^{max} \quad (7)$$

Where P_u^{min}, P_u^{max} are the low and high power of 'uth' thermal unit. P_u is the real power generation of 'uth' thermal unit.

2.1.4. Minimum uptime limit

It is the minimum hours the thermal unit will on-line i.e. turned on position before the shut down. Here, $T_{u,up}$ is the minimum uptime of thermal unit 'u'. $T_{u,on}$ is the on-time of thermal unit.

$$T_{u,on} \geq T_{u,up} \quad (8)$$

2.1.5. Minimum downtime limit

It is the minimum hours the thermal unit will be in off-line i.e. shutdown position before the commencement of turned on. Here, $T_{u,down}$ is the minimum downtime of thermal unit 'u'. $T_{u,off}$ is the off time of thermal unit.

$$T_{u,off} \geq T_{u,down} \quad (9)$$

3. PROPOSED TECHNIQUE

3.1. Whale optimization algorithm (WOA)

This method is concerned with a meta-heuristic algorithm that resembles the biological behavior of mammals. WOA is proposed by Lewis and Mirjalili. Two strategies are applied to that show the hunting action of humpback whales. The former is related to the bubble net attacking method and the latter one concerned to search for prey. Two approaches are mapped out in the bubble net attacking method namely encircling prey and spiral updating position. Humpback whales first predict the location of the prey and make encirclement. In WOA [18], during the encircling of prey, the initial candidate solution is considered nearer to the optimal solution. Other agents change their positions during searching to reach the best position. The mathematical equations are presented to represent the following actions.

$$\vec{Y}(t+1) = \vec{Y}(\mathrm{t}) - \vec{A}.\vec{D} \tag{10}$$

$$\vec{D} = \left|\vec{C}.\vec{Y}(\mathrm{t}) - \vec{Y}(t)\right| \tag{11}$$

$\dot{\vec{Y}}$(t) indicates the initial best position of iteration 't' and $\vec{Y}(t+1)$ represents the current position and $\vec{D}$ presents the space between prey and whale, the symbol | | produces the absolute value. The vector coefficients are $\vec{A}$ and $\vec{C}$ whose values can be calculated using (12).

$$\vec{A} = 2.\vec{a}.\vec{r} + \vec{a} \tag{12}$$

$$\vec{C} = 2.\vec{r} \tag{13}$$

The value of $\vec{a}$ is reduced from a value of 2 to 0 during the iteration process and $\vec{r}$ is the random number between [0,1]. Based on the positions of whale and prey, the spiral equations are developed, which stimulate the helix shape movement of the whale.

$$\vec{D'} = \left|\vec{Y}(\mathrm{t}) - \vec{Y}(t)\right| \tag{14}$$

$$\vec{Y}(t+1) = e^{bk}.\cos(2\pi\mathrm{k}).\vec{D'} + \vec{Y}(\mathrm{t}) \tag{15}$$

$\vec{D'}$ is the gap between prey and whale and k is the random number over the range of [-1,1]. During the process of the algorithm, a probability of 50 percent is selected for choosing either spiral path movement or shrinking circle path by the humpback whale.

$$\vec{Y}(t+1) = \begin{cases} \vec{Y} - \vec{A}.\vec{D}, & if\ p < 0.5 \\ e^{bk}.\cos(2\pi\mathrm{k}).\vec{D'} + \vec{Y}(\mathrm{t}) & if\ p < 0.5 \end{cases} \tag{16}$$

p indicates the random number between [0,1].

Random search prey is implemented by the humpback whale because of the unknown optimal design in the bubble net method. Based on the reference whale, the search agent will move away from the reference. The search agent position will be updated according to a randomly chosen in return instead of a better search agent.

$$\vec{D} = \left|\vec{C}.\overrightarrow{Yrand} - \vec{Y}\right|$$
$$\vec{Y}(t+1) = \overrightarrow{Yrand} - \vec{A}.\vec{D} \tag{17}$$

WOA provide high convergence rate and prevents the local optima during the iteration process.

3.2. Self-organizing migrating algorithm (SOMA)

SOMA [19] is a metaheuristic algorithm inspired by the biological technique related to swarm intelligence. SOMA works on the population relating to the cooperation between the individuals which is termed migration in reaching the global optimal solution. In the initial stage, parameters are defined like population size, PRT, step, path length, iteration, and the population is generated randomly in the search space.

$$x_{p,i} = x_i^l + rand(0,1) * (x_i^h - x_i^l) \tag{18}$$

$x_{p,i}$ indicates the ith variable of pth population. x_i^l, x_i^h are the lower and upper power limits of ith variable. Each population has an m-dimensional vector of variables with power limit restrictions. The leader is chosen based on population strength projected by the cost function. Jumping until a route length is reached moves everyone toward the leader. Path length indicates leadership proximity. Each population leap determines the new strength value. PRT vector is generated by comparing a random integer to PRT before leaping a person.

$$PRTVector = \begin{cases} 1 & if\ rand < PRT \\ 0 & if\ rand > PRT \end{cases} \tag{19}$$

The migration loop is referred to as the iteration loop and is used for the stopping process. The migration of an individual towards the leader position in each migration loop is represented by (20).

$$x_{p,i}^{Ml+1} = x_{p,i\,start}^{Ml} + (x_{B,i}^{Ml} - x_{p,i\,start}^{Ml}) * s * PRTVector \quad (20)$$

Ml indicates the migration loop, s is the step, $x_{p,i}^{Ml+1}$ is a vector representing the new position of the p^{th} individual of i^{th} variable migrating to the leader position with step s until greater than path length PL. PL indicates the trajectory path. $x_{B,i}^{Ml}$ is the leader position of B^{th} individual of i^{th} variable in the migration loop Ml. The iteration is stopped when the migration loop reaches the maximum loop.

3.3. Hybrid method

The hybrid method is the composition of two or more techniques applied to achieve a global optimal solution. WOA and SOMA combination is implemented as a hybrid method. The procedure applied to solve the optimization problem is represented in steps:

- Consider initial parameters are like population size, PRT, step, path length, and maximum iteration.
- Before the commencement of the iteration process random population is generated and the fitness of each population is predicted.
- Based on the strength of the population the best leader is selected using the whale optimization technique.
- Encircling prey, mechanism of shrinking encircling, and spiral updating position are implemented using (10) to (17) in achieving better or leader solution.
- Generate the PRT vector using (19) and all individuals migrate in the migration loop towards the leader position with the updating of the new position until the maximum iteration is reached, finally the optimal value is predicted. Flowchart of hybrid WOA-SOMA is shown in Figure 1.

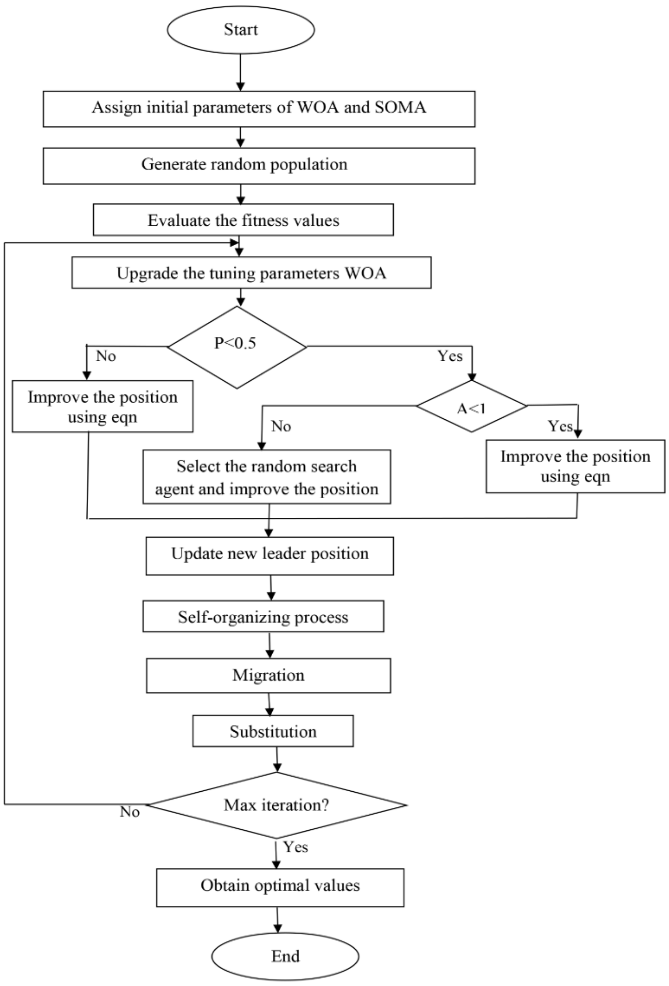

Figure 1. Flow chart of hybrid WOA-SOMA

The proposed hybrid method (WOA-SOMA) is an optimization strategy designed to solve the UC problem considering spinning reserve cost. In this context, each algorithmic parameter or concept maps to specific elements of the IEEE 39-Bus system as follows:

Hybrid method parameter	IEEE 39-bus system parameter
Agent position	Unit schedule (on/off), power level
Fitness function	Total cost (fuel + emission + reserve)
Population size	Number of candidate schedules
Migration loop in SOMA	Iterative refinement of generator states
Step size, path length	Degree of adjustment in power dispatch
Constraint handling	Min/max limits, spinning reserve, ramp rates
Problem dimension	Number of generators in the system

4. NUMERICAL SIMULATION

The suggested hybrid technique is used to two test systems: a four-unit system with eight load demands and an IEEE 39 bus system with ten thermal units. Case (i) Maximum iterations 50, population size 20, step value 0.3, step length 3.0. Table 1 displays maximum and minimum power restrictions, cost coefficients, uptime/downtime, cold start/hot start costs [20].

Different load demands for a four-unit system are given in Table 2. The on/off status of the power units is shown in Table 3. Thermal unit 3 is completely in off state and generating unit 4 will remain in off state except 3 hours. Dispatching of load demand among the thermal units and its corresponding cost values are shown in Table 4. The total cost obtained for a four-unit system is 73,732.660 ($). The obtained cost value is made in comparison with the existing literature methods which illustrate the better cost value. With the proposed hybrid WOA-SOMA the obtained cost value is less than compared with the harmony search algorithm, TLPSO, binary differential evolution, LR with PSO which is shown in Table 5.

Table 1. Data related to four generator system

P_{max} (MW)	P_{min} (MW)	a_u	b_u	c_u	HSC ($)	CSC ($)	MUT (h)	MDT (h)	CST (h)	Initial status(h)
300	75	684.74	16.83	0.0021	500	1100	5	4	5	8
250	60	585.62	16.95	0.0042	170	400	5	3	5	8
80	25	213	20.74	0.0018	150	350	4	2	4	-5
60	20	252	23.6	0.0034	0	0.02	1	1	0	-6

Table 2. Demand of four generator system on hour basis

Hours	1st	2nd	3rd	4th	5th	6th	7th	8th
Load (MW)	450	530	600	540	400	280	290	500

Table 3. On/off status of 4 unit system

Hour	P_1	P_2	P_3	P_4
1	1	1	0	0
2	1	1	0	0
3	1	1	0	1
4	1	1	0	0
5	1	1	0	0
6	1	1	0	0
7	1	1	0	0
8	1	1	0	0

Table 4. Load sharing using hybrid WOA-SOMA

Hour (h)	G_1 (MW)	G_2 (MW)	G_3 (MW)	G_4 (MW)	Cost ($)
450	300	150	0	0	9,145.36
530	300	230	0	0	10,629.04
600	300	250	0	50	12,448.86
540	300	240	0	0	10,818.28
400	276.19	123.81	0	0	8,241.78
280	196.19	83.81	0	0	6,103.14
290	202.857	87.143	0	0	6,279.82
500	300	200	0	0	10,066.36
					73,732.66

Table 5. Comparison of cost value with existing methods

Method	Overall cost ($)		
	Best	Average	Worst
Improved Lagrangian relaxation [21]	75,232	--	--
A. SMP [22]	74,812	74,877	75,166
Lagrangian relaxing and particle swarm optimization [21]	74,808	--	--
Binary differential evolution [23]	74,676	--	--
Two layer particle swarm optimization (TLPSO) [20]	74,476	74,500	74,675
Hybrid WOA - SOMA	73,732	74,090	76,265

Case (ii) in this case study, the constraint without spinning reserve and with spinning reserve is considered. The initial parameters are considered which are shown in Table 6 and the corresponding load demand for 10-unit thermal system [24] is given in Table 7. The scheduling of load dispatch with committed thermal units is shown in Table 8. The obtained total cost of all thermal units overload demand of thermal units is 5,64,196.4 ($). With the proposed hybrid technique, the obtained cost value is made in comparison with the existing method which is shown in Table 9. For different spinning reserve value, the cost values vary. As the spinning reserve increases the cost value also increases which can be observed in Table 10.

Table 6. Comparison of cost value with other existing methods

P^{max} (MW)	P^{min} (MW)	a_u	b_u	c_u	T^{on} (Hr)	T^{off} (Hr)	S^H ($)	S^C ($)	T^C (Hr)	Initial state
455	150	1000	16.19	0.00048	8	8	4500	9000	5	8
455	150	970	17.26	0.00031	8	8	5000	10000	5	8
130	20	700	16.6	0.002	5	5	550	1100	4	-5
130	20	680	16.5	0.00211	5	5	560	1120	4	-5
162	25	450	19.7	0.00398	6	6	900	1800	4	-6
80	20	370	22.2	0.00712	3	3	170	340	2	-3
85	25	480	27.74	0.00079	3	3	260	520	2	-3
55	10	660	25.9	0.00413	1	1	30	60	0	-1
55	10	665	27.2	0.00222	1	1	30	60	0	-1
55	10	670	27.79	0.00173	1	1	30	60	0	-1

Table 7. Load demand of the IEEE 39 bus system over 24 hours

Hour	Demand (MW)	Hour	Demand (MW)	Hour	Demand (MW)
1	700	9	1,300	17	1,000
2	750	10	1,400	18	1,100
3	850	11	1,450	19	1,200
4	950	12	1,500	20	1,400
5	1,000	13	1,400	21	1,300
6	1,100	14	1,300	22	1,100
7	1,150	15	1,200	23	900
8	1,200	16	1,050	24	800

Table 8. Scheduling of load of among 10 power units over 24 hours

P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	Cost ($)
455	245	0	0	0	0	0	0	0	0	13,683.13
455	295	0	0	0	0	0	0	0	0	14,554.5
455	265	130	0	0	0	0	0	0	0	16,923.29
455	340	130	0	25	0	0	0	0	0	19,176.85
455	390	130	0	25	0	0	0	0	0	20,051.16
455	360	130	130	25	0	0	0	0	0	22,387.04
455	410	130	130	25	0	0	0	0	0	23,261.98
455	455	130	130	30	0	0	0	0	0	24,820.34
455	455	130	130	85	20	25	0	0	0	27,251.06
455	455	130	130	162	33	25	0	10	0	30,075.86
455	455	130	130	162	73	25	10	0	10	31,926.21
455	455	130	130	162	80	25	43	10	10	33,890.16
455	455	130	130	162	33	25	0	10	0	30,075.86
455	455	130	130	95	0	25	10	0	0	27,556.79
455	455	130	130	30	0	0	0	0	0	24,820.34
455	310	130	130	25	0	0	0	0	0	21,513.66
455	260	130	130	25	0	0	0	0	0	20,641.82
455	350	130	130	25	0	0	10	0	0	23,131.86
455	455	130	130	30	0	0	0	0	0	24,820.34
455	455	130	130	162	33	25	0	10	0	30,075.86
455	455	130	130	85	20	25	0	0	0	27,251.06
455	340	130	130	0	20	25	0	0	0	23,084.56
										5,64,196.4

With the variation of load demand the on/off status of the thermal unit varies. At a maximum load of 1500 MW all the thermal units are in on state at 12th hour generating the cost value of 33,890.16 ($). At minimum load of 700 MW first and second thermal unit are on state and remaining thermal units are at off state and the associated cost value is 13,683.13 ($).

Table 9. Comparison of IEEE 39 bus system cost value

Method	Cost value ($)	Method	Cost value ($)
PSO-LR [25]	565,869	EP [29]	565,352
LRGA [26]	564,800	SPL [30]	564,950
DP [27]	565,825	BPSO [31]	565,804
ALR [28]	565,508	WAO-SOMA	564,196

Table 10. SR of IEEE 39 system

Spinning reserve	Cost ($)
5%	5,91,244.87
8%	6,17,496.02
10%	6,36,278.93

5. CONCLUSION

A novel hybrid WOA-SOMA is modeled for solving an optimization problem concerned to minimization of cost. To evaluate the potential of the hybrid method it is test on two test systems i.e. four unit system and IEEE 39 bus system with 10 thermal units. Equality and inequality constraints are considered in four unit system of optimization problem and an additional spinning reserve constraint was considered in IEEE 39 bus system. The obtained optimal value of cost using hybrid WOA and SOMA shows a better value compared with other existing methods. In hybrid WOA-SOMA algorithm, the total cost obtained for a four-unit system is 73,732.660 ($) and 39 bus system with 10 thermal units 564,196 ($). The emission cost is 172.19 ($). One possible future endeavor is increasing the number of units in a 24-hour period. This work considers constraints such as power balance, spinning reserve, minimum up and down limits, generation unit ramp limits, and generating capacity limits. However, future consideration of security constraints, such as transmission parameters and contingency analysis, may lead to additional non-linearities.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
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R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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