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RESEARCH

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A meliorated Harris Hawks optimizer for combinatorial unit commitment problem with photovoltaic applications

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Abstract

Conventional unit commitment problem (UCP) consists of thermal generating units and its participation schedule, which is a stimulating and significant responsibility of assigning produced electricity among the committed generating units matter to frequent limitations over a scheduled period view to achieve the least price of power generation. However, modern power system consists of various integrated power generating units including nuclear, thermal, hydro, solar and wind. The scheduling of these generating units in optimal condition is a tedious task and involves lot of uncertainty constraints due to time carrying weather conditions. This difficulties come to be too difficult by growing the scope of electrical power sector day by day, so that UCP has connection with problem in the field of optimization, it has both continuous and binary variables which is the furthermost exciting problem that needs to be solved. In the proposed research, a newly created optimizer, i.e., Harris Hawks optimizer (HHO), has been hybridized with sine–cosine algorithm (SCA) using memetic algorithm approach and named as meliorated Harris Hawks optimizer and it is applied to solve the photovoltaic constrained UCP of electric power system. In this research paper, sine–cosine Algorithm is used for provision of power generation (generating units which contribute in electric power generation for upload) and economic load dispatch (ELD) is completed by Harris Hawks optimizer. The feasibility and efficacy of operation of the hybrid algorithm are verified for small, medium power systems and large system considering renewable energy sources in summer and winter, and the percentage of cost saving for power generation is found. The results for 4 generating units, 5 generating units, 6 generating units, 7 generating units, 10 generating units, 19 generating units, 20 generating units, 40 generating units and 60 generating units are evaluated. The 10 generating units are evaluated with 5% and 10% spinning reserve. The efficacy of the offered optimizer has been verified for several standard benchmark problem including unit commitment problem, and it has been observed that the suggested optimizer is too effective to solve continuous, discrete and nonlinear optimization problems.

Keywords: Meta-heuristics, Harris Hawks optimizer, Unit commitment problem (UCP), Profit-based UCP, Economic load dispatch (ELD)

Introduction

Machine learning and artificial intelligence and so many problems are related to real world which have continuous and discrete behavior and constrained and unconstrained in nature. For this kind of attributes, there are a few challenges to handle a few sorts of issues utilizing traditional methodologies with scientific techniques [1]. A few sorts of research have tried that these all strategies are insufficient viable or effective to bargain numerous kinds of non-continuous problem and non-differentiable problem and furthermore in such huge numbers of real-world problem. In this way, meta-heuristic algorithm is considered and it is used to handle such a significant number of problems which are generally basic in nature and easily executed. Nowadays, the recent developed optimizer is Harris Hawks optimizer [HHO] [2]. Original version of Harris Hawks optimizer (HHO) had highlights that can in any case be improved as it might insight convergence problems or may effectively get caught in neighborhood optima [3]. Many variants had been developed which are discussed in Table 1 (a), which are used to improve or upgrade the existing HHO, so that the efficiency of the optimization techniques will be enhanced [4]. The procedure of optimization technique is proceeded till this can fulfill the most extreme iteration. In the present days, developing mindfulness and enthusiasm for effective, economical and fruitful utilization of such kinds of meta-heuristic calculation is under current examination. Modified version of existing algorithm was also upgraded by mutation to solve the real-world optimization problem also [5]. Nonetheless, after no free lunch theorem (NFL) [6], wide range for optimization dependent through enhancement methods prescribed and showed normal equal execution on the off chance that it is applied to every likely sort of errands dependent on optimization technique [7].

In the recent year, the electrical power sector is classified as huge proportions, vastly interconnected and highly nonlinear as dimension of electric power system is rising continuously due to huge electrical power demand in all the essential segment like commercial, agriculture, residential and industrial region. On electricity grid, the influence of overloading occurs due to rising the propensities in electrical load demand, privatization and deregulation taking place on electrical grids. For this condition, it needs progress of electric grid as the same step, as the rise in electric load demand and efficient power generation scheduling and commitment has the ability to regulate the time varying electrical load demand which is run for utilization of available grid [8]. Nowadays, recent power sector has some various sources of electrical power locations containing hydro-, thermal and nuclear power generation system; during a whole day, the electric power demand fluctuates with various peak values [9]. Thus, it is essential to determine that power generating units should be turned on, when necessary in power system network and the preparation or order in which the generating unit should kept in turn off condition is by considering the efficiency of cost for turn on and shut down for the respective power generating units. The whole procedure of constructing these assessments is known as unit commitment (UC) [10].

The main novelty of the proposed research work includes the hybrid variant of Harris Hawks optimizer, i.e., hybrid Harris Hawks–Sine–Cosine algorithm (hHHO-SCA) has been developed. The exploration phase of the existing Harris Hawks optimizer has been improved. A recently invented hybridized optimizer using memetic algorithm approach is used to solve unit commitment problem of power system. This paper offers

Table 1 (a) Assessment of several heuristics and meta-heuristics search optimization techniques. (b) Literature survey of unit commitment. (c) Literature survey of wind power uncertainty. (d) Literature survey of solar uncertainty

Reference Nos.	Year of publication	Main findings or conclusion relevant to proposed research work	Algorithm name
(a)			
[77]	2020	mGWO optimizer was designed to get suitable balance between exploration and exploitation phases. It was tested on IEEE CEC 2017 and IEEE CEC 2014 standard functions. And it is also verified on engineering design problem in real-world and multilevel thresholding problems	Memory-based Gray Wolf Optimizer [mGWO]
[1]	2020	MG-SCA optimizer was implemented to solve optimization problems. It was verified on standard IEEE CEC 2014 benchmark functions to check the efficiency of this algorithm	Memory-Guided Sine–Cosine Algorithm [MG-SCA]
[78]	2020	Orthogonally designed Adapted Grasshopper Optimization was designed to solve optimization problem. It was tested on 30 IEEE CEC2017 benchmarks to find effectiveness of the meta-heuristic algorithm	Orthogonally designed Adapted Grasshopper Optimization [OAGO]
[79]	2020	A smart meta-heuristic algorithm was implemented to solve engineering design problems and it was tested on 15 benchmark on CEC 2015 by Wilcoxon's test and statistical analysis.	Smart Flower Optimization Algorithm [SFOA]
[80]	2020	Hybrid PSO and GWO algorithm was designed to solve global optimization problem	Hybrid Crossover-Oriented PSO and GWO [HC-PSOGWO]
[81]	2020	Imperialist Competitive Learner-Based Optimization was implemented to solve engineering design problem	Imperialist Competitive Learner-Based Optimization [ICLBO]
[82]	2020	Barnacles Mating Optimizer was designed to solve the problem related to engineering optimization	Barnacles Mating Optimizer [BMO]
[83]	2020	Equilibrium Optimizer was created to solve optimization problems and it was test on 58 unimodal, multimodal, and composition functions and three engineering problems	Equilibrium Optimizer [EO]
[84]	2020	Improved Fitness-Dependent Optimizer Algorithm was designed and tested on CEC2019 to validate its feasibility to real-world problem	Improved Fitness-Dependent Optimizer Algorithm [IFDOA]
[85]	2020	Spotted Hyena Optimizer based on swarm based optimization in the area of meta-heuristic research to improve the exploratory search	Spotted Hyena Optimizer [SHO]
[86]	2020	Improved Whale Optimization Algorithm was designed with using the mechanism of joint search to solve the global optimization problems	Improved Whale Optimization Algorithm [IWOA]

Table 1 (continued)

Reference Nos.	Year of publication	Main findings or conclusion relevant to proposed research work	Algorithm name
[87]	2020	Multi-Strategy Enhanced Sine–Cosine Algorithm was calculated to engineering design problem in real world and improve the global optimization	MSESCA
[88]	2020	Refined Selfish Herd Optimizer was designed to solve global optimization problem	Refined Selfish Herd Optimizer [RSHO]
[89]	2020	Hybrid Harris Hawks optimizer combined with SCA was implemented to get solutions of numerical and engineering optimization problems	Intensify Harris Hawks Optimizer [IHHO]
[75]	2019	GLF–GWO was implemented with leadership-based quality to solve the global optimization problem. The leadership quality was improved by Levy flight (LF) searching techniques. It was tested on standard benchmark functions including IEEE CEC 2006 and IEEE CEC 2014.	leadership quality was improved by Levy flight (LF) search and Gray Wolf Optimizer [GLF–GWO]
[76]	2019	GWO optimizer had been modified with DE to avoid trapped in local optima and solve optimization problems. It was verified on 23 standard benchmarks	Greedy differential evolution—Gray Wolf Optimizer [gDE-GWO]
[90]	2019	A novel meta-heuristic optimizer, Artificial Ecosystem-Based Optimization was implemented to resolve the problem related with unidentified search space	Artificial Ecosystem-Based Optimization [AEBO]
[91]	2019	Incremental Gray Wolf Optimizer and Expanded Gray Wolf Optimizer were the improved version of GWO which used to get solution for the global optimization problem	Incremental Gray Wolf Optimizer and Expanded Gray Wolf Optimizer [I-GWO and Ex-GWO]
[92]	2019	Life Choice-Based Optimizer was considered to resolve optimization problems and it was tested on six CEC-2005 functions	life Choice-Based Optimizer [LCBO]
[93]	2019	Multi-objective technique was invented to get solutions of the problem related to truss method	Multi-objective Heat Transfer Search Algorithm [MHTSA]
[94]	2019	Simplified Salp Swarm Algorithm was created to resolve the optimization problem and it was verified on 23 common benchmark to check the feasibility of this technique	Simplified Salp Swarm Algorithm [SSSA]
[95]	2019	New method was designed and tested on 28 numbers of standard benchmark problem to solve global Optimization problems	Self-adaptive differential artificial bee colony algorithm [SA-DABC]

Table 1 (continued)

Reference Nos.	Year of publication	Main findings or conclusion relevant to proposed research work	Algorithm name
[73]	2018	Modified SCA technique was developed by opposition-based learning and added the self-adaptive factor to solve the global optimization problem in real world. It was verified on 23 standard benchmarks and IEEE CEC 2014 standard test functions	Modified Sine–Cosine Algorithm [m-SCA]
[74]	2018	SCA algorithm was improved with crossover scheme to develop the capability of exploitation to real-world solve optimization problem. It was tested on standard IEEE CEC 2014 and IEEE CEC 2017 test functions	Improved Sine–Cosine Algorithm [ISCA]

References	Year of publication	Indexing of journal (Scopus/SCI index etc.)	Main findings or conclusion relevant to proposed research work	Remarks
(b)				
[96]	2019	Science Citation Index expanded	Comparative presentations on some benchmark instances were analyzed	Optimization of UCP were solved including wrap-around scheduling and ramp-rate constraint
[97]	2019	Science Citation Index	IEEE-9 bus system was applied to experiment the capability of technique considering different objectives	Resolution of optimum electric power flow based on mutual reactive and active cost by particle swarm optimization [PSO]
[98]	2019	Science Citation Index	4th, 5th, 6th, 7th, 10th, 19th, 20th and 40th gen. units test systems were used to solve UCP optimization problem.	An optimum forceful generation scheduling by sine cosine algorithm [SCA]
[99]	2019	Science Citation Index	Framework: Quantum Inspired Binary Gray Wolf Optimizer was designed to solve UCP	FQIBGWO
[100]	2019	Scopus	An Improved DA-PSO Optimization used to solve UCP and the 5th, 6th, 10th, and 26th gen. units test systems were applied to check the efficacy of the suggested research work	Dragonfly algorithm was joined with particle swarm Optimization [DA-PSO]
[101]	2018	Science Citation Index	Hybrid GWO combined with RES technique was designed to solve UCP and it had been tested on standard 23 benchmark problems and 7th, 10th, 19th, 20th and 40th systems taken to validate the effectiveness of the planned method	Hybrid Gray wolf optimizer combined with random exploratory search technique [hGWO-RES]

Table 1 (continued)

References	Year of publication	Indexing of journal (Scopus/SCI index etc.)	Main findings or conclusion relevant to proposed research work	Remarks
[102]	2017	Scopus	Gravitational Search Algorithm was designed to solve UCP and the viability of the suggested method was tested on tested on 10-generating unit system later extended up to 40-generating unit test system with 24 -h time horizon	Gravitational Search Algorithm [GSA]
[103]	2016	Scopus	SFLA was created for short duration optimum schedule of thermal power generation units including prohibited Operational zone (poz) constraints and emission limitation	Shuffled Frog Leaping Algorithm [SFLA]
[104]	2016	Scopus	4-, 10-, 20-, 40-, 80-, 100-unit systems were applied to check effectiveness of research work	Advanced 3-stage method to solve the UCP
[105]	2016	Scopus	10 generating units considering 24-h test system was used to check the effectiveness of the research work	Fireworks Algorithm [FA]
[106]	2016	Science Citation Index	The suggested memetic algorithm was verified for standard IEEE benchmark containing of 4th, 10th, 20th and 40th power generating unit	Harmony Search [HS]
[107]	2016	Scopus	WIC-PSO was designed to solve UCP and efficacy and viability of the suggested technique were verified on system considering and not including additional pumped storage plant.	Weighted-Improved Crazy Particle Swarm Optimization [WIC-PSO]
[108]	2015	Scopus	PSO was useful to reduce total operating price and exploit total benefit. Here 12 scenarios had been measured in the existence of battery banks and without them in 2 operating modes: grid-connected mode and stand-alone mode	Here-and-Now [HN] approach in battery banks (BBs)

Table 1 (continued)

References	Year of publication	Indexing of journal (Scopus/SCI index etc.)	Main findings or conclusion relevant to proposed research work	Remarks
[106]	2015	Science Citation Index	Hybrid HS–random search technique was invented to resolve single-area UCP and the suggested method had been verified on standard IEEE systems containing of 4th, 10th, 20th and 40th units to check the efficacy of the method.	Hybrid Harmony Search–Random Search algorithm [hHS-RES]
[109]	2015	Science Citation Index expanded	Demand Response Based approach including ramp rate constraints was designed to solve large scale UCP	Demand response [DR]
[110]	2015	Science Citation Index	A hybrid DE–RS optimization technique was designed to solve unit commitment problem and it was tested on IEEE benchmark systems consisting of 4 unit, 10 unit, 20th and 40th test systems	hybrid DE–Random Search [hDE-RS]
[111]	2015	Science Citation Index	A new hybrid PSO–GWO method was implemented to solve UCP and it was tested on 30-bus system, 14-bus system and 10th power generation model	hybrid PSO–GWO
[112]	2015	Science Citation Index expanded	56 MW 1 gas turbine and 1 steam turbine, 2L 2 gas turbines, 530 MW and 1 steam turbine and 530 MW, 1 steam turbine and 3LR—2 gas turbines were considered to examination the viability of the research	The proposed research work analyzed the significance of certain design including construction.
[113]	2015	Science Citation Index	10th power gen. unit was considered to checked the efficacy of the research	Distributed power systems (DPSs) with IRESs
[114]	2015	Scopus	3rd and 8th gen. units were considered to check the efficacy of the research as taken for the wind power predicting errors.	Fuzzy Chance-Constrained Program [FCCP]
[115]	2015	Science Citation Index expanded	10, 20 ,30, 40, 60, 80,100 unit system were applied to check effectiveness of research work	Binary Artificial Bee Colony Algorithm [BABCA]

Table 1 (continued)

References	Year of publication	Indexing of journal (Scopus/SCI index etc.)	Main findings or conclusion relevant to proposed research work	Remarks
[116]	2014	Scopus	Improved Shuffled Frog Leaping procedure was considered to solve UCP considering a constrained including multi objective combined emission	Improved Shuffled Frog Leaping Algorithm [ISFLA]
[117]	2014	Science Citation Index	To authenticate the viability and efficacy of the submitted method (BGSA) to solve UCP, the suggested BGSA was verified on dissimilar systems size created on basic systems of 10th gen. unit, 20th, 40th, 60th, 80th and 100th gen. unit	BGSA with the Lambda-Iteration technique was applied and the data regarding system load and wind power prediction were collected
[117]	2014	Science Citation Index	Model of thermal UCP with wind power addition was recognized and constrain programming was useful to mimic the special belongings of wind power variation.	Founds TUCPW model
[118]	2014	Science Citation Index expanded	Validate the ability of used the algorithm to solve the UCP, it was applied on a 10-, 20-, 40-, 60-, 80- and 100 unit systems	Dynamic technique for probabilistic charge of power generator inaccessibility was planned
[119]	2013	Science Citation Index	Cuckoo Search Algorithm was implemented to solve UCP and model power system including 10 power plant with generating units had been used in this study	Cuckoo Search Algorithm [CSA]
[120]	2013	Science Citation Index	Classical model of the Dynamic Combined Economic–environmental was implemented for optimum power generation scheduling in the electricity market with consideration of availability of power generation units	Multi-objective-based Genetic Algorithm
[121]	2012	Scopus	10,20,40,60,80,100 unit test system were used	Variable Neighborhood Search [VNS]

Table 1 (continued)

References	Year of publication	Indexing of journal (Scopus/SCI index etc.)	Main findings or conclusion relevant to proposed research work	Remarks
[122]	2012	Science Citation Index	Shuffled Frog Leaping Algorithm was designed to solve UCP. To validate the enactment of the suggested method was useful for standard IEEE 14-, 30-, 56-, 118-slandered bus and 10th gen. test unit, 20th gen. test unit for 1-day forecast period	Shuffled Frog Leaping Algorithm [SFL]
(c)				
[123]	2018	Scopus	Multi-objective GA method was invented to find optimal solution for UCP including lowest emission.	Multi-objective GA was used and data regarding load demand considering renewable energy schedule are collected from the proposed research work.
[124]	2018	Science Citation Index	FCUCP technique was designed to solve UCP considering wind power generation including ramp limit	Frequency-Constrained Unit Commitment Problem [FCUCP] was used to solve UCP and Forecast wind power data are collected for day ahead
[125]	2018	Science Citation Index expanded	ABC-CSA for cost assessment considering wind power were implemented and the effectiveness had been tested in IEEE 30 buses of six generator test systems with 10-generating unit test systems	Artificial Bee Colony and Cuckoo Search Algorithm [ABC-CSA] were applied and cost estimated data were collected
[126]	2016	Scopus	MTLBO technique was invented to solve UCP by using standard IEEE ten-unit test system and 26-unit reliability test system	Modified Teaching–Learning-Based Optimization algorithm [MTLBO]
[127]	2016	Science Citation Index expanded	MDE method was useful to solve unit commitment problematic considering impact of plug-in EVs	Modified Differential Evolution [MDE]
[128]	2016	Science Citation Index	BASA technique was implemented to solve unit commitment problem including renewable energy sources and hydro electric energy pump storage	BASA was used and data of forecasted wind power and photovoltaic power has been collected from the proposed research work
[129]	2016	Scopus	IEEE 118-bus test system with 54 power generating units used to validate the proposed method	Artificial Computational Intelligence [ACI] was used

Table 1 (continued)

References	Year of publication	Indexing of journal (Scopus/SCI index etc.)	Main findings or conclusion relevant to proposed research work	Remarks
[130]	2015	Science Citation Index	The proposed research work had been implemented about the collective and individual impact of 3 DERs, including generation for wind power, EDRP and PEV on unit commitment.	Data regarding energy price and hourly electricity demand considering hourly electric vehicle power in charging and discharging mode were collected
[114]	2015	Scopus	A fuzzy technique was used to solve UCP has taken load demand retort, EVs and wind power	Data collection for load demand considering wind power
[131]	2015	Science Citation Index	The proposed research work was implemented to find out the PDF of a resolute commitment of power generators or not.	Priority List (PL) method
[132]	2014	Science Citation Index	The proposed research method was used to solve UCP including pumped hydro energy storage and wind power	Constraints of pumped storage power plant were collected
[117]	2014	Science Citation Index	To authenticate the viability and efficacy of the submitted method (BGSA) to solve UCP, the recommended method was verified on various system	BGSA with the Lambda-Iteration method was applied and the data regarding system load and wind power prediction were collected
[133]	2013	Scopus	LR-PSO Method was designed to solve scheduling of power generation problem for thermal, wind-solar system for deregulated electrical power system	LR-PSO Method
(d)				
[134]	2018	Science Citation Index	Optimum scheduling for unit commitment problem considering photovoltaic insecurity and suitable power of EVs and output showed the reduction of production cost and improved load flow.	Collection of data regarding hourly evidence of solar power on the day of summer and winter day. Also collected data for UC without PV, UC with PV and PEV, PEV and UC with PEV.
[135]	2018	Science Citation Index	Priority-based method was designed to solve stochastic UCP considering parking lot cooperation and renewable energy sources	Priority-based method

Table 1 (continued)

References	Year of publication	Indexing of journal (Scopus/SCI index etc.)	Main findings or conclusion relevant to proposed research work	Remarks
[136]	2018	Scopus	Dynamic programming technique was used to discover realistic conditions of power generating units, while consecutive quadratic programming algorithm was applied for ELD of committed gen. units	Energy storage facilities [ESF]
[137]	2017	Science Citation Index	Cooperative Multi-Swarm PSO was used to solve UCP under Photovoltaic Generation including day-ahead prices	Cooperative Multi-Swarm PSO
[138]	2016	Science Citation Index	Addition of renewable energy, power generation indecisions into stochastic nature of unit commitment considering risk and reserve	SCUC
[139]	2016	Science Citation Index	The proposed method was invented to solve UCP considering presence of discontinuous renewable energy resources	Proposed research work helps to gain knowledge about the benefits of the present methodologies avoiding the obtainable weaknesses
[140]	2016	Science Citation Index expanded	Proposed research work was designed to solve UCP considering solar power system. IEEE 39 bus system and forecasted solar radiation with 24 h load demand had been taken to validate	Collection of data regarding solar irradiance data for 150 MW power plant
[141]	2015	Scopus	The proposed research work was based on function approximation methodology of reinforcement learning to solve UCP with photovoltaic energy sources	The research work proposed a Neural Network based Reinforcement Learning method [NNRL]
[113]	2015	Science Citation Index	10th generating power systems unit was applied to check the efficacy of the research	A whole computational outline of addition considering quantification of vacillations in DPSs with IRESs
[142]	2014	Science Citation Index	BRCFF technique was implemented to solve security-constrained UCP considering solar power	Binary Real Coded Firefly (BRCFF)
[143]	2008	Scopus	GA functioned PSO method was designed to solve UCP considering wind and solar Energy Systems	[GA-PSO] Genetic Algorithm operated Particle Swarm Optimization

the resolution of unit commitment optimization problems of the power system by using the hybrid algorithm, as UCP is linked optimization as it has both binary and continuous variables; the strategy adopted to tackle both variables is different. In this paper, the proposed sine–cosine algorithm searches allocation of generators (units that participate in generation to take upload) and once units are decided, allocation of generations (economic load dispatch) is done by Harris Hawks optimizer. The feasibility and efficacy of operation of the hybrid algorithm are verified for small, medium power systems and large system considering renewable energy sources in summer and winter and the percentage of cost saving for power generation is found. The results for 4 generating units, 5 generating units, 6 generating units, 7 generating units, 10 generating units, 19 generating units, 20 generating units, 40 generating units and 60 generating units are evaluated. The 10 generating units are evaluated with 5% and 10% spinning reserve.

Survey of literature

In the field of research area, the optimization method is the vastest region of research through which the research works are effectively moving forward. Nowadays, researchers are working with multiple works for various problems using different techniques and they are capable of measuring the output successfully. To discover the new algorithms, the research work is on successfully running condition and to mitigate the drawbacks of present existing techniques.

Some of the research works in the field of optimization include ant colony optimization (ACO) algorithm [11], ant lion optimizer (ALO) [12], adaptive gbest-guided search algorithm (AGG) [13], bat algorithm (BA) [14], biogeography-based optimization (BBO) [15], branch and bound (BB) [16], binary bat algorithm (BBA) [17], bird swarm algorithm (BSA) [18], bacterial foraging optimization algorithm (BFOA) [19], backtracking search optimization (BSO) [20], and binary gravitational search algorithm (BGSA) [21], colliding bodies optimization (CBO) [22], cuckoo search algorithm (CS) [23], chaotic krill herd algorithm (CKHA) [24], cultural evolution algorithm (CEA) [25], dragonfly algorithm (DA) [26], dynamic programming (DP) [27], earthworm optimization algorithm (EOA) [28], elephant herding optimization (EHO) [29], electromagnetic field optimization (EFO) [30], exchange market algorithm (EMA) [31], forest optimization algorithm (FOA) [32], fireworks algorithm (FA) [33], flower pollination algorithm (FPA) [34], gravitational search algorithm (GSA) [35], genetic algorithm (GA) [36], firefly algorithm (FFA) [37], grasshopper optimization algorithm (GOA) [38], gray wolf optimizer (GWO) [39], human group optimizer (HGO) [40], Hopfield method [41], interior search algorithm (ISA) [42], imperialist competitive algorithm (ICA) [43], krill herd algorithm (KHA) [44], invasive weed optimization (IWO) [45], lightning search algorithm (LSA) [46], league championship algorithm (LCA) [47], multi-verse optimizer (MVO) [48], mixed integer programming (MIP) [49], mine blast algorithm (MBA) [50], moth-flame optimization (MFO) [51], simulated annealing (SA) [52], monarch butterfly optimization (MBO) [53], particle swarm optimization (PSO) [54], random walk gray wolf optimizer (RW-GWO) [55], optics inspired optimization (OIO) [56], runner-root algorithm (RRA) [57], sine–cosine algorithm (SCA) [58], shuffled frog-leaping algorithm (SFLA) [59], stochastic fractal search (SFS) [60],seeker optimization algorithm (SOA) [61], teaching–learning-based optimization (TLBO) [62], symbiotic organisms search (SOS)

[63], search group algorithm (SGA) [64], salp swarm algorithm (SSA) [65], and whale optimization algorithm (WOA) [66], weighted superposition attraction (WSA) [67], virus colony search (VCS) [68], water wave optimization (WWO) [69], Tabu search (TS) [70], water cycle algorithm (WCA) [71], wind-driven optimization (WDO) [72], modified sine–cosine algorithm [m-SCA] [73], and improved sine–cosine algorithm [ISCA] [74]. Leadership quality was improved by Levy flight (LF) search and gray wolf optimizer [GLF–GWO] [75], greedy differential evolution–gray wolf optimizer [gDE-GWO] [76], memory-based gray wolf optimizer [mGWO] [77], and memory-guided sine–cosine algorithm [MG-SCA] [1].

Faisal Rahiman Pazheri et al. presented scheduling of power station with energy storage facility. Utilities of power are stimulated by converting the present conventional power plant into hybrid power plant by installing available energy storage facilities and renewable electric power unit to come across the sudden increase in the power demand. Facility of energy storage maintains a level of the penetration of renewable power to 10% of required load demand throughout the period of operation for hybrid power plant [136]. Chandrasekaran et al. proposed FF algorithm to get solution of the SUC problem for thermal/solar power sector considering issues regarding smart grid. The research paper included some critical review on reliable impacts of major resources of smart grid considering demand response (DR) and solar energy. Thus, it was essential to implement method for an integration of thermal and solar generating system [144]. Selvakumar et al. implemented a new strategy for solving unit commitment problem for thermal units integrated with solar energy system. There would be changes in the cost of power generation considered solar energy. The main objective was reduction of total production price for the electricity generating unit, and this paper also explained the variances by considering solar energy and non-considering the solar power [140]. Senjyu et al. proposed a new method using genetic algorithm operated PSO to solve the thermal UCP considering wind and solar energy system. This method was able to minimize production cost and produce high-quality solutions [143]. Ma et al. discussed about appliances scheduling via cooperative multi-swarm PSO under photovoltaic (PV) generation and day-ahead prices. This research work studied about the problem including scheduling appliances in residential system unit. The model of an appliance-scheduling was established for home energy management system which was based on day-ahead electricity price and PV generation [137]. Abujarad et al. discussed a review on current methods for commitment of generating unit in existence of irregular renewable energy resource [139]. Maryam Shahbazitabar and Hamdi Abdi implemented a new priority-based stochastic unit commitment as parking lot cooperation and renewable energy sources. This paper discussed about the fastest nature of heuristic method which was established on list of priority selections to get solution for stochastic nature of the problem related to unit commitment and useful to simple 10 unit systems where the study was addition considering electrical vehicles parking allocation considering wind farm and solar farm over 24-h time horizon [135]. Quan et al. proposed a comparative review on integrated renewable energy generation uncertainties which were captured by list of prediction intervals, into stochastic unit commitment considering reserve and risk [138]. Jasmin et al. implemented an optimization technique about reinforcement learning to solve unit commitment problem considering photovoltaic sources. For stochastic behavior of the associated power and solar irradiance, the arrangement of the different types of power generating sources considering solar energy turned to be an optimization problem stochastic in nature. This paper discussed about the optimization technique and reinforcement learning that can provide uncertainty of the environment of the nature which is very effective [141]. Saniya Maghsudlu and Sirus Mohammadi proposed a method to solve the problem in optimum schedule of commitment unit as appropriate control of EVs and PV uncertainty. The meta-heuristic approach, cuckoo search algorithm, was developed by greatest convergence speed to attain the optimal solution and get solution of UCP. The research discussed about case study of IEEE 10 unit system which was used to examine the impact of PV and PEVs on scheduling of generating unit [134].

Problematic design

The generating power is distributed along with utilities of generator scheduling which will meet the time varying load demand for a specific time period known as unit commitment problem (UCP). The main objective of UCP is minimization of the overall cost for production considering different system constraints. The overall costs of production including sum of shutdown cost and start-up cost, cost of fuel are given below:

$$\min(\text{TFC}) = \sum_{t=1}^{H}\sum_{n=1}^{N}\left\{F_{\text{cost}n}(P_{nt}) + \text{SUC}_{n,t} + \text{SDC}_{nt}\right\} \tag{1}$$

The total cost of fuel over the scheduled time span 't' is:

$$\text{TFC} = \sum_{t=1}^{T}\sum_{n=1}^{\text{NU}}\left[F_{\text{cost}} \times U_{n,t} + \text{SUC}_{n,t}(1 - U_{n,(t-1)}) \times U_{n,t}\right] \tag{2a}$$

$$\text{TFC} = \sum_{t=1}^{T}\sum_{n=1}^{\text{NU}}[(A_nP_n^2 + B_nP_n + C_n) \times U_{n,t} + \text{SUC}_{n,t}(1 - U_{n,(t-1)}) \times U_{n,t}] \tag{2b}$$

Here, cost for fuel $F_{\text{cost}n}(P_{nt})$ is stated as quadratic design that is mostly worked by researchers, also named as equation of convex function.

The cost of fuel of (n) unit at (t) hour can be mathematically represented as an equation which is given below:

$$F_{\text{cost}}(P_n) = A_nP_n^2 + B_nP_n + C_n \tag{3}$$

where A_n, B_n and C_n are represented as coefficients of cost that may expressed as \$/h, \$/MWh, and \$/MWh^2 correspondingly.

Start-up cost can mathematically be represented by step function which is given below:

$$\text{SUC}_{n,t} == \begin{cases} \text{HSU}_n; & \text{for} \quad T_n^{\text{DW}} \le T_n^{\text{UP}} \le (T_n^{\text{DW}} + T_n^{\text{COLD}}) \\ \text{CSU}_n; & \text{for} \quad T_n^{\text{UP}} > (T_n^{\text{DW}} + T_n^{\text{COLD}}) \end{cases} \qquad (n \in \text{NU}; \quad t = 1, 2, 3, \ldots, T) \tag{4}$$

Usual value of the **shutdown cost** for standard system is denoted as zero, and this can be established as fixed cost followed by the equation number (5).

$$\mathrm{SDC}_{nt} = \mathrm{KP}_{nt} \tag{5}$$

where K is represented as incremental cost for shutdown.

It is subjected through some constraints followed by (1) system constraints and (2) unit constraints.

Constraints for system

System constrains are interrelated with all generating unit existing in the systems. The systems constrains are characterized into two types like:

Power balance or load balance constraints

In power system, the constraint including power balance or load balance is more important parameter consisting of summation of whole committed generating unit at *t*th time span which must be larger than or equivalent to the power demand for the particular time span '*t*'

$$\sum_{n=1}^{\mathrm{NU}} P_{n,t} \times U_{n,t} = \mathrm{PD}_n. \tag{6}$$

Spinning reserve (SR) constraints

Reliability of the system can be considered as facility of extra capability of power generation that is more important to deed instantly when failure occurred due to sudden change in load demand for such power generating unit which is already running. The extra capability of power generation is recognized as spinning reserve which is exactly represented as (Fig. 1):

$$\sum_{n=1}^{\mathrm{NU}} P_{n,t}^{\mathrm{MAX}} \times U_{n,t} \geq \mathrm{PD}_t + \mathrm{SR}_t. \tag{7}$$

Constraints for power generating unit

The specific constraints related to particular power generating unit existing in the systems are called generating unit constraint which are given as:

Thermal unit constraints

Thermal power units are controlled manually. This type of unit needs to undertake the change of temperature gradually, so it takes certain time span to take the generating unit accessible. Some crew members are essential to execute the maintenance and procedure of some thermal power generating units.

Minimum up time

This constraint is defined here as the minimum period of time previously the unit can be start over when the unit has already been shut down which is mathematically defined as:

$$T_{n,t}^{\mathrm{ON}} \geq T_n^{\mathrm{UP}} \tag{8}$$

where $T_{n,t}^{\mathrm{ON}}$ is defined as interval through which the generating unit n is constantly ON (in hours) and T_n^{UP} is defined as minimum up time (in hours) for the generating unit n (Fig. 1).

Minimum down time

When the power generating units will be DE-committed, there is required least period of time for recommitment of the unit which is mathematically given as:

$$T_{n,t}^{\mathrm{OFF}} \geq T_n^{\mathrm{DW}} \tag{9}$$

where $T_{n,t}^{\mathrm{OFF}}$ is time period for which generating unit n is constantly OFF (in hours) and T_n^{DW} is denoted as minimum down time (in hours) for the unit.

Adequate minimum downtime and uptime repair by heuristic mechanism accepted at those stages are stated in Fig. 2.

Maximum and minimum power generating limits

All power generating units have its individual maximum/minimum electric power generating limit, below and outside which it cannot produce, and this is known as maximum and minimum power limits, which is mathematically written as:

$$P_n^{\mathrm{MIN}} \leq P_{n,t} \leq P_n^{\mathrm{MAX}}. \tag{10}$$

Initial status for operation of electrical units

For every units, the initial operating position must proceed as the day's earlier generation schedule is taken into consideration; thus, each and all generating units can fulfill its lowest downtime/uptime (Figs. 3, 4, 5, 6, 7).

Step 1: Sort the generators in descending order of maximum generating capacity.

Step 2: *for* $n = 1$ *to* NG

if $U_{n,t} = 0$

then $U_{n,t} = 1$

else if $T_{n,t}^{OFF} > MDT_n$

then $T_{n,t}^{ON} = T_{n,t-1}^{ON} + 1$

and $T_{n,t}^{OFF} = 0$

Step 3: Verify new generating power of units.

Step 4: if $\sum_{n=1}^{NG} P_{n,t}^{MAX} U_{n,t} \geq PD_n + SR_n$ then stop the algorithm, else go to step-2

Step 5: if $T_{n,t}^{OFF} < MDT_n$ then do $l = t - T_{n,t}^{OFF} + 1$ and set $u_{n,t} = 1$

Step 6: Calculate $T_n^l = T_{n,l-1}^{ON} + 1$ and $T_{n,t}^{OFF} = 0$

Step 7: if $1 > t$, Verify generator output power for $\sum_{n=1}^{NG} P_{n,t}^{MAX} U_{n,t} \geq PD_t + SR_n$, else increment 1 by 1 and go to step-5

Fig. 1 PSEUDO code of SR repairing

for $t = 1$ *to* T

if $t == 1$

Compute $T_t^{ON} = T_{t0}^{ON} U_{n,t} + U_{n,t}^{/}$

Compute $T_t^{OFF} = (T_{t0}^{OFF})^{/} \overline{T_t^{ON}} + \overline{T_t^{ON}}$

else

Compute $T_t^{ON} = T_{t-1}^{ON} U'_{n,t} + U_{n,t}^{/}$

Compute $T_n^{OFF} = (T_{n-1}^{OFF})^{/} \overline{T_n^{ON}} + \overline{T_n^{ON}}$

end

end

Fig. 2 PSEUDO code for MUD/MUT constraints

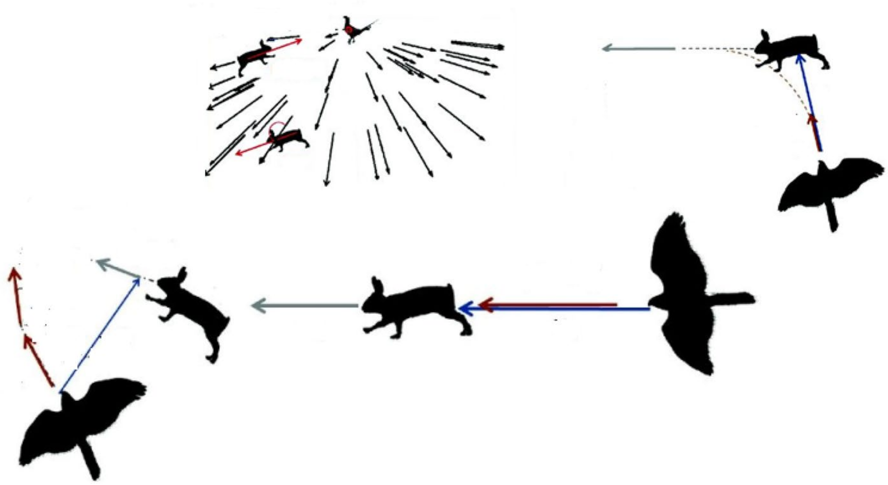

Fig. 3 Surprise attack

Crew constraint

When any power plant consists of more than one units, they could not turn on at the same period of time. So there need more than one crew member to attend such units in the same time while starting up.

Unit accessibility constraint

The constraint shows accessibility of power generating unit surrounded by any of the resulting various circumstances:

(A) Accessible or Not Accessible.
(B) Must Out or Outage.
(C) Must Run.

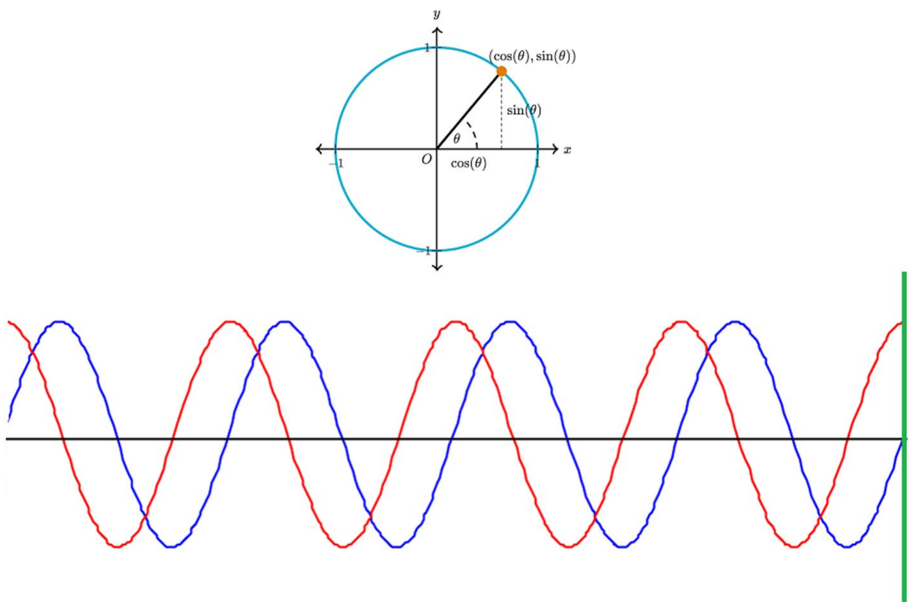

Fig. 4 Basic of SCA

Initial status of power generation unit

It signifies value of initial grade of power generating unit. Its favorable rate signifies the position of current generating unit which is already in up condition, which means that numeral time periods of the generating units are already up, and if its negative value is an index of the integer of hours, then the generating unit has been already in down condition. The position of the generating unit ± earlier the first hour through the schedule is an essential feature to define whether its latest situation interrupts the constraint of T_n^{UP} and T_n^{DW}.

Methods

The mathematical formulation of the Harris Hawks optimizer has been explained in this section. The position updating mechanism of the harris hawks optimizer has been presented in Eqs. (11), (12) and (13). Presently, considering the equivalent possibility w for each adjusting system depends upon areas for additional individuals to approach sufficiency while confronting as a prey, given in Eq. (11) (Figs. 3 and 4)

$$X(iteration+1) = \{X_{rand}(iteration) - r_1 \times abs(X_{rand}(iteration) - 2 \times r_2 \times X(iteration))\}; \quad w \geq .5 \tag{11}$$

$$X(iteration{+}1) = \{(X_{rabbit}(iteration) - X_m(iteration)) - r_3 \times (\mathrm{LB} + r_4 \times (\mathrm{UB} - \mathrm{LB}))\}; \quad w < .5 \tag{12}$$

$$X_m(iteration) = \frac{1}{N}\left(\sum_{i=1}^{N} X_i(iteration)\right) \tag{13}$$

where r_1,r_2,r_3,r_4, and w are random records in the middle of (0, 1); those are upgraded in every cycle, $X(iteration + 1)$ is denoted as Rabbit's position and N is defined as total amount of Harris hawks

Normal area for Harris Hawks is accomplished utilizing Eq. (13) (Fig. 5).

a

PSEUDO code of the Proposed algorithm

INPUTS: The population size is taken as N and maximum iteration number is taken as $iter\max$
OUTPUTS: The position of prey (rabbit) and its value of fitness
Initialization of random population $X_i (i = 1, 2, 3......., N)$
While (iteration < $iter\max$)
  Calculation of the fitness value of Harris hawks
  Set the parameter X_{rabbit} as the best position of the prey (rabbit)
  for (each Harris hawks (X_i))
    Do Update energy at initial condition E_O
    if $|E| \geq 1$ **then**
      Position vector updated using $E = 2 \times E_0 \times \left(1 - \frac{iteration}{iter\max}\right)$ → **Phase of Exploration**
    else if $q \geq 0.5$ **then**
      $X(iteration+1) = \{X_{rand}(iteration) - r_1 \times abs(X_{rand}(iteration) - 2 \times r_2 \times X(iteration))$
    else if $q < 0.5$ **then**
      $X(iteration+1) = \{(X_{rabbit}(iteration) - X_m(iteration)) - r_3 \times (LB + r_4 \times (UB - LB))$
    if $|E| < 1$ **then** → **Phase of Exploitation**
      $X(iteration+1) = \Delta X(iteration) - E \times abs(JX_{rabbit}(iteration) - X(iteration))$
    if $(r \geq 0.5)$ and $|E| \geq 0.5$ **then** → **Soft encircle**
      Position vector updated using $\Delta X(iteration) = (X_{rabbit}(iteration) - X(iteration))$
    else if $(r \geq 0.5)$ and $|E| < 0.5$ **then** → **Hard encircle**
      Position vector updated using $X(iteration+1) = X_{rabbit}(iteration) - E \times abs(\Delta X(iteration))$
    else if $(r < 0.5)$ and $|E| \geq 0.5$ **then** → **Soft encircle with advanced fast dives**
      Position vector updated using $Y = X_{rabbit}(iteration) - E \times abs(JX_{rabbit}(iteration) - X(iteration))$
    else if $(r < 0.5)$ and $|E| < 0.5$ **then** → **Hard encircle with advanced fast dives**
      Position vector updated using $X(iteration+1) = \Delta X(iteration) - E \times abs(JX_{rabbit}(iteration) - X(iteration))$
      end
    end
  end
end

Initialize the X_i of the search agents using final position obtained through Harris Hawks optimizer
Do
    Evaluate each of the search agents using objective functions
    Update the best fitness obtained so far
    Update the random numbers r_1, r_2, r_3 and r_4
  if $r_4 < 0.5$
    Update the position of search agents using
    $X_i(iteration+1) = X_i(iteration) + r_1 \times \sin(r_2) \times |r_3 \times P_i(iteration) - X_i(iteration)|$
  else
    Update the position of search agents using
    $X_i(iteration+1) = X_i(iteration) + r_1 \times \cos(r_2) \times |r_3 \times P_i(iteration) - X_i(iteration)|$
  end
While $(iteration < iter\max)$
Return the best optimal solution
  Record the mean, best, worst fitness and standard deviation.
  Save the global optimum value obtained through successive trial runs

Fig. 5 **a** Pseudocode of proposed hybrid hHHO-SCA algorithm. **b** Flowchart for hHHO-SCA technique

Change after the period for investigation of the period of exploitation is shown:

$$E = 2 \times E_0 \times \left(1 - \frac{iteration}{iter\max}\right) \tag{14}$$

where E is the avoidance energy for rabbit, E_0 the early condition for energy and $iter\max$ = maximum iteration

$$X(iteration + 1) = \Delta X(iteration) - E \times abs(JX_{rabbit}(iteration) - X(iteration)) \tag{15}$$

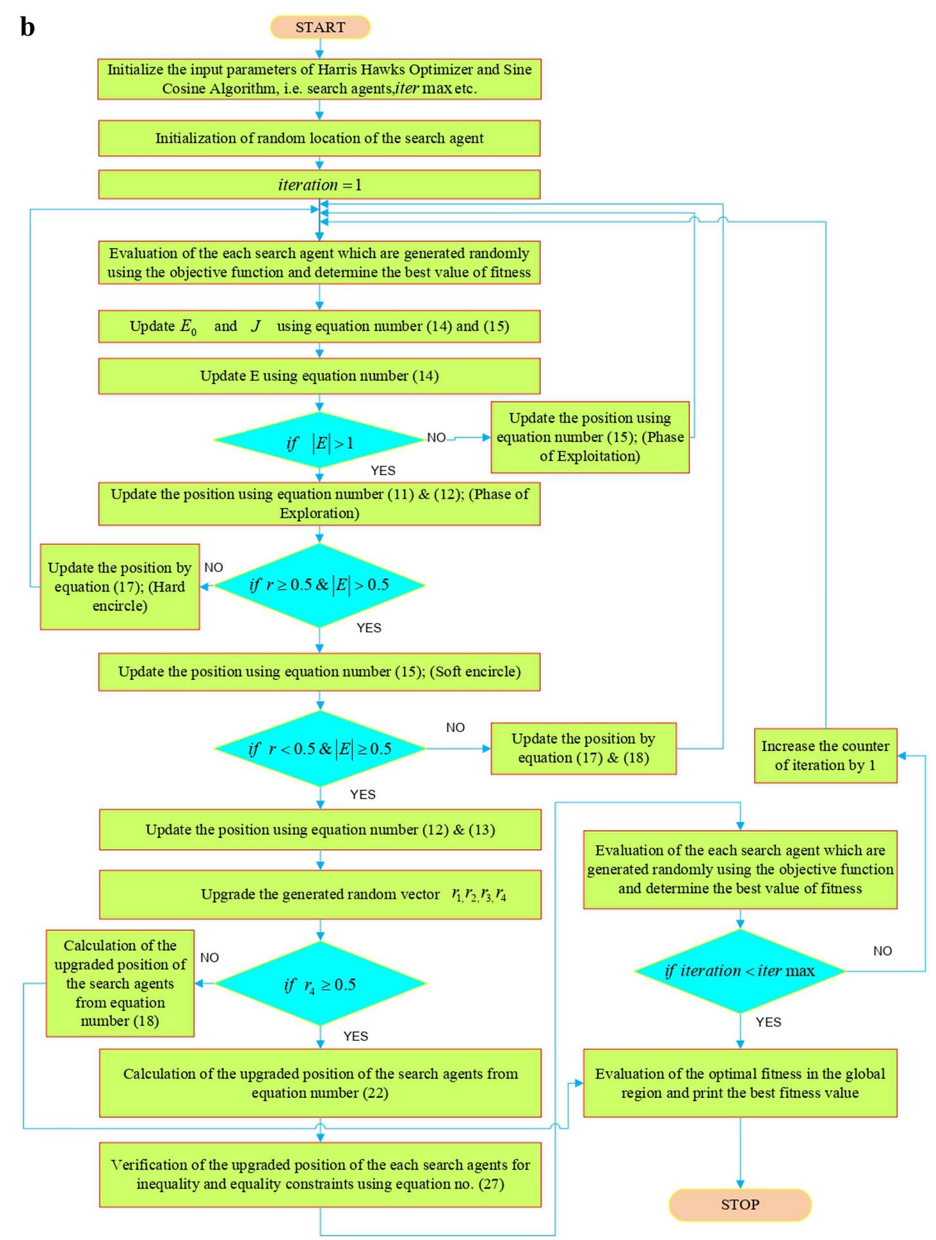

Fig. 5 continued

$$\Delta X(iteration) = (X_{rabbit}(iteration) - X(iteration)) \tag{16}$$

$$X(iteration + 1) = X_{rabbit}(iteration) - E \times abs(\Delta X(iteration)) \tag{17}$$

$$Y = X_{rabbit}(iteration) - E \times abs(JX_{rabbit}(iteration) - X(iteration)) \tag{18}$$

$$Z = Y + S \times LF(D). \tag{19}$$

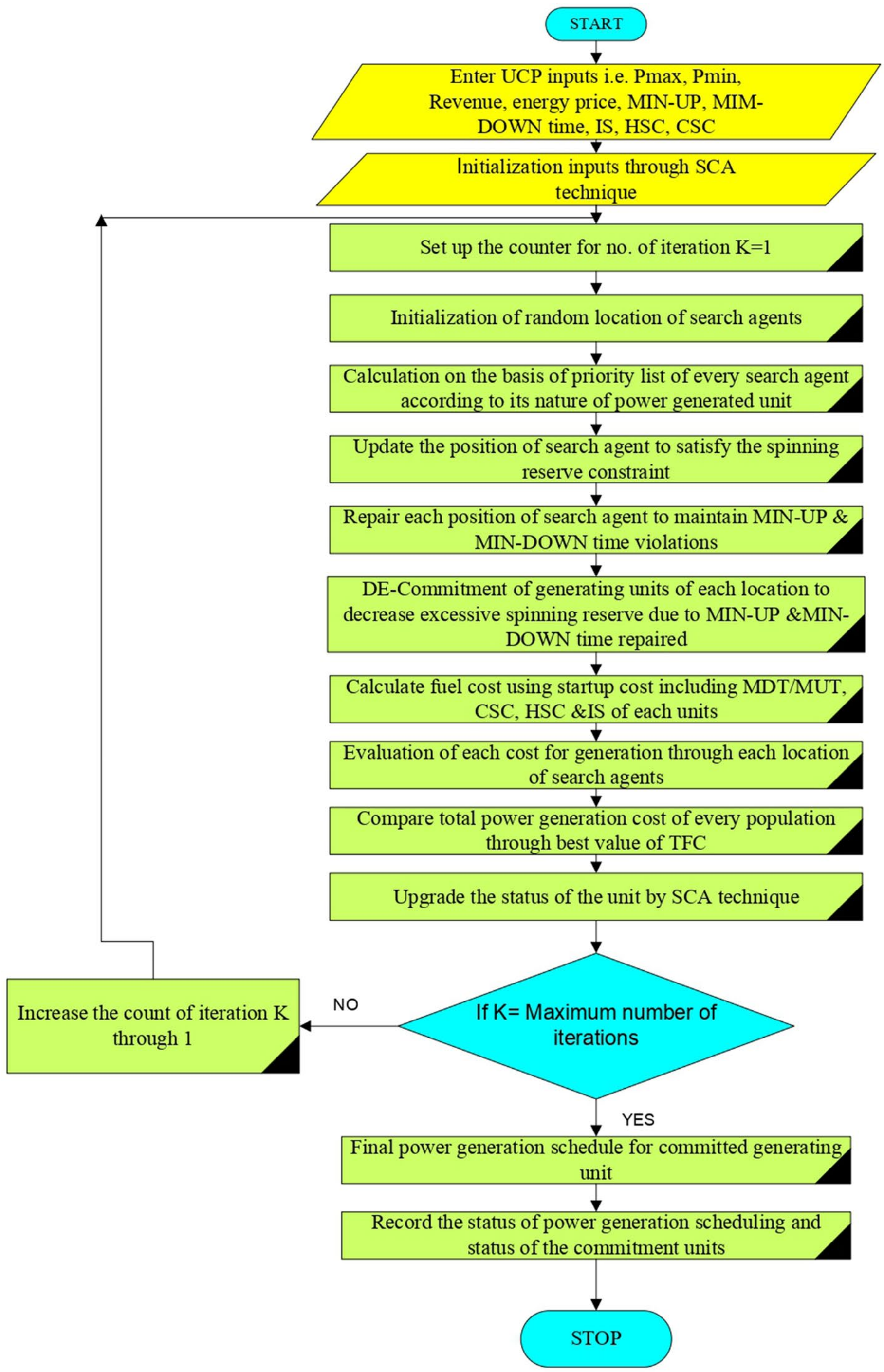

Fig. 6 Flowchart of complete procedure of commitment by SCA method

Along these lines, to find out the better solution of a soft enclose, the Hawks birds of prey are able to choose their development Y that depends upon standard that is shown in Eq. (18)

Established $Lf(D)$ patterns are constructed which track the given instruction in Eq. (20),

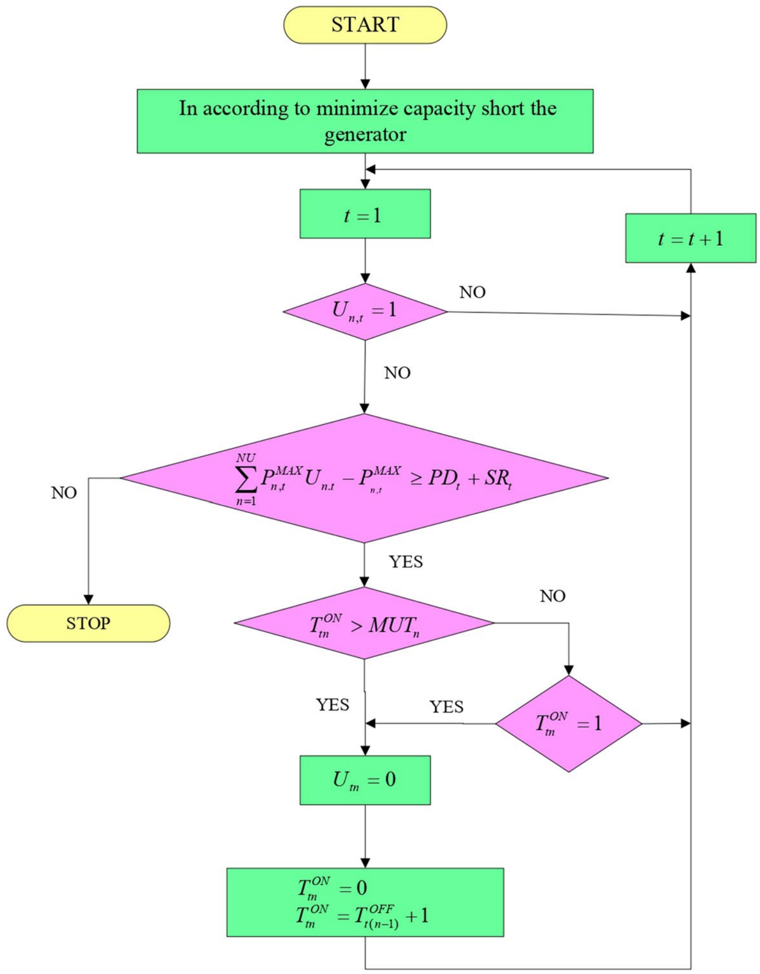

Fig. 7 Flowchart of handle minimum uptime–downtime constraints

where D = dimension of problems, S = dimension of random vectors with size $1 \times D$

$$LF(x) = 0.01\left(\frac{\mu \times \sigma}{|\nu|^{\frac{1}{\beta}}}\right) \tag{20}$$

$$\sigma = \left(\frac{\Gamma(1+\beta) \times \sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left(\frac{1+\beta}{2}\right) \times \beta \times 2\left(\frac{\beta-1}{2}\right)}\right)^{\frac{1}{\beta}} \tag{21}$$

where μ, σ are denoted as such kind of values randomly in between (0, 1) and β set to 1.5 which is a constant known as default.

The final and actual positions through this period of soft encircle can be updated using Eqs. (22) and (23) shown below:

$$X(iteration+1)=\begin{cases} Y\ ;\ \text{if}\ F(Y)<F(X(iteration)) \\ Z\ ;\ \text{if}\ F(Z)<F(X(iteration)) \end{cases} \tag{22}$$

$$Y=X_{rabbit}(iteration)-E\times abs(JX_{rabbit}(iteration)-X_m(iteration)) \tag{23}$$

$$Z=Y+S\times Lf(D) \tag{24}$$

$X_m(iteration)$ can be obtained from Eq. (23).

The SCA optimization technique is mathematically written as:

$$X_i(iteration+1)=X_i(iteration)+r_1\times\sin(r_2)\times|r_3\times P_i(iteration)-X_i(iteration)| \tag{24}$$

$$X_i(iteration+1)=X_i(iteration)+r_1\times\cos(r_2)\times|r_3\times P_i(iteration)-X_i(iteration)| \tag{25}$$

$$X_i(iteration+1)=\begin{cases} X_i(iteration)+r_1\times\sin(r_2)\times|r_3\times P_i(iteration)-X_i(iteration)|\ ;\ \text{if}\ r_4<0.5 \\ X_i(iteration)+r_1\times\cos(r_2)\times|r_3\times P_i(iteration)-X_i(iteration)|\ ;\ \text{if}\ r_4\geq 0.5 \end{cases} \tag{26}$$

Here, r_4 is denoted as random numbers [0, 1].

This method based on the suggested process may balance exploitation as well as exploration to get favorable solutions in the area of search space and lastly meet to find global optimal solutions using Eq. (27) (Fig. 6).

$$r_1=\left(2-iteration\times\frac{2}{Iter\max}\right) \tag{27}$$

Handling of spinning reserve constraints

The simple possible solution that was obtained by SCA technique is highly unsuccessful to satisfy spinning reserve necessity (Fig. 7). Also handling of minimum uptime and downtime leads to extra spinning reserve. Thus, it is compulsory to handle/adjust spinning reserve necessity heuristically. The flowchart in Fig. 8 explains whole process to repair spinning reserve necessity.

De-committing of excess of units

It is obvious from the code given over that during fix of MDT, MUT, and spinning reserve we need to take generating unit status "ON" if these requirements are violated by putting it off. Since we do as such against the caution given by algorithm, obliviously it brings about additional save. This circumstance is exceptionally unwanted; thus, we need to recommit some of the units once again in order to archive economic operation. In the following, the heuristic methodology is received for de-committing the additional spinning reserve (Figs. 9, 10).

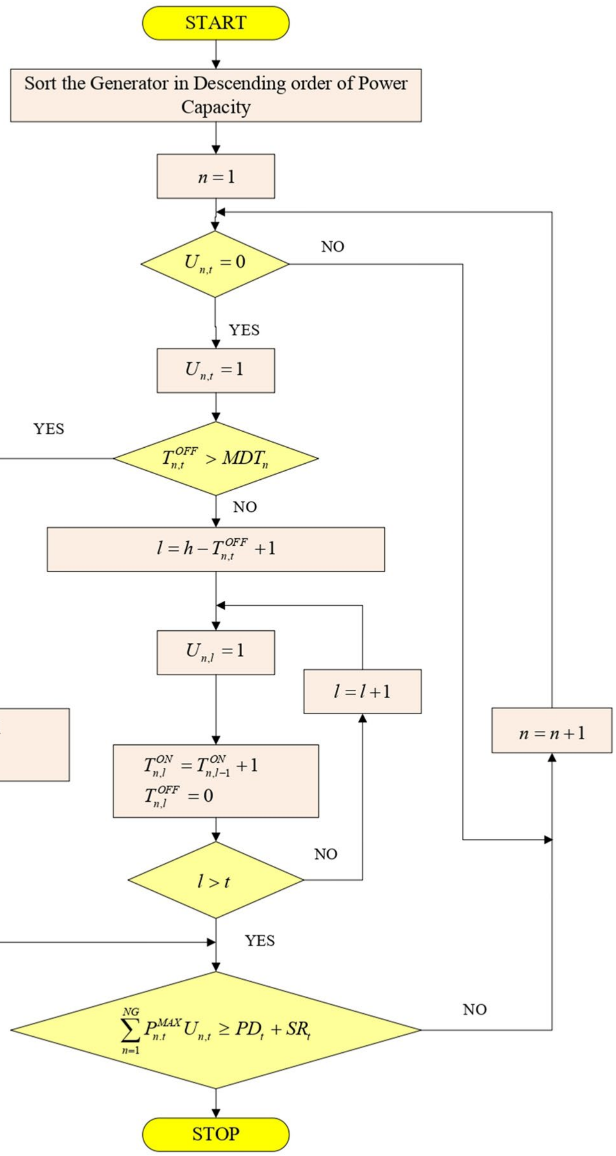

Fig. 8 Flowchart for repairing spinning reserve

Results and discussion

In order to validate the efficacy of the hHHO-SCA optimization technique, the outcomes of hHHO-SCA algorithm have been given below. The generating units' data are shown in Additional file 1: Annexure-A1 to A6 and its comparative analysis considering

for t=1:T
for n=1:NG
do $n = t(NG+1-i)$ and calculate generating power $\sum_{n=1}^{NG} P_{n,t}^{MAX} U_{n,t} - P_{n,t}^{MAX} \geq PD_t + SR_t$
if $U_{n,t} = 1$ **then**
if $\sum_{n=1}^{NG} P_{n,t}^{MAX} U_{n,t} - P_{n,t}^{MAX} \geq PD_t + SR_t$ **then**
if $(T_{t,n}^{ON} > MUT_n) \mid (T_{t,n}^{ON} = 1)$ **then**
do $U_{t,n} = 0$ and $T_{t,n}^{ON} = 0$
if t==1 **then**
do $T_{t,n}^{OFF} = T_{t_0,n}^{OFF} + 1$
else
do $T_{t,n}^{OFF} = T_{t-1,n}^{OFF} + 1$
end
else
continue;
end
else
break;
end
end
end

Fig. 9 Pseudocode of decommitment for excessive power generating unit

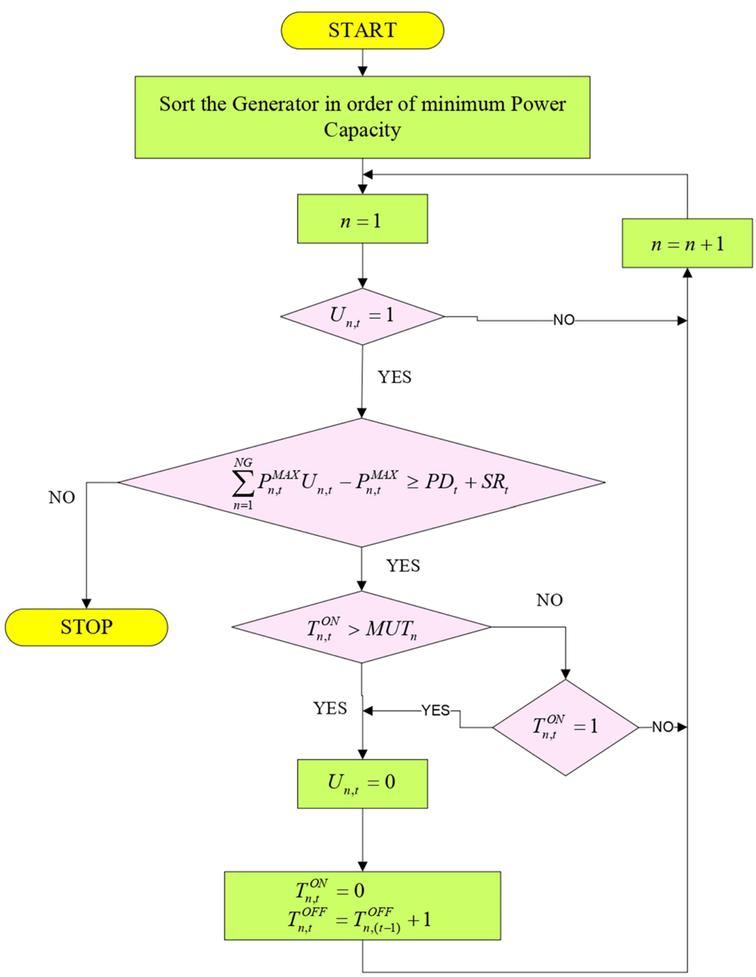

Fig. 10 Flowchart for the decommitment for excessive power generating units

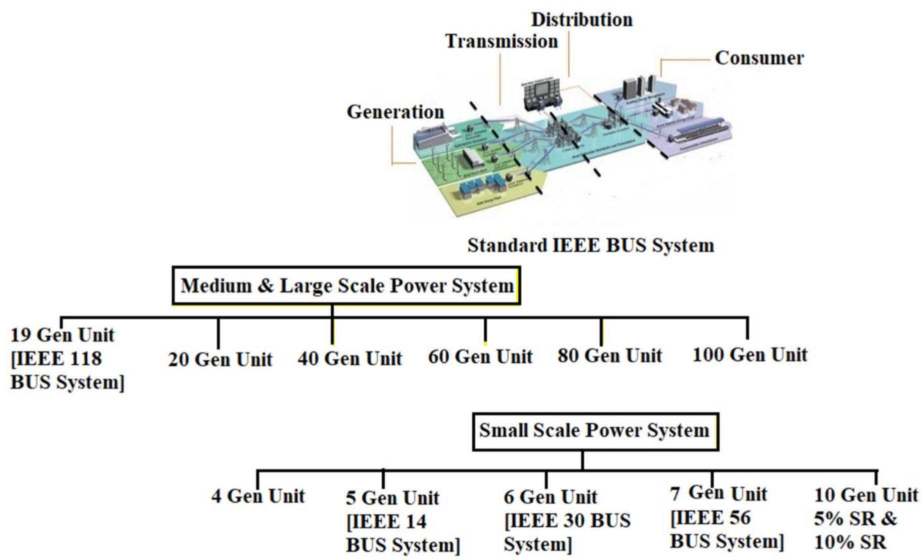

Fig. 11 Standard test systems

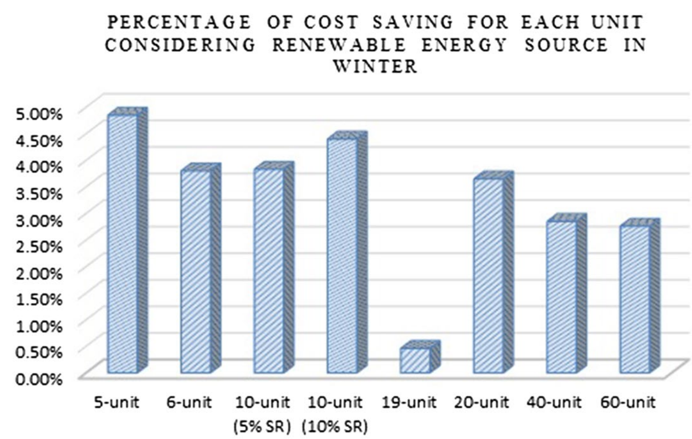

Fig. 12 Percentage of cost saving for each unit considering renewable energy source in winter using hHHO-SCA optimization technique

solar energy in summer and winter are shown in Table 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 21, 22, 23, 24 and 25 (Figs. 11, 12 and 13).

5-Generating Unit Test Systems: The first test system contains IEEE-14 bus systems which have 24-hour power demand with 10% spinning reserve. The hHHO-SCA technique is considered for 100 iterations. Tables 2 and 12 show that optimal scheduling for this test system considering summer and winter, respectively, using the hHHO-SCA algorithm is 8226.6 $/hour and 8572.9 $/hour. Without considering the renewable energy sources, the total generation cost is 9010.1$/hour.

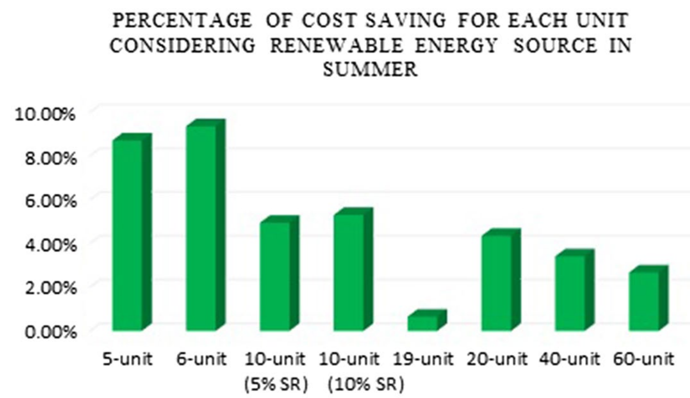

Fig. 13 Percentage of cost saving for each unit considering renewable energy source in winter using hHHO-SCA optimization technique

6-Generating Unit Test System: The second test system contains 6-generating units for IEEE-30 bus test systems with 24-hour electrical load demand including

Table 2 Power scheduling for 5 generating system considering renewable energy in summer

Hour	Generation schedule of committed units				
	GU1	GU2	GU3	GU4	GU5
1	148	0	0	0	0
2	173	0	0	0	0
3	220	0	0	0	0
4	104	140	0	0	0
5	119	140	0	0	0
6	108	140	0	0	0
7	227	0	0	0	0
8	0	97.45	100	0	0
9	0	60.33	100	0	0
10	0	106.66	0	0	0
11	62.83	0	0	0	0
12	83.94	0	0	0	0
13	105.14	0	0	0	0
14	113.53	0	0	0	0
15	150.41	0	0	0	0
16	176.14	0	0	0	0
17	206.16	0	0	0	0
18	207.4	0	0	0	0
19	210.41	0	0	0	0
20	203.49	0	0	0	0
21	175.84	0	0	0	0
22	157	0	0	0	0
23	138	0	0	0	0
24	103	0	0	0	0

Table 3 Power scheduling for 6-generating unit system considering renewable energy in summer

Hour	Generation schedule of committed units					
	GU1	GU2	GU3	GU4	GU5	GU6
1	166	0	0	0	0	0
2	154.35294	41.647059	0	0	0	0
3	181.52941	47.470588	0	0	0	0
4	196.52466	50.683857	19.79148	0	0	0
5	200	60.78125	22.61875	0	0	0
6	200	51.875	20.125	0	0	0
7	195.52941	50.470589	0	0	0	0
8	164.60588	43.844118	0	0	0	0
9	176.33	0	0	0	0	0
10	133.66	0	0	0	0	0
11	109.83	0	0	0	0	0
12	113.94	0	0	0	0	0
13	118.14	0	0	0	0	0
14	130.53	0	0	0	0	0
15	163.41	0	0	0	0	0
16	143.76235	39.377647	0	0	0	0
17	164.36706	43.792941	0	0	0	0
18	163.74118	43.658824	0	0	0	0
19	171.16118	45.248824	0	0	0	0
20	172.87412	45.615882	0	0	0	0
21	160.80941	43.030588	0	0	0	0
22	142.82353	39.176471	0	0	0	0
23	161	0	0	0	0	0
24	131	0	0	0	0	0

10% SR [145]. The hHHO-SCA algorithm is assessed for 100 iterations. Tables 3 and 13 show that optimal scheduling for this test system considering summer and winter, respectively, using the hHHO-SCA algorithm is 12229 $/hour and 12977 $/hour. Without considering the renewable energy sources, the total generation cost is 13489.93957 $/hour.

10-Generating Unit Test System: The third system contains 10 units power generating units. This system has been verified for 24-hour electric power demand outline at various spinning reserve capability. Case-1 consists of spinning reserve capability of 5%, and case-2 contains spinning reserve capability of 10%.

Case-1: 10-Generating Unit Test System (SR = 5%): The system consists of 10 power generating units with 24-hour electrical load demand including 5% SR [146]. The

Table 4 Power scheduling for 10-generating unit system (5% SR) considering renewable energy in summer

Hour	Generation schedule of committed units									
	GU1	GU2	GU3	GU4	GU5	GU6	GU7	GU8	GU9	GU10
h1	400	150	150	0	0	0	0	0	0	0
h2	450	150	150	0	0	0	0	0	0	0
h3	455	197.5	197.5	0	0	0	0	0	0	0
h4	455	247.5	247.5	0	0	0	0	0	0	0
h5	455	272.5	272.5	0	0	0	0	0	0	0
h6	455	322.5	322.5	0	0	0	0	0	0	0
h7	455	347.5	347.5	0	0	0	0	0	0	0
h8	455	370.225	370.225	0	0	0	0	0	0	0
h9	455	414.665	414.665	0	0	0	0	0	0	0
h10	455	446.33	446.33	0	25	0	0	0	0	0
h11	455	455	455	0	47.83	0	0	0	0	0
h12	455	455	455	0	88.94	0	0	0	0	0
h13	455	434.07	434.07	0	25	0	0	0	0	0
h14	455	382.765	382.765	0	25	0	0	0	0	0
h15	455	337.705	337.705	0	25	0	0	0	0	0
h16	455	260.57	260.57	0	25	0	0	0	0	0
h17	455	241.08	241.08	0	25	0	0	0	0	0
h18	455	293.2	293.2	0	25	0	0	0	0	0
h19	455	350.205	350.205	0	25	0	0	0	0	0
h20	455	455	455	0	28.49	0	0	0	0	0
h21	455	422.42	422.42	0	0	0	0	0	0	0
h22	455	322.5	322.5	0	0	0	0	0	0	0
h23	455	435	0	0	0	0	0	0	10	0
h24	455	345	0	0	0	0	0	0	0	0

hHHO-SCA technique is evaluated for 100 iterations. Tables 4 and 14 show that optimal scheduling for this test system considering summer and winter, respectively, using the hHHO-SCA algorithm is 529980 $/hour and 536200 $/hour. Without considering the renewable energy sources, the total generation cost is 557533.12$/hour.

Case-2: 10-Generating Unit System (SR = 10%): The system consists of 10 power generating units with 24-hour electrical load demand including 10% SR [146]. The hHHO-SCA technique is evaluated for 100 iterations. Tables 5 and 15 show that optimal scheduling for this test system considering summer and winter, respectively, using the hHHO-SCA algorithm is 534050 $/hour and 539110 $/hour. Without considering the renewable energy sources, the total generation cost is 563937.6875$/hour.

Table 5 Power scheduling for 10-generating unit system (10% SR) considering renewable energy in summer

Hour	Generation schedule of committed units									
	GU1	GU2	GU3	GU4	GU5	GU6	GU7	GU8	GU9	GU10
h1	400	150	150	0	0	0	0	0	0	0
h2	450	150	150	0	0	0	0	0	0	0
h3	455	197.5	197.5	0	0	0	0	0	0	0
h4	455	247.5	247.5	0	0	0	0	0	0	0
h5	455	272.5	272.5	0	0	0	0	0	0	0
h6	455	322.5	322.5	0	0	0	0	0	0	0
h7	455	347.5	347.5	0	0	0	0	0	0	0
h8	455	370.225	370.225	0	0	0	0	0	0	0
h9	455	402.165	402.165	0	25	0	0	0	0	0
h10	455	446.33	446.33	0	25	0	0	0	0	0
h11	455	455	455	0	27.93	20	0	0	0	0
h12	455	455	455	0	68.94	20	0	0	0	0
h13	455	424.07	424.07	0	25	20	0	0	0	0
h14	455	382.765	382.765	0	25	0	0	0	0	0
h15	455	350.205	350.205	0	0	0	0	0	0	0
h16	455	273.07	273.07	0	0	0	0	0	0	0
h17	455	253.58	253.58	0	0	0	0	0	0	0
h18	455	305.7	305.7	0	0	0	0	0	0	0
h19	455	362.705	362.705	0	0	0	0	0	0	0
h20	455	394.245	394.245	130	0	20	0	0	0	0
h21	455	347.42	347.42	130	0	20	0	0	0	0
h22	455	247.5	247.5	130	0	20	0	0	0	0
h23	455	315	0	130	0	0	0	0	0	0
h24	455	215	0	130	0	0	0	0	0	0

Medium-Scale and Large-Scale Electrical Power System (19-, 20-, 40-, 60-, 80- and 100-Unit System): The data for 20 and 40 generating unit test systems and the 10-unit system had been doubled and quadrupled, and electric power demand is multiplied by two and four times correspondingly [145].

19-Generating Unit System: The fourth system contains 19 power generating units of IEEE-118 bus test system with a 24-hour electricity load demand including 10% SR [145]. The hHHO-SCA technique is evaluated for 100 iterations. Tables 6 and 16 show that optimal scheduling for this test system considering summer and winter, respectively, using the hHHO-SCA algorithm is 207180 $/hour and 207560 $/hour. Without considering the renewable energy sources, the total generation cost is 208510 $/hour.

20-Generating Unit System: The fifth system contains 20-power generating units with 24-hour electricity demand including 10% SR [145]. The hHHO-SCA algorithm is assessed for 100 iterations. Tables 7 and 17 show that optimal scheduling for this

Table 6 Power scheduling for 19-generating unit system considering renewable energy in summer

Hour	Generation schedule of committed units (GU1-GU20)																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	464.871134	0	0	224.278351	0	0	0	0	0	0	363.634021	0	900	517.216495	0	700	0	0	0
2	408.861157	0	0	182.270868	0	0	0	0	0	0	313.225041	314.475041	853.291735	457.911813	0	669.964345	0	0	0
3	429.734202	0	0	0	0	0	0	0	0	0	332.010782	333.260782	884.601303	480.012685	0	696.801116	93.5791299	0	0
4	437.532204	0	0	0	0	0	0	0	0	0	339.028983	340.278983	896.298306	488.269392	0	700	98.5921311	0	0
5	431.236473	0	0	199.052355	0	0	0	0	0	0	333.362826	334.612826	886.85471	481.603325	0	698.732608	94.5448758	0	0
6	500	0	0	310.192308	0	0	0	0	20	20	0	400	900	600	0	700	189.807692	0	0
7	500	0	0	333.649547	0	0	0	0	20	22.4365559	0	400	900	600	0	700	209.913897	0	0
8	482.351946	0	0	237.38896	0	0	0	0	20	0	379.366752	380.616752	900	535.72559	0	700	0	0	0
9	451.445339	0	51.3231	214.209004	0	0	0	0	20	0	351.550805	352.800805	900	503.000947	0	700	0	0	0
10	500	0	86.3462065	259.447183	0	0	0	0	0	0	399.999998	0	900	566.866612	0	700	0	0	0
11	461.073759	0	56.9137956	221.430319	0	0	0	0	0	0	360.216383	0	900	513.195744	0	700	0	0	0
12	389.424418	0	30	167.693314	0	0	0	0	0	0	295.731976	296.981976	824.136627	437.331737	0	644.97425	67.6657024	0	0
13	430.746495	0	0	198.684871	0	0	0	0	0	0	0	334.171845	886.119742	481.084524	0	698.102633	94.2298895	0	0
14	435.957414	0	0	202.59306	0	0	0	0	0	0	0	338.861672	893.936121	486.601967	0	700	97.5797659	0	0
15	500	0	162.576328	357.91109	0	0	127.874732	0	27.0478502	0	0	0	900	600	0	700	0	0	0
16	500	0	139.592668	0	0	0	106.284021	0	20	0	0	400	900	600	0	700	205.263311	0	0
17	479.877738	0	67.8322348	0	0	0	0	0	20	0	377.139964	378.389964	900	533.10584	0	700	125.81426	0	0
18	487.002239	0	0	0	0	0	0	0	20	0	383.552016	384.802016	900	540.649431	0	700	130.394297	0	0
19	444.372623	0	0	208.904467	0	0	0	0	0	0	345.185361	346.435361	900	495.512189	0	700	0	0	0
20	417.447224	0	0	188.710418	0	0	0	0	0	0	320.952502	322.202502	866.170837	467.002943	0	681.003573	0	0	0
21	410.191869	0	0	183.268902	0	0	0	0	0	0	314.422682	315.672682	855.287803	459.320802	0	671.67526	0	0	0
22	460.28747	0	0	220.840603	0	0	0	0	0	0	359.508723	0	900	512.363204	0	700	0	0	0
23	458.939334	0	0	219.8295	0	0	0	0	0	0	358.2954	0	900	510.935765	0	700	0	0	0
24	431.175857	0	0	0	0	0	0	0	0	0	333.308271	334.558271	886.763785	481.539143	0	698.654673	0	0	0

Table 7 Power scheduling for 20-generating unit system considering renewable energy in summer

Hour	Generation schedule of committed units (GU1-GU20)																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	455	163.333333	163.333333	0	0	0	0	0	0	0	455	0	163.333333	0	0	0	0	0	0	0
2	455	196.666667	196.666667	0	0	0	0	0	0	0	455	0	196.666667	0	0	0	0	0	0	0
3	455	260	260	0	0	0	0	0	0	0	455	0	260	0	0	0	0	10	0	0
4	455	330	330	0	0	0	0	0	0	0	455	0	330	0	0	0	0	0	0	0
5	455	363.333333	363.333333	0	0	0	0	0	0	0	455	0	363.333333	0	0	0	0	0	0	0
6	455	421.666667	421.666667	0	0	0	0	0	0	0	455	0	421.666667	0	25	0	0	0	0	0
7	455	411.666667	411.666667	130	0	0	0	0	0	0	455	0	411.666667	0	25	0	0	0	0	0
8	455	436.816667	436.816667	130	0	0	0	10	0	0	455	0	436.816667	0	25	0	0	0	0	10
9	455	341.0825	341.0825	130	25	0	0	0	0	0	455	341.0825	341.0825	130	25	0	0	0	0	0
10	455	388.165	388.165	130	25	0	0	0	0	0	455	388.165	388.165	130	25	0	0	0	0	0
11	455	410.7075	410.7075	130	25	0	0	0	0	0	455	410.7075	410.7075	130	25	0	0	0	0	0
12	455	433.485	433.485	130	25	0	0	0	0	0	455	433.485	433.485	130	25	0	0	0	0	0
13	455	418.285	418.285	0	25	0	0	0	10	0	455	418.285	418.285	130	0	0	0	0	0	0
14	455	402.6325	402.6325	0	25	0	0	0	0	0	455	402.6325	402.6325	0	0	0	0	0	0	0
15	455	355.1025	355.1025	0	25	0	0	0	0	0	455	355.1025	355.1025	0	0	0	0	0	0	0
16	455	279.035	279.035	0	25	0	0	0	0	0	455	279.035	279.035	0	0	0	0	0	0	0
17	455	256.79	256.79	0	25	0	0	0	0	0	455	256.79	256.79	0	0	0	0	0	0	0
18	455	307.85	307.85	0	25	0	0	0	0	0	455	307.85	307.85	0	0	0	0	0	0	0
19	455	361.3525	361.3525	0	25	0	0	0	0	0	455	361.3525	361.3525	0	0	0	0	0	0	0
20	455	455	455	0	26.745	0	0	0	0	0	455	455	455	0	26.745	0	0	10	0	0
21	455	416.21	416.21	0	0	0	0	0	0	0	455	416.21	416.21	0	25	0	0	0	0	0
22	455	421.666667	421.666667	0	0	0	0	0	0	0	455	0	421.666667	0	25	0	0	0	0	0
23	455	432.5	432.5	0	0	0	0	0	0	0	455	0	0	0	25	0	0	0	0	0
24	455	332.5	332.5	0	0	0	0	0	0	0	455	0	0	0	25	0	0	0	0	0

Table 8 Power scheduling for 40-generating unit system considering renewable energy in summer

Hour	Generation schedule of committed units (GU1-GU20)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	455	163.3333333	163.333	0	0	0	0	0	0	0	455	163.3333333	163.3333333	0	0	0	0	0	0	0
2	455	175	175	0	0	0	0	0	0	0	455	175	175	130	0	0	0	0	0	0
3	455	241.6666667	241.666	0	0	0	0	0	0	0	455	241.6666667	241.6666667	129.999	0	0	0	0	0	0
4	455	264.2857143	264.285	0	0	0	0	0	0	0	455	264.2857143	264.2857143	130	0	0	0	0	0	0
5	455	287.1428571	287.142	0	0	0	0	0	10	10	455	287.1428571	287.1428571	130	0	0	0	0	0	0
6	455	343.5714286	343.571	0	0	0	0	0	0	0	455	343.5714286	343.5714286	130	0	0	0	0	0	0
7	455	390.7142857	390.714	0	0	0	0	0	0	0	455	390.7142857	390.7142857	0	0	0	0	0	0	0
8	455	415.7785714	415.778	0	0	0	0	0	0	0	455	415.7785714	415.7785714	0	0	0	0	0	10	0
9	455	401.16625	401.166	0	0	0	0	0	0	0	455	401.16625	401.16625	0	25	0	0	0	0	0
10	455	437.2075	437.207	0	25	0	25	0	0	0	455	437.2075	437.2075	0	25	0	25	0	0	0
11	455	455	455	0	29.276	0	25	0	0	0	455	455	455	0	29.27666667	0	25	0	0	0
12	455	455	455	0	76.313	20	25	10	0	0	455	455	455	0	76.31333333	0	25	0	0	0
13	454.9999998	435.3925001	435.392	0	25.000	20	0	0	0	0	454.9999998	435.3925001	435.3925001	0	25.0000001	0	0	0	0	0
14	455	385.06625	385.066	0	25	20	0	0	0	0	455	385.06625	385.06625	130	25	0	0	0	0	0
15	455	341.30125	341.301	0	25	0	0	0	0	0	455	341.30125	341.30125	130	25	0	0	0	0	0
16	455	258.8925	258.892	0	25	0	25	0	0	0	455	258.8925	258.8925	130	25	20	0	0	0	0
17	455	236.52	236.52	0	25	0	25	0	0	0	455	236.52	236.52	130	25	20	0	0	0	0
18	455	287.05	287.05	0	25	0	25	0	0	0	455	287.05	287.05	129.999	25	20	0	0	0	0
19	455	360.67625	360.676	0	25	0	0	0	0	0	455	360.67625	360.67625	0	25	0	0	0	0	0
20	455	455	455	0	30.872	0	0	10.00000001	0	0	455	455	455	0	30.8725	0	0	0	0	0
21	455	403.105	403.105	0	0	0	0	0	0	0	455	403.105	403.105	0	0	0	0	0	0	0
22	455	404.1666667	404.166	0	0	0	0	0	0	0	455	404.1666667	404.1666667	0	0	0	0	0	0	0
23	455	321	321	0	0	0	0	0	0	0	455	321	321	0	0	0	0	0	0	0
24	455	415	415	0	0	0	0	0	0	0	455	415	415	0	0	0	0	0	0	0

Table 8 (continued)

Hour	Generation schedule of committed units (GU21-GU40)																			
	21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
1	455	163.333	0	0	0	0	0	0	0	0	455	163.3333333	0	0	0	0	0	0	0	0
2	455	175	0	0	0	0	0	0	0	0	455	175	0	0	0	0	0	0	0	0
3	455	241.666	0	0	0	0	0	0	0	0	455	241.6666667	0	0	0	0	0	0	0	0
4	455	264.285	264.285	0	0	0	0	0	0	0	455	264.2857143	0	0	0	0	0	0	0	0
5	455	287.142	287.142	0	0	20	0	0	0	0	455	287.1428571	0	0	0	0	0	0	0	0
6	455	343.571	343.571	0	0	20	25	0	0	0	455	343.5714286	0	0	0	0	0	0	0	0
7	455	390.714	390.714	0	0	20	25.0000001	0	0	0	455	390.7142857	0	0	0	0	0	0	0	0
8	455	415.778	415.778	0	0	20	25	0	0	10	455	415.7785714	0	0	0	0	0	0	0	0
9	455	401.166	401.166	0	0	0	0	0	0	0	455	401.16625	401.16625	130	0	0	0	0	0	0
10	455	437.207	437.207	0	0	0	0	0	0	0	455	437.2075	437.2075	130	0	0	25	0	0	0
11	455	455	455	0	29.276	0	0	10	0	0	455	455	455	130	0	0	25	0	0	0
12	455	455	455	0	76.313	20	0	0	10	0	455	455	455	130	0	0	25	0	0	0
13	454.9999998	435.392	435.392	0	25.000	20	0	0	0	0	454.9999998	435.3925001	435.3925001	129.999	0	0	0	0	0	0
14	455	385.066	385.066	0	25	20	0	0	0	0	455	385.06625	385.06625	0	0	0	0	0	0	0
15	455	341.301	341.301	0	25	0	0	0	0	0	455	341.30125	341.30125	0	0	0	0	0	0	0
16	455	258.892	258.892	0	25	0	0	0	0	0	455	258.8925	258.8925	0	0	0	0	0	0	10
17	455	236.52	236.52	0	25	0	0	0	0	0	455	236.52	236.52	0	0	0	0	0	0	0
18	455	287.05	287.05	0	25	0	0	0	0	0	455	287.05	287.05	0	0	0	0	0	0	0
19	455	360.676	360.676	0	25	0	0	0	0	0	455	360.67625	360.67625	0	0	0	0	0	0	0
20	455	455	455	0	30.8725	0	0	0	0	0	455	455	455	0	30.8725	0	0	0	0	0
21	455	403.105	403.105	0	0	0	0	0	0	0	455	403.105	403.105	130	25	0	0	0	0	0
22	455	404.166	404.166	0	0	0	0	0	0	0	455	0	0	130	25	0	0	0	0	0
23	455	321	0	0	0	0	0	0	0	0	455	0	0	130	25	20	0	0	0	0
24	455	0	0	0	0	0	0	0	0	0	0	0	0	130	25	20	0	0	0	0

Table 9 Power scheduling for 60-generating unit system considering renewable energy in summer

Hour	Generation schedule of committed units (GU1-GU20)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	455	211.11111	211.11111	0	0	0	0	0	0	0	455	211.11111	211.11111	0	0	0	0	0	0	0
2	455	238.88889	238.88889	0	0	0	0	0	0	0	455	238.88889	238.88889	0	25	0	0	0	0	0
3	455	280.55556	280.55556	0	25	20	0	0	0	0	455	280.55556	280.55556	0	25	20	0	0	10	0
4	455	341.11111	341.11111	0	25	20	0	0	0	0	455	341.11111	341.11111	0	25	20	0	0	0	0
5	455	366.11111	366.11111	0	25	20	0	0	0	0	455	366.11111	366.11111	0	25	20	25	0	0	0
6	455	405	405	130	25	0	0	0	0	0	455	405	405	0	25	0	25	0	0	0
7	455	395.5	395.5	130	25	0	0	0	0	0	455	395.5	395.5	0	25	0	25	0	10	0
8	455	422.545	422.545	130	25	0	0	0	0	0	455	422.545	422.545	0	25	0	0	0	0	0
9	455	398.57545	398.57545	130	25	0	0	0	0	0	455	398.57545	398.57545	0	25	0	0	0	0	0
10	455	413.555	413.555	130	25	0	0	0	0	0	455	413.555	413.555	0	25	0	0	0	0	0
11	455	453.98583	453.98583	0	25	20	0	0	10	0	455	453.98583	453.98583	0	25	0	0	0	0	0
12	455	455	455	0	63.156667	20	0	0	0	0	455	455	455	0	63.156667	0	25	0	0	0
13	455	441.51167	441.51167	0	25	20	0	0	0	0	455	441.51167	441.51167	0	0	0	25	0	0	0
14	455	411.71083	411.71083	0	25	0	0	0	0	0	455	411.71083	411.71083	0	0	0	25	0	0	0
15	455	363.78417	363.78417	0	25	0	0	0	0	0	455	363.78417	363.78417	0	0	0	25	0	0	0
16	455	289.26167	289.26167	0	25	0	0	0	0	0	455	289.26167	289.26167	0	0	0	0	0	0	0
17	455	262.68	262.68	0	25	0	0	0	0	0	455	262.68	262.68	0	0	20	0	0	0	0
18	455	292.2	292.2	0	25	0	0	0	0	0	455	292.2	292.2	0	0	20	0	0	0	0
19	455	345.45083	345.45083	0	25	0	0	0	0	0	455	345.45083	345.45083	0	0	20	0	0	0	0
20	455	437.37417	437.37417	0	25	20	0	10	0	0	455	437.37417	437.37417	0	25	0	0	0	0	0
21	455	424.98545	424.98545	0	0	20	25	0	0	0	455	424.98545	424.98545	0	25	0	0	0	0	0
22	455	436.11111	436.11111	0	0	20	25	0	0	0	455	436.11111	436.11111	0	25	0	0	0	0	0
23	455	435.625	435.625	0	0	0	25	0	0	10	455	435.625	435.625	0	25	0	0	0	0	0
24	455	455	455	0	0	0	0	0	0	0	455	455	455	0	56.25	0	0	0	0	0

Table 9 (continued)

Hour	Generation schedule of committed units (GU21-GU40)																			
	21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
1	455	211.11111	211.11111	0	0	0	0	0	0	0	455	211.11111	0	0	0	0	0	0	0	0
2	455	238.88889	238.88889	0	0	0	0	0	0	0	455	238.88889	0	0	0	0	0	0	0	0
3	455	280.55556	280.55556	0	0	0	0	0	0	0	455	280.55556	0	0	0	0	0	0	0	0
4	455	341.11111	341.11111	0	0	20	0	0	0	0	455	341.11111	0	0	25	20	0	0	0	0
5	455	366.11111	366.11111	0	0	20	25	0	0	0	455	366.11111	0	0	25	20	25	0	0	0
6	455	405	405	0	25	20	25	0	0	0	455	405	0	0	25	20	25	0	0	0
7	455	395.5	395.5	0	25	0	25	0	0	0	455	395.5	395.5	0	25	20	25	0	0	0
8	455	422.545	422.545	130	25	0	0	0	0	0	455	422.545	422.545	0	25	0	0	0	0	0
9	455	398.57545	398.57545	130	25	0	0	0	0	0	455	398.57545	398.57545	130	25	0	0	0	0	0
10	455	413.555	413.555	130	25	0	0	0	0	0	455	413.555	413.555	130	25	0	0	0	0	10
11	455	453.98583	453.98583	130	25	0	25	0	0	0	455	453.98583	453.98583	130	25	0	0	0	0	0
12	455	455	455	130	63.156667	0	25	0	0	0	455	455	455	130	63.156667	0	0	0	0	0
13	455	441.51167	441.51167	0	0	0	25	0	0	0	455	441.51167	441.51167	130	25	0	0	0	0	0
14	455	411.71083	411.71083	0	0	0	0	0	0	0	455	411.71083	411.71083	0	0	0	0	0	0	0
15	455	363.78417	363.78417	0	0	0	0	0	0	0	455	363.78417	363.78417	0	0	0	0	0	0	0
16	455	289.26167	289.26167	0	0	0	0	0	0	0	455	289.26167	289.26167	0	0	0	0	0	0	0
17	455	262.68	262.68	0	0	0	0	0	0	0	455	262.68	262.68	0	0	0	0	0	0	0
18	455	292.2	292.2	0	0	0	0	0	0	0	455	292.2	292.2	0	0	0	0	0	0	0
19	455	345.45083	345.45083	0	0	0	0	0	0	0	455	345.45083	345.45083	0	0	0	0	0	0	0
20	455	437.37417	437.37417	0	0	0	0	10	0	0	455	437.37417	437.37417	0	0	0	0	0	0	0
21	455	424.98545	424.98545	0	0	0	0	0	0	0	455	424.98545	424.98545	0	0	0	0	10	0	0
22	455	436.11111	436.11111	0	0	0	0	0	0	0	455	436.11111	436.11111	0	0	0	0	0	0	0
23	455	435.625	435.625	0	0	0	0	0	0	0	455	435.625	0	0	0	0	0	0	0	0
24	455	455	455	0	56.25	0	0	0	0	0	455	0	0	0	56.25	0	0	0	0	0

Table 9 (continued)

Hour	Generation schedule of committed units (GU41-GU60)																			
	41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
1	455	211.11111	211.11111	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	455	238.88889	238.88889	0	25	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0
3	455	280.55556	280.55556	0	25	20	0	0	0	0	0	0	0	130	25	0	0	0	0	0
4	455	341.11111	341.11111	0	25	20	0	0	0	0	0	0	0	130	25	0	0	0	0	0
5	455	366.11111	366.11111	0	25	20	0	0	0	0	0	0	0	130	25	0	0	0	0	0
6	455	405	405	130	25	0	25	0	0	0	0	0	0	130	25	0	0	0	0	0
7	455	395.5	395.5	130	25	0	25	0	0	0	0	0	0	130	25	0	0	0	0	0
8	455	422.545	422.545	130	25	0	25	0	0	0	0	0	0	130	25	0	0	0	0	0
9	455	398.57545	398.57545	130	25	0	0	0	0	0	455	398.57545	0	0	25	0	0	0	0	0
10	455	413.555	413.555	130	25	0	0	0	0	0	455	413.555	413.555	0	25	0	0	0	0	0
11	455	453.98583	453.98583	0	25	20	0	0	0	0	455	453.98583	453.98583	0	25	0	0	0	0	0
12	455	455	455	0	63.156667	20	25	0	10	0	455	455	455	0	63.156667	0	0	0	0	0
13	455	441.51167	441.51167	0	0	20	25	0	0	0	455	441.51167	441.51167	0	25	0	0	0	0	0
14	455	411.71083	411.71083	0	0	0	25	0	0	0	455	411.71083	411.71083	0	0	0	0	0	0	0
15	455	363.78417	363.78417	0	0	0	0	0	0	0	455	363.78417	363.78417	0	0	0	0	10	0	0
16	455	289.26167	289.26167	0	0	0	0	0	0	0	455	289.26167	289.26167	0	0	0	25	0	0	0
17	455	262.68	262.68	0	0	0	0	10	0	0	455	262.68	262.68	0	0	0	25	0	0	0
18	455	292.2	292.2	130	0	0	0	0	0	0	455	292.2	292.2	130	0	0	25	0	0	0
19	455	345.45083	345.45083	130	0	0	0	0	0	0	455	345.45083	345.45083	130	0	0	0	0	0	0
20	455	437.37417	437.37417	130	0	0	25	0	0	10	455	437.37417	437.37417	130	0	20	0	0	10	0
21	455	424.98545	424.98545	130	0	0	25	0	0	0	455	424.98545	0	130	0	20	0	0	10	0
22	455	436.11111	0	130	25	0	25	0	0	0	0	0	0	130	0	20	0	0	0	0
23	0	435.625	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
24	0	0	0	0	56.25	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0

Table 10 Power scheduling for 80-generating unit system considering renewable energy in summer

Hour	Generation schedule of committed units (GU1-GU20)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	455	240	240	0	0	0	0	0	0	0	455	240	240	0	0	0	0	0	0	0
2	455	266.42857	266.42857	0	0	0	0	0	0	0	455	266.42857	266.42857	0	0	0	0	0	0	0
3	455	336.07143	336.07143	0	0	0	0	0	0	0	455	336.07143	336.07143	0	0	0	0	0	0	0
4	455	343.66667	343.66667	0	0	20	25	0	0	0	455	343.66667	343.66667	0	0	0	0	0	0	0
5	455	368.33333	368.33333	0	0	20	25	0	0	0	455	368.33333	368.33333	0	0	0	0	0	0	0
6	455	426.33333	426.33333	0	0	20	25	0	0	0	455	426.33333	426.33333	0	0	0	0	0	0	0
7	455	450.66667	450.66667	0	0	20	25	10	0	0	455	450.66667	450.66667	0	25	20	0	0	0	0
8	455	443.46563	443.46563	130	0	20	25	0	0	0	455	443.46563	443.46563	0	25	20	0	0	0	0
9	455	455	455	130	89.29125	20	25	0	0	0	455	455	455	130	89.29125	20	25	0	0	0
10	455	455	455	130	162	45.8325	25	10	10	10	455	455	455	130	162	45.8325	25	10	10	10
11	455	455	455	130	162	80	25	25.85375	10	10	455	455	455	130	162	80	25	25.85375	10	10
12	455	455	455	130	162	80	25	55	42.2425	10	455	455	455	130	162	80	25	55	42.2425	10
13	455	455	455	130	162	44.0175	25	10	10	10	455	455	455	130	162	44.0175	25	10	10	10
14	455	455	455	130	89.44125	20	25	0	0	10	455	455	455	130	89.44125	0	25	0	0	0
15	455	455	455	130	26.30125	0	25	0	0	0	455	455	455	130	26.30125	0	0	0	0	0
16	455	364.44625	364.44625	130	25	0	0	0	0	0	455	364.44625	364.44625	130	25	0	0	0	0	0
17	455	333.26	333.26	130	25	0	0	0	0	0	455	333.26	333.26	130	25	0	0	0	0	0
18	455	387.9	387.9	130	25	0	0	0	0	0	455	387.9	387.9	130	25	0	0	0	0	0
19	455	450.02563	450.02563	130	25	0	0	0	0	0	455	450.02563	450.02563	130	25	0	0	0	0	10
20	455	455	455	130	162	48.43625	25	10	10	10	455	455	455	130	162	48.43625	25	10	10	10
21	455	455	455	130	94.355	20	25	0	0	10	455	455	455	130	94.355	20	25	0	0	0
22	455	428.4375	428.4375	0	0	20	25	0	0	0	455	428.4375	428.4375	0	25	20	25	0	0	0
23	455	395	395	0	0	0	25	0	0	0	455	395	395	0	0	0	0	0	0	0
24	455	410	410	0	0	0	25	0	10	0	455	410	410	0	0	0	0	0	0	0

Table 10 (continued)

Hour	Generation schedule of committed units (GU21-GU40)																			
	21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
1	455	240	240	0	0	0	0	0	0	0	455	240	240	0	0	0	0	0	0	0
2	455	266.42857	266.42857	0	0	0	0	0	0	0	455	266.42857	266.42857	0	0	0	0	0	0	0
3	455	336.07143	336.07143	0	0	0	0	0	0	0	455	336.07143	336.07143	0	0	0	0	0	0	0
4	455	343.66667	343.66667	130	25	20	0	0	0	0	455	343.66667	343.66667	0	0	0	0	0	0	0
5	455	368.33333	368.33333	130	25	20	0	0	0	0	455	368.33333	368.33333	130	0	0	0	0	0	0
6	455	426.33333	426.33333	130	25	20	0	0	0	0	455	426.33333	426.33333	130	0	0	0	0	0	0
7	455	450.66667	450.66667	130	25	0	0	0	0	0	455	450.66667	450.66667	130	0	0	0	0	0	0
8	455	443.46563	443.46563	130	25	0	0	0	0	0	455	443.46563	443.46563	130	0	0	25	0	0	0
9	455	455	455	130	89.29125	0	25	0	0	0	455	455	455	130	89.29125	0	25	10	0	0
10	455	455	455	130	162	45.8325	25	10	10	10	455	455	455	130	162	45.8325	25	10	10	10
11	455	455	455	130	162	80	25	25.85375	10	10	455	455	455	130	162	80	25	25.85375	10	10
12	455	455	455	130	162	80	25	55	42.2425	10	455	455	455	130	162	80	25	55	42.2425	10
13	455	455	455	130	162	44.0175	25	10	10	10	455	455	455	130	162	44.0175	25	10	10	0
14	455	455	455	130	89.44125	20	25	0	0	0	455	455	455	130	89.44125	0	25	0	10	0
15	455	455	455	130	26.30125	0	0	0	0	10	455	455	455	130	26.30125	0	0	10	0	0
16	455	364.44625	364.44625	130	25	0	0	0	0	0	455	364.44625	364.44625	130	25	0	0	0	0	0
17	455	333.26	333.26	130	25	0	0	0	0	0	455	333.26	333.26	130	25	0	0	0	0	10
18	455	387.9	387.9	130	25	20	25	0	0	0	455	387.9	387.9	130	25	0	25	0	0	0
19	455	450.02563	450.02563	130	25	20	25	0	0	10	455	450.02563	450.02563	130	25	0	25	0	0	0
20	455	455	455	130	162	48.43625	25	10	10	10	455	455	455	130	162	48.43625	25	10	10	10
21	455	455	455	130	94.355	0	0	0	0	0	455	455	455	130	94.355	20	0	10	0	0
22	455	428.4375	428.4375	0	0	0	0	0	0	0	455	428.4375	428.4375	0	0	20	0	0	0	0
23	455	395	395	0	0	0	0	0	0	0	455	395	395	0	0	0	0	0	0	0
24	455	410	410	0	0	0	0	0	0	0	455	410	410	0	0	0	0	10	0	10

Table 10 (continued)

Hour	Generation schedule of committed units (GU41-GU60)																			
	41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
1	455	240	240	0	0	0	0	0	0	0	455	240	240	0	0	0	0	0	0	0
2	455	266.42857	266.42857	130	0	0	0	0	0	0	455	266.42857	266.42857	0	0	0	0	0	0	0
3	455	336.07143	336.07143	130	0	0	0	0	0	0	455	336.07143	336.07143	0	0	0	0	0	0	0
4	455	343.66667	343.66667	130	0	0	25	0	0	0	455	343.66667	343.66667	0	0	0	0	0	0	0
5	455	368.33333	368.33333	130	0	0	25	0	0	0	455	368.33333	368.33333	0	0	0	0	0	0	0
6	455	426.33333	426.33333	130	0	0	25	0	0	0	455	426.33333	426.33333	130	0	0	0	0	0	0
7	455	450.66667	450.66667	130	0	20	25	0	0	0	455	450.66667	450.66667	130	0	20	25	0	0	0
8	455	443.46563	443.46563	130	25	20	25	0	0	0	455	443.46563	443.46563	130	0	20	25	0	0	0
9	455	455	455	130	89.29125	20	25	0	0	0	455	455	455	130	89.29125	20	25	0	0	0
10	455	455	455	130	162	45.8325	25	10	10	0	455	455	455	130	162	45.8325	25	0	0	0
11	455	455	455	130	162	80	25	25.85375	10	10	455	455	455	130	162	80	25	25.85375	10	10
12	455	455	455	130	162	80	25	55	42.2425	10	455	455	455	130	162	80	25	55	42.2425	10
13	455	455	455	130	162	44.0175	25	0	0	0	455	455	455	130	162	44.0175	25	10	0	0
14	455	455	455	130	89.44125	0	25	0	0	0	455	455	455	130	89.44125	0	25	0	0	0
15	455	455	455	0	26.30125	0	0	0	0	0	455	455	455	130	26.30125	0	0	0	0	0
16	455	364.44625	364.44625	0	25	0	0	0	0	0	455	364.44625	364.44625	130	25	0	0	0	0	0
17	455	333.26	333.26	0	25	0	0	0	0	0	455	333.26	333.26	130	25	0	0	0	0	0
18	455	387.9	387.9	0	25	0	25	0	0	0	455	387.9	387.9	130	25	0	0	0	0	0
19	455	450.02563	450.02563	0	25	0	25	0	0	0	455	450.02563	450.02563	130	25	0	0	0	0	0
20	455	455	455	130	162	48.43625	25	10	10	10	455	455	455	130	162	48.43625	25	0	0	0
21	455	455	455	130	94.355	20	25	0	0	0	455	455	455	130	94.355	20	25	0	0	0
22	455	428.4375	428.4375	130	0	20	0	0	0	0	455	428.4375	428.4375	0	0	20	25	0	0	0
23	455	395	395	130	0	0	0	0	0	0	455	395	395	0	0	0	0	0	0	0
24	455	410	410	130	0	0	0	0	0	0	455	410	410	0	0	0	0	0	0	0

Table 10 (continued)

Hour	Generation schedule of committed units (GU61-GU80)																			
	61	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**
1	455	240	0	0	0	0	0	0	0	0	455	240	0	0	0	0	0	0	0	0
2	455	266.42857	0	0	0	0	0	0	0	0	455	266.42857	0	0	0	0	0	0	0	0
3	455	336.07143	0	0	25	0	0	0	0	0	455	336.07143	0	0	0	0	0	0	0	0
4	455	343.66667	343.66667	130	25	20	0	0	0	0	455	343.66667	0	130	25	0	0	0	0	0
5	455	368.33333	368.33333	130	25	20	0	0	0	0	455	368.33333	0	130	25	0	0	0	0	0
6	455	426.33333	426.33333	130	25	20	0	0	0	0	455	426.33333	0	130	25	0	0	0	0	0
7	455	450.66667	450.66667	130	25	20	0	10	0	0	455	450.66667	0	130	25	0	25	0	0	0
8	455	443.46563	443.46563	130	25	20	0	0	0	0	455	443.46563	443.46563	130	25	0	25	0	0	0
9	455	455	455	130	89.29125	20	25	0	0	0	455	455	455	130	89.29125	0	25	0	0	0
10	455	455	455	130	162	45.8325	25	0	0	10	455	455	455	130	162	45.8325	25	0	0	0
11	455	455	455	130	162	80	25	25.85375	10	10	455	455	455	130	162	80	25	25.85375	10	10
12	455	455	455	130	162	80	25	55	42.2425	10	455	455	455	130	162	80	25	55	42.2425	10
13	455	455	455	130	162	44.0175	25	10	0	10	455	455	455	130	162	44.0175	25	0	0	0
14	455	455	455	130	89.44125	0	25	0	0	0	455	455	455	130	89.44125	0	25	0	10	0
15	455	455	455	130	26.30125	0	0	0	0	0	455	455	455	0	26.30125	0	0	0	0	0
16	455	364.44625	364.44625	130	25	0	0	0	0	0	455	364.44625	364.44625	0	25	0	0	0	0	0
17	455	333.26	333.26	130	25	0	0	0	0	0	455	333.26	333.26	0	25	0	0	0	0	0
18	455	387.9	387.9	130	25	20	0	0	0	0	455	387.9	387.9	0	25	0	25	0	0	0
19	455	450.02563	450.02563	130	25	20	0	0	0	0	455	450.02563	450.02563	0	25	0	25	0	0	0
20	455	455	455	130	162	48.43625	25	0	0	0	455	455	455	130	162	48.43625	25	0	0	0
21	455	455	455	130	94.355	20	25	0	0	0	455	455	455	130	94.355	20	0	0	0	0
22	455	428.4375	428.4375	0	0	0	25	0	0	0	455	428.4375	428.4375	130	0	20	0	0	0	0
23	455	395	395	0	0	0	0	0	0	0	0	0	0	130	0	0	0	0	0	0
24	0	0	0	0	0	0	0	10	0	0	0	0	0	130	0	0	25	0	0	0

Table 11 Power scheduling for 100-generating unit system considering renewable energy in summer

Hour	Generation schedule of committed units (GU1-GU20)																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	455	231.785	231.785	0	0	0	0	0	0	0	455	231.7857143	231.7857143	0	0	20	0	0	0	0
2	455	223.928	223.9285	130	0	0	25	0	10	0	455	223.9285714	223.9285714	130	0	20	0	0	0	0
3	455	285.714	285.7142	130	0	0	25	0	0	0	455	285.7142857	285.7142857	130	0	20	0	0	0	0
4	455	318.666	318.6666	130	0	0	25	0	0	0	455	318.6666667	318.6666667	130	0	0	0	0	0	0
5	455	324.687	324.6875	129.99	25	0	0	0	0	0	455	324.6875	324.6875	129.999	0	0	0	0	0	0
6	455	355	355	130	25	0	0	0	0	0	455	355	355	130	0	0	0	0	0	0
7	455	405.882	405.8823	0	25	0	0	0	0	0	455	405.8823529	405.8823529	0	0	0	0	0	0	0
8	455	437.085	437.085	0	25	0	0	0	0	0	455	437.0852941	437.0852941	0	0	0	0	0	0	0
9	454.999	449.685	449.685	0	25	0	0	0	0	0	454.999	449.6850001	449.6850001	0	25.00000005	0	0	0	0	0
10	454.999	449.613	449.613	0	25	20.0000001	0	0	0	0	454.999	449.6136844	449.6136844	0	25.0000002	0	25	10.0000001	0	0
11	455	455	455	0	39.283	20	0	0	0	0	455	455	455	0	39.283	0	25	0	0	0
12	455	455	455	130	69.894	20.00000001	25	0	0	0	455	455	455	130	69.894	0	25	0	0	0
13	455	431.657	431.657	129.999	25	0	25	0	0	0	455	431.657	431.657	129.999	25	0	0	0	0	10
14	455	377.526	377.5265	130	0	0	25	10	0	0	455	377.5265	377.5265	130	25	0	0	0	0	0
15	455	325.770	325.7705	130	0	0	0	0	0	0	455	325.7705	325.7705	130	25	0	0	0	0	0
16	455	246.057	246.057	130	0	0	0	0	0	0	455	246.057	246.057	130	25	0	0	0	0	0
17	455	243.358	243.358	0	0	0	0	0	0	0	455	243.358	243.358	0	25	0	0	0	0	0
18	455	279.57	279.57	0	0	0	25	0	0	0	455	279.57	279.57	0	25	0	25	0	0	0
19	455	334.020	334.0205	0	0	0	25	0	0	0	455	334.0205	334.0205	0	25	0	25	0	0	0
20	455	436.924	436.9245	0	25	0	25	0	0	0	455	436.9245	436.9245	0	25	20	25	0	0	0
21	455	422.623	422.623	0	25	0	0	0	0	0	455	422.6231579	422.6231579	0	25	20	0	0	0	0
22	455	419.0625	419.0625	0	25	0	0	0	0	0	455	419.0625	419.0625	130	0	20	0	0	0	0
23	455	453.333	453.333	129.999	25	0	0	0	0	0	455	453.3333334	453.3333334	129.999	0	0	0	0	0	0
24	455	455	455	130	65.714	0	25	0	0	0	455	455	455	130	0	0	0	0	0	0

Table 11 (continued)

Hour	Generation schedule of committed units (GU21-GU40)																			
	21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
1	455	231.785	231.785	0	0	0	0	0	0	0	455	231.7857143	231.7857143	0	0	0	0	0	0	0
2	455	223.928	223.928	0	0	0	0	0	10	0	455	223.9285714	223.9285714	130	0	0	0	0	0	0
3	455	285.714	285.714	0	0	0	0	0	0	0	455	285.7142857	285.7142857	130	25	0	0	0	0	0
4	455	318.666	318.666	0	25	0	0	0	0	0	455	318.6666667	318.6666667	130	25	0	0	0	0	0
5	455	324.687	324.687	0	25	0	0	10	0	0	455	324.6875	324.6875	129.9999999	25	20	0	0	0	0
6	455	355	355	0	25	0	25	0	0	0	455	355	355	130	25	20	0	0	0	0
7	455	405.882	405.882	0	25	0	25	0	0	0	455	405.8823529	405.8823529	0	25	20	0	0	0	0
8	455	437.085	437.085	0	25	0	25	0	10	0	455	437.0852941	437.0852941	0	25	20	0	0	0	10
9	454.999	449.685	449.685	0	25	0	25	0	0	0	454.9999999	449.6850001	449.6850001	0	25.00000005	0	25	0	0	0
10	454.999	449.613	449.613	129.999	25	20	0	0	10	0	454.9999997	449.6136844	449.6136844	0	25.0000002	0	25	0	0	0
11	455	455	455	130	39.283	20	0	0	0	0	455	455	455	0	39.283	0	25	0	0	0
12	455	455	455	130	69.894	20	0	0	10	0	455	455	455	0	69.894	0	0	0	0	0
13	455	431.657	431.657	129.999	25	0	0	0	0	0	455	431.657	431.657	0	0	20	0	0	0	0
14	455	377.526	377.5265	130	0	0	0	0	0	0	455	377.5265	377.5265	0	0	20	0	0	0	0
15	455	325.770	325.7705	130	0	0	0	0	0	0	455	325.7705	325.7705	130	0	20	0	0	0	0
16	455	246.057	246.057	130	0	0	0	0	0	0	455	246.057	246.057	130	0	0	0	0	0	0
17	455	243.358	243.358	0	0	0	0	0	0	0	455	243.358	243.358	129.9999998	0	0	0	0	0	0
18	455	279.57	279.57	0	0	0	25	0	0	0	455	279.57	279.57	130	0	0	0	0	0	0
19	455	334.0205	334.0205	0	0	0	25	0	0	0	455	334.0205	334.0205	130	0	0	0	10	0	0
20	455	436.9245	436.9245	0	0	0	25	0	0	10	455	436.9245	436.9245	0	0	0	0	0	0	0
21	455	422.623	422.623	0	0	0	0	0	0	0	455	422.6231579	422.6231579	0	0	0	0	0	0	0
22	455	419.0625	419.0625	130	0	0	0	0	0	0	455	419.0625	419.0625	0	0	0	0	0	0	0
23	455	453.333	453.3333334	129.999	25	0	0	0	10	0	455	453.3333334	453.3333334	0	0	0	0	0	0	0
24	455	455	455	130	65.714	0	0	0	0	0	455	455	455	0	0	0	0	0	0	0

Table 11 (continued)

Hour	Generation schedule of committed units (GU41-GU60)																			
	41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
1	455	231.785	231.785	0	0	0	25	0	0	0	455	231.785	0	0	0	0	0	0	0	0
2	455	223.928	223.928	0	25	0	25	0	0	0	455	223.928	0	0	0	20	0	0	0	0
3	455	285.7142	285.714	130	25	0	25	0	0	0	455	285.714	0	0	0	20	0	0	0	0
4	455	318.666	318.666	130	25	0	0	0	0	0	455	318.666	318.666	0	0	20	0	0	0	0
5	455	324.6875	324.6875	129.999	25	0	0	0	0	10	455	324.6875	324.6875	0	0	0	0	0	0	0
6	455	355	355	130	25	0	0	0	0	0	455	355	355	130	0	0	0	0	0	0
7	455	405.882	405.882	130	25	0	0	0	0	0	455	405.882	405.882	130	25	0	0	0	0	0
8	455	437.085	437.085	0	25	20	0	0	0	0	455	437.0852	437.085	130	25	0	0	0	0	10
9	454.999	449.685	449.685	0	25	20	25	0	0	0	454.999	449.685	449.685	129.999	25	0	0	0	0	0
10	454.999	449.613	449.6136	0	25	20	25	0	0	0	454.999	449.6136	449.613	129.999	25	0	0	0	0	0
11	455	455	455	0	39.283	0	25	0	0	0	455	455	455	0	39.283	0	0	0	0	0
12	455	455	455	0	69.894	0	0	0	0	0	455	455	455	0	69.894	0	0	0	0	10
13	455	431.657	431.657	129.999	0	0	0	0	0	0	455	431.657	431.657	0	0	0	0	0	0	0
14	455	377.5265	377.5265	130	0	0	0	0	0	0	455	377.5265	377.5265	0	0	0	0	0	0	0
15	455	325.7705	325.7705	130	0	0	0	0	0	0	455	325.7705	325.7705	0	0	0	0	0	0	0
16	455	246.057	246.057	130	0	0	0	0	0	0	455	246.057	246.057	0	0	0	0	0	0	0
17	455	243.358	243.358	129.999	0	0	0	0	0	0	455	243.358	243.358	0	0	0	0	0	0	0
18	455	279.57	279.57	130	0	0	0	0	0	0	455	279.57	279.57	130	0	0	25	0	0	0
19	455	334.0205	334.0205	0	0	0	0	0	0	0	455	334.0205	334.0205	130	0	0	25	0	0	0
20	455	436.9245	436.9245	0	0	20	0	10	0	0	455	436.9245	436.9245	130	0	0	25	0	0	0
21	455	422.623	422.623	0	0	20	0	0	0	0	455	422.6231579	422.6231579	130	25	0	0	0	0	0
22	455	419.0625	419.0625	0	0	20	0	0	0	0	455	419.0625	419.0625	130	25	0	0	0	0	0
23	455	453.333	453.333	0	0	0	0	0	0	0	455	453.3333334	0	0	25	0	0	0	0	0
24	455	455	0	0	0	0	0	0	0	0	0	455	0	0	65.71428572	0	0	0	0	0

Table 11 (continued)

Hour	Generation schedule of committed units (GU61-GU80)																			
	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	455	231.785	0	0	0	0	25	0	0	0	455	231.785	231.78571	0	0	0	0	0	0	0
2	455	223.928	0	130	0	0	25	0	0	0	455	223.928	223.9285714	0	0	0	0	0	0	0
3	455	285.714	0	130	0	0	25	0	0	0	455	285.714	285.7142857	0	0	0	0	0	0	0
4	455	318.666	0	130	0	0	0	0	0	0	455	318.666	318.6666667	130	25	0	0	0	0	0
5	455	324.687	324.6875	129.999	25	20	0	0	0	0	455	324.6875	324.6875	129.9999999	25	20	0	0	0	0
6	455	355	355	130	25	20	0	0	0	0	455	355	355	130	25	20	0	0	0	0
7	455	405.882	405.882	0	25	20	0	0	0	0	455	405.8823	405.8823529	130	25	20	0	0	0	0
8	455	437.085	437.085	0	25	0	25	0	0	0	455	437.0852	437.0852941	130	25	20	0	0	0	0
9	454.999	449.685	449.685	0	25	0	25	0	0	0	454.999	449.685	449.6850001	0	25.00000005	20.00000003	0	0	0	0
10	454.999	449.613	449.613	0	25	0	25	0	0	0	454.999	449.6136	449.6136844	0	25.0000002	20.0000001	0	0	0	0
11	455	455	455	0	39.283	0	0	0	0	0	455	455	455	0	39.283	0	0	0	0	0
12	455	455	455	0	69.894	0	0	0	0	0	455	455	455	0	69.894	0	25	0	0	10
13	455	431.657	431.657	0	0	20	0	0	0	0	455	431.657	431.657	0	0	0	25	0	0	0
14	455	377.5265	377.5265	130	0	20	0	0	0	0	455	377.5265	377.5265	0	0	20	25	0	0	0
15	455	325.7705	325.7705	130	0	20	0	0	0	0	455	325.7705	325.7705	0	0	20	0	0	0	0
16	455	246.057	246.057	130	0	0	0	0	0	0	455	246.057	246.057	130	0	20	0	0	0	0
17	455	243.358	243.358	129.999	0	0	0	0	0	0	455	243.358	243.358	129.9999998	0	0	0	0	0	0
18	455	279.57	279.57	130	0	0	25	0	0	0	455	279.57	279.57	130	0	0	25	0	0	0
19	455	334.0205	334.0205	130	0	0	25	10	0	0	455	334.0205	334.0205	130	0	0	25	0	0	0
20	455	436.9245	436.9245	0	0	0	25	10	0	0	455	436.9245	436.9245	130	0	0	25	0	0	0
21	455	422.623	422.6231	0	0	0	0	0	0	0	455	422.623	422.6231579	0	0	0	0	0	0	0
22	455	419.0625	419.0625	0	0	0	0	0	0	0	455	419.0625	0	0	0	0	0	0	0	0
23	0	453.333	0	0	0	0	0	0	0	0	0	0	0	0	25.00000002	0	0	0	0	0
24	0	0	0	0	65.714	0	0	0	0	0	0	0	0	0	65.71428572	20.00000001	0	0	0	0

Table 11 (continued)

Hour	Generation schedule of committed units (GU81-GU100)																			
	81	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**100**
1	0	0	0	0	0	20	0	0	0	0	0	0	0	0	25	0	0	0	0	0
2	0	0	0	0	0	20	0	0	0	0	0	0	0	0	25	0	0	0	0	0
3	0	0	0	0	0	20	0	0	0	0	0	0	0	0	25	0	0	0	0	0
4	0	0	0	130	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0
5	0	0	0	129.999	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0
6	0	0	355	130	0	0	25	0	0	0	0	0	0	0	25	0	0	0	0	0
7	0	0	405.882	130	0	0	25	0	0	0	0	0	0	130	25	0	0	0	0	0
8	0	0	437.085	130	0	20	25	0	0	0	0	0	0	130	25	20	0	0	0	0
9	454.999	449.685	449.685	129.999	0	20	0	0	0	0	0	0	0	129.999	25.00000005	20.00000003	0	0	0	0
10	454.999	449.613	449.613	0	0	20.0000001	0	0	0	0	454.999	449.613	0	129.9999	25.0000002	20.0000001	25	0	0	0
11	455	455	455	0	39.283	20	0	0	0	0	455	455	455	130	39.283	0	25	0	0	0
12	455	455	455	0	69.894	20.00000001	25	0	0	0	455	455	455	0	69.894	0	25	0	0	0
13	455	431.657	431.657	0	25	20	25	0	0	0	455	431.657	431.657	0	0	0	0	0	0	0
14	455	377.5265	377.5265	0	25	0	25	0	0	0	455	377.5265	377.5265	0	0	0	0	0	0	0
15	455	325.7705	325.7705	0	25	0	0	0	0	0	455	325.7705	325.7705	0	0	0	0	0	0	0
16	455	246.057	246.057	0	25	0	0	0	0	0	455	246.057	246.057	0	0	0	0	0	0	0
17	455	243.358	243.358	0	0	0	0	0	0	0	455	243.358	243.358	0	0	0	0	0	0	0
18	455	279.57	279.57	0	0	0	0	0	0	0	455	279.57	279.57	0	0	0	0	0	0	0
19	455	334.0205	334.0205	0	0	0	0	10	0	0	455	334.020	334.0205	0	25	0	0	0	0	0
20	455	436.9245	436.9245	0	0	20	0	0	0	0	455	436.924	436.9245	130	25	0	0	0	0	0
21	455	422.623	422.623	0	0	20	0	0	0	0	455	422.623	0	130	25	0	0	0	0	0
22	0	0	419.0625	0	0	20	0	0	0	0	0	0	0	130	25	0	0	0	0	0
23	0	0	0	129.999	25	20.00000001	0	0	0	0	0	0	0	129.9999999	25.00000002	0	0	0	0	0
24	0	0	0	130	65.71428572	0	0	0	0	0	0	0	0	130	65.71428572	20.00000001	0	0	0	0

Table 12 Power scheduling for 5-generating unit system considering renewable energy in winter

Hour	Generation schedule of committed units				
	GU1	GU2	GU3	GU4	GU5
h1	0	48	100	0	0
h2	0	73	100	0	0
h3	220	0	0	0	0
h4	144	0	100	0	0
h5	119	140	0	0	0
h6	108	140	0	0	0
h7	227	0	0	0	0
h8	202	0	0	0	0
h9	175.4271	0	0	0	0
h10	130.44	0	0	0	0
h11	93.4	0	0	0	0
h12	111.96	0	0	0	0
h13	135.01	0	0	0	0
h14	151.48	0	0	0	0
h15	162.88	0	0	0	0
h16	196.4	0	0	0	0
h17	220.91	0	0	0	0
h18	222.68	0	0	0	0
h19	222.02	0	0	0	0
h20	209.82	0	0	0	0
h21	176	0	0	0	0
h22	157	0	0	0	0
h23	138	0	0	0	0
h24	103	0	0	0	0

test system considering summer and winter, respectively, using the hHHO-SCA algorithm is 1076400 $/hour and 1084100 $/hour. Without considering the renewable energy sources, the total generation cost is 1125200 $/hour.

40-Generating Unit System: The sixth system contains 40-power generating units having a 24-hour electricity demand including 10% SR [145]. The hHHO-SCA technique is evaluated for 100 iterations. Tables 8 and 18 show that optimal scheduling for this test system considering summer and winter, respectively, using the hHHO-SCA algorithm is 2176900 $/hour and 2189400 $/hour. Without considering the renewable energy sources, the total generation cost is 2253700 $/hour.

60-Generating Unit System: The seventh system contains 60-power generating units with 24-hour electricity demand including 10% SR [145]. The hHHO-SCA technique is evaluated for 100 iterations. Tables 9 and 19 show that optimal scheduling for this test system considering summer and winter, respectively, using the hHHO-SCA algorithm is 8226.6 $/hour and 8572.9 $/hour. Without considering the renewable energy sources, the total generation cost is 9010.1$/hour.

Table 13 Power scheduling for 6-generating unit system considering renewable energy in winter

Hour	Generation schedule of committed units					
	GU1	GU2	GU3	GU4	GU5	GU6
h1	166	0	0	0	0	0
h2	154.35294	41.647059	0	0	0	0
h3	181.52941	47.470588	0	0	0	0
h4	196.52466	50.683857	19.79148	0	0	0
h5	200	60.78125	22.61875	0	0	0
h6	200	51.875	20.125	0	0	0
h7	195.52941	50.470589	0	0	0	0
h8	168.35294	44.647059	0	0	0	0
h9	150.58702	40.840077	0	0	0	0
h10	157.44	0	0	0	0	0
h11	140.4	0	0	0	0	0
h12	141.96	0	0	0	0	0
h13	148.01	0	0	0	0	0
h14	168.48	0	0	0	0	0
h15	175.88	0	0	0	0	0
h16	160.44706	42.952941	0	0	0	0
h17	176.51412	46.395882	0	0	0	0
h18	176.32471	46.355294	0	0	0	0
h19	180.72235	47.297647	0	0	0	0
h20	178.08706	46.732941	0	0	0	0
h21	160.94118	43.058824	0	0	0	0
h22	142.82353	39.176471	0	0	0	0
h23	161	0	0	0	0	0
h24	131	0	0	0	0	0

80-Generating Unit System: The eighth system contains 80-power generating units with 24-hour power demand including 10% SR [145]. The hHHO-SCA technique is evaluated for 100 iterations. Tables 10 and 20 show that optimal scheduling for this test system considering summer and winter, respectively, using the hHHO-SCA algorithm is 5578000 $/hour and 5591700 $/hour.

100-Generating Unit System: The ninth system contains 100-power generating units with 24-hour power demand including 10% SR [145]. The hHHO-SCA technique is evaluated for 100 iterations. Tables 11 and 21 show that optimal scheduling for this test system considering summer and winter, respectively, using the hHHO-SCA algorithm is 5530800 $/hour and 552990 $/hour (Tables 22, 23, 24, 25).

Table 14 Power scheduling for 10-generating unit system (5% SR) considering renewable energy in winter

Hour	Generation schedule of committed units									
	GU1	GU2	GU3	GU4	GU5	GU6	GU7	GU8	GU9	GU10
1	400	150	150	0	0	0	0	0	0	0
2	450	150	150	0	0	0	0	0	0	0
3	455	197.5	197.5	0	0	0	0	0	0	0
4	455	247.5	247.5	0	0	0	0	0	0	0
5	455	272.5	272.5	0	0	0	0	0	0	0
6	455	322.5	322.5	0	0	0	0	0	0	0
7	455	347.5	347.5	0	0	0	0	0	0	0
8	455	372.5	372.5	0	0	0	0	0	0	0
9	455	422.21355	422.21355	0	0	0	0	0	0	0
10	455	455	455	0	31.44	0	0	0	0	0
11	455	455	455	0	78.4	0	0	0	0	0
12	455	455	455	0	96.96	20	0	0	0	0
13	455	439.005	439.005	0	25	20	0	0	0	0
14	455	391.74	391.74	0	25	20	0	0	0	0
15	455	343.94	343.94	0	25	0	0	0	0	0
16	455	283.2	283.2	0	0	0	0	0	0	0
17	455	260.955	260.955	0	0	0	0	0	0	0
18	455	313.34	313.34	0	0	0	0	0	0	0
19	455	368.51	368.51	0	0	0	0	0	0	0
20	455	455	455	0	0	24.82	0	10	0	0
21	455	412.5	412.5	0	0	20	0	0	0	0
22	455	312.5	312.5	0	0	20	0	0	0	0
23	455	222.5	222.5	0	0	0	0	0	0	0
24	455	345	0	0	0	0	0	0	0	0

Table 15 Power scheduling for 10-generating unit system (10% SR) considering renewable energy in winter

Hour	Generation schedule of committed units									
	GU1	GU2	GU3	GU4	GU5	GU6	GU7	GU8	GU9	GU10
1	400	150	150	0	0	0	0	0	0	0
2	450	150	150	0	0	0	0	0	0	0
3	455	197.5	197.5	0	0	0	0	0	0	0
4	455	247.5	247.5	0	0	0	0	0	0	0
5	455	272.5	272.5	0	0	0	0	0	0	0
6	455	322.5	322.5	0	0	0	0	0	0	0
7	455	347.5	347.5	0	0	0	0	0	0	0
8	455	372.5	372.5	0	0	0	0	0	0	0
9	455	357.21355	357.21355	130	0	0	0	0	0	0
10	455	393.22	393.22	130	25	0	0	0	0	0
11	455	416.7	416.7	130	25	0	0	0	0	0
12	455	435.98	435.98	130	25	0	0	0	0	0
13	455	384.005	384.005	130	25	0	0	0	0	0
14	455	401.74	401.74	0	25	0	0	0	0	0
15	455	343.94	343.94	0	25	0	0	0	0	0
16	455	283.2	283.2	0	0	0	0	0	0	0
17	455	260.955	260.955	0	0	0	0	0	0	0
18	455	313.34	313.34	0	0	0	0	0	0	0
19	455	368.51	368.51	0	0	0	0	0	0	0
20	455	402.41	402.41	130	0	0	0	10	0	0
21	455	357.5	357.5	130	0	0	0	0	0	0
22	455	257.5	257.5	130	0	0	0	0	0	0
23	455	315	0	130	0	0	0	0	0	0
24	455	215	0	130	0	0	0	0	0	0

Table 16 Power scheduling for 19-generating unit system considering renewable energy in winter

Hour	Generation schedule of committed units (GU1-GU19)																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	464.871134	0	0	224.278351	0	0	0	0	0	0	363.634021	0	900	517.216495	0	700	0	0	0
2	467.567407	0	0	226.300555	0	0	0	0	20	0	366.060666	0	900	520.071372	0	700	0	0	0
3	443.98247	0	0	0	0	0	0	0	20	0	344.834223	346.084223	900	495.099085	0	700	0	0	0
4	429.734204	0	0	0	0	0	30	0	20	0	332.010783	333.260783	884.601306	480.012686	0	696.801107	93.579131	0	0
5	461.145231	0	0	0	0	0	30	0	20	0	360.280707	361.530707	900	513.271421	0	700	113.771934	0	0
6	462.766821	0	0	222.700116	0	0	0	0	0	0	361.740139	362.990139	900	514.988399	0	700	114.814385	0	0
7	471.525922	0	0	229.269442	0	0	0	0	0	0	369.62333	370.87333	900	524.262741	0	700	120.445236	0	0
8	473.734711	0	64.2653162	230.926033	0	0	0	0	0	0	371.61124	372.86124	900	526.601459	0	700	0	0	0
9	500	0	104.251216	282.574487	0	0	73.0844752	0	0	0	400	0	900	599.516922	0	700	0	0	0
10	475.909699	0	65.5282123	232.557274	0	0	36.7083206	0	0	0	373.568729	0	900	528.904387	0	700	123.263378	0	0
11	455.043401	0	0	216.90755	0	0	0	0	0	0	354.789061	0	900	506.810659	0	700	109.849329	0	0
12	435.560947	0	0	202.29571	0	0	30	0	0	0	337.254852	0	893.34142	486.182179	0	699.999999	97.3248942	0	0
13	439.883448	0	44.6097442	205.537586	0	0	30	0	0	0	0	342.395103	899.825172	490.758945	0	700	0	0	0
14	456.271299	0	54.1252705	217.828474	0	0	0	0	0	0	0	357.144169	900	508.110787	0	700	0	0	0
15	429.084292	0	38.3392661	197.438219	0	0	0	0	0	0	331.425862	332.675862	883.626437	479.324544	0	695.965518	0	0	0
16	464.36959	0	58.8275052	223.902193	0	0	0	0	0	0	363.182631	364.432631	900	516.685449	0	700	0	0	0
17	465.431356	0	59.4440145	224.698517	0	0	0	0	0	0	364.138221	365.388221	900	517.809671	0	700	0	0	0
18	458.642607	0	55.5021597	219.606956	0	0	0	0	0	0	358.028347	359.278347	900	510.621584	0	700	0	0	0
19	446.891704	0	0	210.793778	0	0	0	0	0	0	347.452534	348.702534	900	498.179451	0	700	0	0	0
20	486.055749	0	0	240.166812	0	0	0	0	20	0	0	383.950175	900	539.647264	0	700	0	0	0
21	469.926646	0	0	228.069984	0	0	0	0	20	0	0	369.433981	900	522.569389	0	700	0	0	0
22	454.894925	0	0	216.796193	0	0	0	0	20	0	354.655432	0	900	506.65345	0	700	0	0	0
23	0	0	0	236.329462	0	0	0	0	20	0	378.095355	379.345355	900	534.229829	0	700	0	0	0
24	0	0	0	220.718574	0	0	0	0	0	0	359.362289	360.612289	900	512.190928	0	700	113.115921	0	0

Table 17 Power scheduling for 20-generating unit system considering renewable energy in winter

Hour	Generation schedule of committed units (GU1-GU20)																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	455	163.333333	163.333333	0	0	0	0	0	0	0	455	163.333333	0	0	0	0	0	0	0	0
2	455	196.666667	196.666667	0	0	0	0	0	0	0	455	196.666667	0	0	0	0	0	0	0	0
3	455	220	220	130	0	0	0	0	0	0	455	220	0	0	0	0	0	0	0	0
4	455	286.666667	286.666667	130	0	0	0	0	0	0	455	286.666667	0	0	0	0	0	0	0	0
5	455	320	320	130	0	0	0	0	0	0	455	320	0	0	0	0	0	0	0	0
6	455	343.333333	343.333333	130	0	0	0	0	0	0	455	343.333333	0	130	0	0	0	0	0	0
7	455	376.666667	376.666667	130	0	0	0	0	0	0	455	376.666667	0	130	0	0	0	0	0	0
8	455	393.333333	393.333333	130	0	0	25	0	0	0	455	393.333333	0	130	25	0	0	0	0	0
9	455	344.856775	344.856775	130	0	0	25	0	0	0	455	344.856775	344.856775	130	25	0	0	0	0	0
10	455	394.11	394.11	130	0	0	25	0	0	0	455	394.11	394.11	130	25	0	0	0	0	0
11	455	418.35	418.35	130	25	0	0	0	0	0	455	418.35	418.35	130	25	0	0	0	0	0
12	455	440.49	440.49	130	25	0	0	0	0	0	455	440.49	440.49	130	25	0	0	0	0	0
13	455	422.0025	422.0025	130	25	0	0	0	0	0	455	422.0025	422.0025	0	25	0	0	0	0	0
14	455	412.12	412.12	0	25	0	0	0	0	0	455	412.12	412.12	0	0	0	0	0	0	0
15	455	358.22	358.22	0	25	0	0	0	0	0	455	358.22	358.22	0	0	0	0	0	0	0
16	455	284.1	284.1	0	25	0	0	0	0	0	455	284.1	284.1	0	0	0	0	0	0	0
17	455	260.4775	260.4775	0	25	0	0	0	0	0	455	260.4775	260.4775	0	0	0	0	0	0	0
18	455	304.17	304.17	0	25	0	0	0	0	0	455	304.17	304.17	0	0	20	0	0	0	10
19	455	359.255	359.255	0	25	0	0	0	0	0	455	359.255	359.255	0	0	20	0	0	0	0
20	455	454.955	454.955	0	25	0	0	0	0	0	455	454.955	454.955	0	25	20	0	0	0	0
21	455	416.25	416.25	0	0	0	0	0	0	0	455	416.25	416.25	0	25	0	0	0	0	0
22	455	421.666667	421.666667	0	0	0	0	0	0	0	455	421.666667	0	0	25	0	0	0	0	0
23	455	432.5	432.5	0	0	0	0	0	0	0	455	0	0	0	25	0	0	0	0	0
24	455	332.5	332.5	0	0	0	0	0	0	0	455	0	0	0	25	0	0	0	0	0

Table 18 Power scheduling for 40-generating unit system considering renewable energy in winter

Hour	Generation schedule of committed units (GU1-GU20)																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	455	196	196	0	0	0	0	0	0	0	455	196	196	0	0	0	0	0	0	0
2	455	231	231	0	0	0	0	0	0	0	455	231	231	0	25.0000001	0	0	0	0	0
3	455	271	271	130	25	20	0	0	0	0	455	271	271	0	25	0	0	0	0	0
4	455	292.5	292.5	130	25	20	0	0	0	0	455	292.5	292.5	0	25	0	0	0	0	0
5	455	321.666667	321.666667	130	25	20	0	0	0	0	455	321.666667	321.666667	0	25	0	0	0	0	0
6	455	390	390	130	25	0	0	10	0	0	455	390	390	0	25	0	0	0	0	0
7	455	367.857143	367.857143	130	25	0	0	0	0	0	455	367.857143	367.857143	0	25	0	0	0	0	0
8	455	415	415	0	25	0	0	0	0	0	455	415	415	0	25	0	0	0	0	0
9	455	413.053388	413.053388	0	25	0	0	0	0	0	455	413.053388	413.053388	0	25	0	0	0	0	0
10	455	427.055	427.055	0	25	0	0	0	0	0	455	427.055	427.055	130	25	0	0	0	0	0
11	455	445.425	445.425	0	25	0	25	0	0	0	455	445.425	445.425	130	25	0	25	0	0	0
12	455	452.745	452.745	0	25.0000001	0	25	0	0	0	455	452.745	452.745	130	25.0000001	0	25	0	0	0
13	455	408.50125	408.50125	0	0	0	25	0	0	0	455	408.50125	408.50125	130	0	0	25	0	0	0
14	455	365.435	365.435	0	0	0	0	0	0	0	455	365.435	365.435	130	0	0	0	0	0	0
15	455	349.11	349.11	0	0	0	0	0	0	0	455	349.11	349.11	0	0	0	0	0	0	0
16	455	277.675	277.675	0	0	0	0	0	0	0	455	277.675	277.675	0	0	0	0	0	0	0
17	455	269.61375	269.61375	0	0	0	0	0	0	0	455	269.61375	269.61375	0	0	0	0	0	0	0
18	455	314.585	314.585	0	0	0	0	0	0	0	455	314.585	314.585	0	0	0	0	10	0	0
19	455	365.2525	365.2525	0	0	0	0	0	0	0	455	365.2525	365.2525	0	25	0	0	0	0	0
20	455	440.6025	440.6025	130	0	20	0	0	0	0	455	440.6025	440.6025	0	25	20	25	10	0	0
21	455	455	455	130	95	20	0	0	0	0	455	455	455	0	95	20	25	0	0	0
22	455	435.833333	435.833333	130	25	20	0	0	0	0	455	435.833333	435.833333	0	25	20	25	0	0	0
23	455	376	376	130	25	0	0	0	0	0	455	376	376	0	25	0	0	0	0	0
24	455	381.25	381.25	130	25	0	0	0	0	0	455	381.25	381.25	0	25	0	0	0	0	0

Table 18 (continued)

Hour	Generation schedule of committed units (GU21-GU40)																			
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	455	196	0	0	0	0	0	0	0	0	455	0	0	0	0	0	0	0	0	0
2	455	231	0	0	0	0	0	0	0	0	455	0	0	0	0	0	0	0	0	0
3	455	271	0	0	0	0	25	0	0	0	455	0	0	0	0	0	0	0	0	0
4	455	292.5	292.5	0	0	0	25	0	0	0	455	0	0	0	0	0	0	0	0	0
5	455	321.666667	321.666667	0	0	0	25	0	0	0	455	0	0	0	25	0	0	0	0	0
6	455	390	390	0	0	0	25	0	0	0	455	0	0	0	25	0	0	0	0	0
7	455	367.857143	367.857143	0	0	0	0	0	0	0	455	0	367.857143	0	25	0	0	0	0	0
8	455	415	415	0	0	0	0	0	0	0	455	0	415	0	25	0	0	0	0	0
9	455	413.053388	413.053388	0	0	0	0	0	0	0	455	413.053388	413.053388	0	25	0	0	0	0	0
10	455	427.055	427.055	130	25	0	0	0	0	0	455	427.055	427.055	0	25	0	0	0	0	0
11	455	445.425	445.425	130	25	0	0	0	0	0	455	445.425	445.425	0	25	0	0	0	0	0
12	455	452.745	452.745	130	25.0000001	0	0	0	0	0	455	452.745	452.745	130	0	0	25	0	0	0
13	455	408.50125	408.50125	130	25	0	0	0	0	0	455	408.50125	408.50125	130	0	0	25	0	0	0
14	455	365.435	365.435	130	25	0	0	0	0	0	455	365.435	365.435	130	0	0	25	0	0	0
15	455	349.11	349.11	0	25	0	0	0	0	0	455	349.11	349.11	130	0	0	0	0	0	0
16	455	277.675	277.675	0	0	0	0	0	0	0	455	277.675	277.675	130	0	0	0	0	0	0
17	455	269.61375	269.61375	0	0	0	0	0	0	0	455	269.61375	269.61375	0	0	0	0	0	0	0
18	455	314.585	314.585	0	0	0	0	0	0	10	455	314.585	314.585	0	25	0	0	0	0	0
19	455	365.2525	365.2525	0	0	0	0	0	0	0	455	365.2525	365.2525	0	25	0	0	0	0	0
20	455	440.6025	440.6025	0	0	0	0	0	0	0	455	440.6025	440.6025	0	25	0	0	0	0	0
21	455	455	455	130	0	0	0	0	10	0	0	455	0	0	95	20	0	10	0	0
22	455	435.833333	435.833333	130	0	0	0	0	0	0	0	0	0	0	25	20	0	0	0	0
23	455	376	0	130	0	0	0	0	0	0	0	0	0	0	25	20	0	0	0	0
24	455	0	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 19 Power scheduling for 60-generating unit system considering renewable energy in winter

Hour	Generation schedule of committed units (GU1-GU20)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	455	340	340	0	0	0	0	0	0	0	455	340	340	0	0	0	0	0	0	0
2	455	382.857143	382.857143	0	0	0	0	0	0	0	455	382.857143	382.857143	0	0	0	0	0	0	0
3	455	435.714286	435.714286	0	0	0	0	0	0	0	455	435.714286	435.714286	0	0	0	0	0	0	0
4	455	405.555556	405.555556	0	0	0	0	0	0	0	455	405.555556	405.555556	0	0	0	0	0	0	0
5	455	395	395	0	0	0	0	0	0	0	455	395	395	0	0	0	0	0	0	0
6	455	442	442	0	25	0	0	0	0	0	455	442	442	0	0	0	0	0	0	0
7	455	443.5	443.5	130	25	0	0	0	0	0	455	443.5	443.5	130	0	0	0	0	0	0
8	455	455	455	130	47.5	0	0	0	0	0	455	455	455	130	47.5	0	25	0	0	0
9	455	417.452258	417.452258	130	25	0	0	0	0	0	455	417.452258	417.452258	130	25	0	25	0	0	0
10	455	429.286667	429.286667	130	25	0	0	0	0	0	455	429.286667	429.286667	130	25	0	25	0	0	0
11	455	439.033333	439.033333	130	25	0	25	0	0	0	455	439.033333	439.033333	130	25	0	25	0	0	0
12	455	448.913333	448.913333	130	25	0	25	0	0	0	455	448.913333	448.913333	130	25	0	0	0	0	0
13	455	424.4175	424.4175	130	0	0	25	0	0	0	455	424.4175	424.4175	0	25	0	0	0	0	0
14	455	370.29	370.29	130	0	0	0	0	0	0	455	370.29	370.29	0	0	0	0	0	0	0
15	455	337.323333	337.323333	0	0	0	0	0	0	0	455	337.323333	337.323333	0	0	0	0	0	0	0
16	455	328.14	328.14	0	0	0	0	0	0	0	455	328.14	328.14	0	0	0	0	0	0	0
17	455	311.691	311.691	0	0	0	0	0	0	0	455	311.691	311.691	0	0	0	0	0	0	0
18	455	364.668	364.668	0	0	0	0	0	0	0	455	364.668	364.668	0	0	0	0	0	0	0
19	455	390.702	390.702	0	0	20	0	0	0	0	455	390.702	390.702	130	0	0	0	0	0	0
20	455	455	455	130	105.964	20.0000002	25	10	0	0	455	455	455	130	105.964	20.0000002	0	10	10	0
21	455	444.5	444.5	130	25	20	25	0	0	0	455	444.5	444.5	130	25	20	0	0	0	0
22	455	455	455	130	70	0	25	0	0	0	455	455	455	130	70	20	25	0	0	0
23	455	455	455	130	29.1666669	0	0	0	0	0	455	455	455	130	29.1666669	0	25	0	0	0
24	455	455	455	130	58	0	0	0	0	0	455	455	455	0	58	0	25	0	0	0

Table 19 (continued)

Hour	Generation schedule of committed units (GU21-GU40)																			
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	455	340	340	0	0	0	0	0	0	0	455	340	0	0	0	0	0	0	0	0
2	455	382.857143	382.857143	0	0	0	0	0	0	0	455	382.857143	0	0	0	0	0	0	0	0
3	455	435.714286	435.714286	0	0	0	0	0	0	0	455	435.714286	0	0	0	0	0	0	0	0
4	455	405.555556	405.555556	0	0	0	0	0	0	0	455	405.555556	405.555556	0	0	0	0	0	0	0
5	455	395	395	0	0	0	0	0	0	0	455	395	395	0	0	0	0	0	0	0
6	455	442	442	130	25	0	0	0	0	0	455	442	442	0	0	0	0	0	0	0
7	455	443.5	443.5	130	25	0	0	0	0	0	455	443.5	443.5	0	25	0	0	0	0	0
8	455	455	455	130	47.5	0	0	0	0	0	455	455	455	0	47.5	0	0	0	0	0
9	455	417.452258	417.452258	130	25	0	0	0	0	0	455	417.452258	417.452258	0	25	0	0	0	0	0
10	455	429.286667	429.286667	130	25	0	0	0	0	0	455	429.286667	429.286667	0	25	0	0	0	0	0
11	455	439.033333	439.033333	130	25	0	0	0	0	0	455	439.033333	439.033333	0	25	0	25	0	0	0
12	455	448.913333	448.913333	130	25	0	0	0	0	0	455	448.913333	448.913333	130	25	20	25	0	0	0
13	455	424.4175	424.4175	0	0	0	0	0	0	0	455	424.4175	424.4175	130	25	20	25	0	0	0
14	455	370.29	370.29	0	0	0	0	0	0	0	455	370.29	370.29	130	25	20	0	0	0	0
15	455	337.323333	337.323333	0	0	0	0	0	0	0	455	337.323333	337.323333	129.999999	0	0	0	0	0	0
16	455	328.14	328.14	0	0	0	0	0	0	0	455	328.14	328.14	130	0	0	0	0	0	0
17	455	311.691	311.691	0	0	0	0	0	0	0	455	311.691	311.691	0	0	0	0	0	0	0
18	455	364.668	364.668	0	0	0	0	0	0	0	455	364.668	364.668	0	0	0	25	0	0	0
19	455	390.702	390.702	130	0	20	25	0	0	0	455	390.702	390.702	0	0	0	25	0	0	0
20	455	455	455	130	105.964	20.0000002	25	0	0	10	455	455	455	0	0	0	25	0	0	0
21	455	444.5	444.5	130	25	20	25	0	0	0	455	444.5	444.5	0	0	0	0	0	0	0
22	455	455	455	130	70	0	0	0	0	0	455	455	0	130	70	0	0	0	0	0
23	455	455	455	130	29.1666669	0	0	0	0	0	455	0	0	130	29.1666669	0	0	0	0	0
24	455	455	455	0	58	0	0	0	0	0	0	0	0	130	58	0	0	0	0	0

Table 19 (continued)

Hour	Generation schedule of committed units (GU41-GU60)																			
	41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	25	0	25	0	0	0	0	0	0	130	25	0	25	0	0	0
4	0	0	405.555556	0	25	0	25	0	0	0	0	0	0	130	25	0	25	0	0	0
5	0	0	395	0	25	0	25	0	0	0	0	0	395	130	25	0	25	0	0	0
6	0	0	442	0	25	0	0	0	0	0	0	0	442	130	25	0	0	0	0	0
7	0	0	443.5	0	25	0	0	0	0	0	0	0	443.5	130	25	0	0	0	0	0
8	0	0	455	0	47.5	0	0	0	0	0	0	0	455	130	47.5	0	0	0	0	0
9	455	417.4522	417.4522	0	0	0	0	0	0	0	0	417.4522	417.4522	0	0	0	0	0	0	0
10	455	429.2866	429.286667	0	0	0	0	0	0	0	455	429.2866	429.2866	0	0	0	0	0	0	0
11	455	439.033	439.03333	130	0	0	0	0	0	0	455	439.0333	439.0333	0	0	0	0	0	0	0
12	455	448.913	448.9133	130	0	20	25	0	0	0	455	448.9133	448.9133	0	0	0	0	0	0	0
13	455	424.4175	424.4175	130	0	20	25	0	0	0	455	424.4175	424.4175	0	0	0	0	0	0	0
14	455	370.29	370.29	130	0	20	25	0	0	0	455	370.29	370.29	130	0	0	0	0	0	0
15	455	337.323	337.323	129.999999	0	0	0	0	0	0	455	337.3233	337.323333	129.999	0	0	0	0	0	0
16	455	328.14	0	0	0	0	0	0	0	0	455	328.14	0	130	0	0	0	0	0	0
17	455	311.691	0	0	0	0	0	0	0	0	455	311.691	0	130	0	0	0	0	0	0
18	455	364.668	0	0	25	0	0	0	0	0	455	364.668	0	130	0	0	25	0	0	0
19	455	390.702	0	0	25	0	0	0	0	0	455	390.702	0	130	25	0	25	0	0	0
20	455	455	0	0	105.964	0	0	0	0	0	455	455	0	0	105.964	0	25	0	0	0
21	455	444.5	0	0	25	0	0	0	0	0	455	444.5	0	0	25	0	0	0	0	0
22	0	0	0	130	70	0	0	0	0	0	0	455	0	0	70	0	0	0	0	0
23	0	0	0	130	29.1666669	0	0	0	0	0	0	0	0	0	29.1666	0	0	0	0	0
24	0	0	0	130	0	0	0	0	0	0	0	0	0	0	58	0	0	0	0	0

Table 20 Power scheduling for 80-generating unit system considering renewable energy in winter

Hour	Generation schedule of committed units (GU1-GU20)																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**1 0**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	455	219.642	219.64285	130	25	0	0	0	0	0	455	219.6428	219.64285	0	0	0	0	0	0	0
2	455	253.571	253.57142	130	25	0	0	0	0	0	455	253.5714	253.57142	0	0	0	0	0	0	0
3	455	315.714	315.71428	130	25	0	0	0	0	0	455	315.7142	315.71428	0	0	0	0	0	0	0
4	455	377.5	377.5	130	25	20	0	0	0	0	455	377.5	377.5	0	0	0	0	0	0	0
5	455	384	384	130	25	20	0	0	0	0	455	384	384	0	0	0	0	0	0	0
6	455	396.562	396.5625	130	25	20	0	0	0	0	455	396.5625	396.5625	130	25	20	25	0	0	0
7	455	428.437	428.4375	130	25	20	25	0	0	0	455	428.4375	428.4375	130	25	20	25	0	0	0
8	455	446.250	446.25000	129.99999	25.000000	20.000000	25	0	0	0	455	446.2500	446.25000	129.99999	25.00000	20	25	0	0	10
9	455	455	455	130	91.178387	20	25	0	0	0	455	455	455	130	91.17838	20	25	0	10	0
10	455	455	455	130	162	48.805	25	10	10	10	455	455	455	130	162	48.805	25	10	10	10
11	455	455	455	130	162	80	25	29.67	10	10	455	455	455	130	162	80	25	29.67	10	10
12	455	455	455	130	162	80	25	55	45.745	10	455	455	455	130	162	80	25	55	45.74	10
13	455	455	455	130	162	46.50125	25	10	10	10	455	455	455	130	162	46.50125	25	10	10	10
14	455	455	455	130	92.935	20	25	0	0	0	455	455	455	130	92.935	20	25	0	0	0
15	455	454.555	454.555	130	25	20	0	0	0	0	455	454.555	454.555	130	25	0	0	0	0	10
16	455	363.212	363.2125	130	25	20	0	0	0	0	455	363.2125	363.2125	130	25	0	0	0	0	0
17	455	334.806	334.80687	130	25	0	0	0	0	0	455	334.8068	334.80687	130	25	0	0	0	0	0
18	455	394.792	394.7925	130	25	0	0	0	0	0	455	394.7925	394.7925	130	25	0	0	0	0	10
19	455	455	455	130	27.1275	0	0	0	0	0	455	455	455	130	27.1275	0	25	0	0	0
20	455	455	455	130	162	49.2275	25	10	10	10	455	455	455	130	162	49.2275	25	10	10	10
21	455	455	455	130	118.125	20	25	0	0	0	455	455	455	130	118.125	20	25	10	0	0
22	455	451	451	0	0	20	25	0	0	0	455	451	451	0	0	20	0	0	0	0
23	455	394.642	394.64285	0	0	0	0	0	0	10	455	394.6428	394.64285	0	0	0	0	0	0	0
24	455	385.384	385.38461	0	0	0	0	0	0	0	455	385.3846	385.38461	0	0	0	0	0	0	0

Table 20 (continued)

Hour	Generation schedule of committed units (GU21-GU40)																			
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	455	219.642	219.642857	130	0	0	0	0	0	0	455	219.642857	219.642857	0	0	0	0	0	0	0
2	455	253.571429	253.571429	130	0	0	0	0	0	0	455	253.571429	253.571429	0	0	0	0	0	0	0
3	455	315.714286	315.714286	130	0	0	0	0	0	0	455	315.714286	315.714286	0	0	0	0	0	0	0
4	455	377.5	377.5	130	0	20	0	0	0	0	455	377.5	377.5	0	0	0	0	0	0	0
5	455	384	384	130	0	20	0	0	0	0	455	384	384	0	0	0	0	0	0	0
6	455	396.5625	396.5625	130	0	20	0	0	0	0	455	396.5625	396.5625	130	0	20	0	0	0	0
7	455	428.4375	428.4375	130	0	0	0	0	0	0	455	428.4375	428.4375	130	0	20	0	0	0	0
8	455	446.250001	446.250001	129.999999	25.0000002	0	0	0	0	0	455	446.250001	446.250001	129.999999	25.0000002	20.0000001	0	0	0	0
9	455	455	455	130	91.1783875	0	25	0	0	0	455	455	455	130	91.1783875	20	25	0	0	0
10	455	455	455	130	162	48.805	25	10	10	10	455	455	455	130	162	48.805	25	10	10	10
11	455	455	455	130	162	80	25	29.675	10	10	455	455	455	130	162	80	25	29.675	10	10
12	455	455	455	130	162	80	25	55	45.745	10	455	455	455	130	162	80	25	55	45.745	10
13	455	455	455	130	162	46.50125	25	10	10	10	455	455	455	130	162	46.50125	25	10	10	10
14	455	455	455	130	92.935	20	25	0	0	0	455	455	455	130	92.935	0	25	0	0	0
15	455	454.555	454.555	130	25	0	0	0	0	10	455	454.555	454.555	130	25	0	0	0	0	10
16	455	363.2125	363.2125	130	25	0	0	0	0	0	455	363.2125	363.2125	130	25	0	0	0	0	0
17	455	334.806875	334.806875	130	25	0	0	0	0	0	455	334.806875	334.806875	130	25	0	0	0	0	0
18	455	394.7925	394.7925	130	25	0	0	0	0	0	455	394.7925	394.7925	130	25	0	0	0	0	0
19	455	455	455	130	27.1275	0	25	0	0	0	455	455	455	130	27.1275	0	0	0	0	0
20	455	455	455	130	162	49.2275	25	10	10	10	455	455	455	130	162	49.2275	25	10	10	10
21	455	455	455	130	118.125	20	25	0	0	0	455	455	455	130	118.125	20	25	0	0	0
22	455	451	451	0	25.0000001	20	0	0	0	0	455	451	451	0	0	20	25	0	0	0
23	455	394.642857	394.642857	0	0	0	0	0	0	0	455	394.642857	394.642857	0	0	20	0	0	0	0
24	455	385.384615	385.384615	0	0	0	0	0	0	0	455	385.384615	385.384615	0	0	0	0	0	0	0

Table 20 (continued)

Hour	Generation schedule of committed units (GU41-GU60)																			
	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
1	455	219.642857	219.642857	0	0	0	0	0	0	0	455	219.642857	219.642857	0	0	0	0	0	0	0
2	455	253.571429	253.571429	0	0	0	0	0	0	0	455	253.571429	253.571429	0	25	0	0	0	0	0
3	455	315.714286	315.714286	0	0	0	0	0	0	0	455	315.714286	315.714286	130	25	0	0	0	0	0
4	455	377.5	377.5	0	25	0	0	0	0	0	455	377.5	377.5	130	25	20	25	0	0	0
5	455	384	384	0	25	0	0	0	0	0	455	384	384	130	25	20	25	0	0	0
6	455	396.5625	396.5625	0	25	0	25	0	0	0	455	396.5625	396.5625	130	25	20	25	0	0	10
7	455	428.4375	428.4375	0	25	0	25	0	0	0	455	428.4375	428.4375	130	25	0	25	0	0	0
8	455	446.250001	446.250001	0	25.0000002	0	25	0	0	0	455	446.250001	446.250001	129.999999	25.0000002	0	25	0	0	0
9	455	455	455	130	91.1783875	0	25	0	0	0	455	455	455	130	91.1783875	0	25	0	0	0
10	455	455	455	130	162	48.805	25	10	10	0	455	455	455	130	162	48.805	25	0	10	0
11	455	455	455	130	162	80	25	29.675	10	10	455	455	455	130	162	80	25	29.675	10	10
12	455	455	455	130	162	80	25	55	45.745	10	455	455	455	130	162	80	25	55	45.745	10
13	455	455	455	130	162	46.50125	25	0	0	0	455	455	455	130	162	46.50125	25	10	0	0
14	455	455	455	130	92.935	0	25	0	0	10	455	455	455	130	92.935	0	25	0	0	0
15	455	454.555	454.555	130	25	0	0	0	0	0	455	454.555	454.555	130	25	0	0	0	0	0
16	455	363.2125	363.2125	130	25	0	0	0	0	0	455	363.2125	363.2125	130	25	0	0	10	0	0
17	455	334.806875	334.806875	130	25	0	0	0	0	0	455	334.806875	334.806875	130	25	0	0	0	0	0
18	455	394.7925	394.7925	130	25	0	25	10	0	0	455	394.7925	394.7925	130	25	0	0	0	0	0
19	455	455	455	130	27.1275	0	25	0	0	0	455	455	455	130	27.1275	0	0	0	0	0
20	455	455	455	130	162	49.2275	25	10	10	0	455	455	455	130	162	49.2275	25	0	0	0
21	455	455	455	0	118.125	20	0	0	10	0	455	455	455	0	118.125	20	25	0	0	0
22	455	451	451	0	25.0000001	20	0	0	0	0	455	451	451	0	0	20	25	0	0	0
23	455	394.642857	394.642857	0	0	0	0	0	0	0	455	394.642857	394.642857	0	0	0	0	0	0	0
24	455	385.384615	385.384615	0	0	0	0	0	0	0	455	385.384615	385.384615	0	0	0	0	0	0	0

Table 20 (continued)

Hour	Generation schedule of committed units (GU60-GU80)																			
	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	455	219.6428	0	0	0	0	0	0	0	0	455	219.642	0	0	0	0	0	0	0	0
2	455	253.5714	0	0	0	0	0	0	0	0	455	253.571	0	0	0	0	0	0	0	0
3	455	315.7142	0	0	0	0	0	0	0	0	455	315.714	0	0	0	0	0	0	0	0
4	455	377.5	0	0	0	0	0	0	0	0	455	377.5	0	0	25	0	0	0	0	0
5	455	384	384	0	0	0	25	0	0	0	455	384	0	0	25	0	0	0	0	0
6	455	396.5625	396.5625	0	0	20	25	0	0	0	455	396.5625	396.5625	0	25	0	0	0	0	10
7	455	428.4375	428.4375	0	25	20	25	0	0	0	455	428.4375	428.4375	0	25	0	0	0	0	0
8	455	446.250	446.250	129.999	25	20	25	0	0	0	455	446.2500	446.250001	0	25.0000002	0	25	0	0	0
9	455	455	455	130	91.1783875	20	25	0	0	0	455	455	455	130	91.1783875	20	25	0	0	0
10	455	455	455	130	162	48.805	25	0	0	0	455	455	455	130	162	48.805	25	0	0	0
11	455	455	455	130	162	80	25	29.675	10	10	455	455	455	130	162	80	25	29.675	10	10
12	455	455	455	130	162	80	25	55	45.745	10	455	455	455	130	162	80	25	55	45.745	10
13	455	455	455	130	162	46.50125	25	0	0	0	455	455	455	130	162	46.50125	25	0	10	10
14	455	455	455	130	92.935	0	25	0	10	0	455	455	455	130	92.935	0	25	0	0	0
15	455	454.555	454.555	0	25	0	25	0	0	0	455	454.555	454.555	0	25	0	0	0	0	0
16	455	363.2125	363.2125	0	25	0	0	0	0	0	455	363.2125	363.2125	0	25	0	0	0	0	10
17	455	334.8068	334.806875	0	25	0	0	0	0	0	455	334.806	334.806875	0	25	0	0	0	0	0
18	455	394.7925	394.7925	0	25	0	0	0	0	0	455	394.7925	394.7925	0	25	0	0	0	0	0
19	455	455	455	0	27.1275	0	0	0	0	0	455	455	455	0	27.1275	0	0	0	0	0
20	455	455	455	130	162	49.2275	25	10	0	0	455	455	455	130	162	49.2275	25	0	0	0
21	455	455	455	130	118.125	20	25	0	0	0	455	455	455	130	118.125	20	25	0	0	0
22	455	451	451	130	0	20	25	0	0	0	455	451	0	130	0	20	25	0	0	0
23	455	394.642857	394.642857	130	0	0	0	0	0	0	0	0	0	130	0	0	0	0	0	0
24	0	0	385.384615	130	0	0	0	0	0	0	0	0	0	130	0	0	0	0	0	0

Table 21 Power scheduling for 100-generating unit system considering renewable energy in winter

Hour	Generation schedule of committed units (GU1-GU20)																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	455	218.214	218.2147	0	0	0	0	10	0	0	455	218.214	218.214	0	0	0	0	0	0	10
2	455	225.357	225.357	0	0	0	0	0	0	0	455	225.357	225.357	0	25	0	0	0	0	0
3	455	281.0714	281.0714	0	0	0	0	0	0	0	455	281.071	281.071	0	25	20	0	0	0	0
4	455	349.285	349.285	0	0	0	0	0	0	0	455	349.285	349.285	0	25	20	0	0	0	10
5	455	375.357	375.35	0	0	0	0	0	0	0	455	375.35	375.357	0	25	20	0	0	0	0
6	455	416.0001	416	129.999	0	0	0	0	0	0	455	416	416	0	25	0	0	0	0	0
7	455	439.375	439.375	130	0	0	0	0	0	0	455	439.375	439.375	0	25	0	0	0	0	0
8	455	424.7222222	424.722	130	0	0	0	0	0	0	455	424.722	424.722	0	25	0	0	0	0	0
9	455	427.3382684	427.338	129.999	0	0	0	0	0	10	455	427.338	427.338	129.999	25	20	25	0	0	0
10	455	435.822	435.822	129.999	25	0	0	0	0	0	455	435.822	435.822	129.999	25	20	25	0	0	0
11	455	452.92	452.92	0	25	0	25	10	0	0	455	452.92	452.92	129.999	25	20	25	0	0	0
12	455	455	455	0	58.137	0	25	0	0	0	455	455	455	130	58.13714286	0	0	10	0	0
13	455	421.900	421.9	0	25	20	25	0	0	0	455	421.900	421.9	129.999	25	0	0	0	10	0
14	455	388.674	388.674	0	25	20	0	0	0	0	455	388.674	388.674	0	0	0	0	0	0	0
15	455	324.894	324.894	0	25	20	0	0	0	0	455	324.894	324.894	0	0	0	25	0	0	0
16	455	246.82	246.82	130	25	0	0	0	0	0	455	246.82	246.82	0	0	0	25	0	0	0
17	455	233.0955	233.0955	130	25	0	0	0	0	0	455	233.0955	233.0955	0	0	0	25	0	0	0
18	455	291.084	291.084	130	25	0	0	0	0	0	455	291.084	291.084	0	0	0	0	0	0	0
19	455	329.3510001	329.351	129.999	25	0	25	0	0	0	455	329.3510001	329.351	0	0	0	0	0	0	0
20	455	439.491	439.491	129.999	25	0	25	0	0	10	455	439.491	439.491	0	25.00000002	20	0	0	0	0
21	455	439.1666668	439.166	0	0	0	25	0	0	0	455	439.1666668	439.166	0	25	20	0	0	0	0
22	455	430	430	0	0	0	0	0	0	0	455	430	430	0	25	20	0	0	0	0
23	455	455	455	0	0	20	0	0	0	0	455	455	455	0	52	0	0	0	0	0
24	454.9999997	455	455	0	0	20	0	10.0000002	0	0	454.9999997	455	455	0	117.0000003	0	0	0	0	0

Table 21 (continued)

Hour	Generation schedule of committed units (GU21-GU40)																			
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	455	218.214	218.214	0	0	0	0	0	0	0	455	218.2142857	218.2142857	0	0	0	0	0	0	0
2	455	225.357	225.357	0	0	20	0	0	0	0	455	225.3571429	225.3571429	0	25	0	0	0	0	0
3	455	281.071	281.071	0	25	20	0	0	0	0	455	281.0714286	281.0714286	0	25	0	0	0	0	0
4	455	349.285	349.285	0	25	20	0	0	0	0	455	349.2857143	349.2857143	0	25	0	0	0	0	0
5	455	375.357	375.357	0	25	20	0	0	0	0	455	375.3571429	375.3571429	0	25	0	0	0	0	0
6	455	416	416	0	25	0	0	0	0	0	455	416.0000001	416.0000001	0	25	0	0	10	0	10
7	455	439.375	439.375	0	25	0	0	0	0	0	455	439.375	439.375	130	25	0	0	0	0	0
8	455	424.722	424.722	0	25	0	0	0	0	0	455	424.7222222	424.7222222	130	25	0	0	0	0	0
9	455	427.338	427.338	0	25	0	0	0	0	0	455	427.3382684	427.3382684	129.9999999	25	0	0	0	0	0
10	455	435.822	435.822	0	25	20	25	0	0	0	455	435.822	435.822	129.9999998	25	0	0	0	0	0
11	455	452.92	452.92	0	25	20	25	0	0	0	455	452.92	452.92	129.9999999	25	0	0	0	0	0
12	455	455	455	130	58.137	20	25	0	0	0	455	455	455	130	58.137	0	0	0	0	0
13	455	421.9005	421.9	129.999	0	0	0	0	0	0	455	421.9005001	421.9005001	0	0	0	25	0	0	0
14	455	388.674	388.674	130	0	0	0	0	0	0	455	388.674	388.674	0	0	0	25	0	0	0
15	455	324.894	324.894	129.999	0	0	0	0	0	0	455	324.894	324.894	0	0	0	25	0	0	0
16	455	246.82	246.82	130	0	0	0	0	0	0	455	246.82	246.82	0	0	0	25	0	0	0
17	455	233.0955	233.0955	0	0	20	25	0	0	0	455	233.0955	233.0955	0	0	20	0	0	0	0
18	455	291.084	291.084	0	0	20	25	0	0	0	455	291.084	291.084	0	0	20	0	0	0	0
19	455	329.351	329.351	0	0	20	25	0	0	0	455	329.3510001	329.3510001	129.9999997	0	20	0	0	0	0
20	455	439.491	439.491	0	25	0	0	0	0	0	455	439.491	439.491	129.9999999	0	0	25	0	0	0
21	455	439.166	439.166	0	25	0	0	0	0	0	455	439.1666668	439.1666668	129.999999	0	0	25	0	0	0
22	455	430	430	0	25	0	0	0	0	0	455	430	430	130	0	0	25	0	0	0
23	455	455	455	130	52	0	0	0	0	0	455	455	455	130	0	20.00000005	0	0	0	0
24	454.9999997	455	455	129.999	117	20	0	0	0	0	454.9999997	455	455	0	0	20	0	0	0	0

Table 21 (continued)

Hour	Generation schedule of committed units (GU41-GU60)																			
	41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
1	455	218.214	218.214	0	0	0	0	0	0	0	455	218.2142857	0	130	0	0	0	0	0	0
2	455	225.357	225.357	0	0	20	0	0	0	0	455	225.3571429	0	130	25	0	0	0	0	0
3	455	281.071	281.071	130	0	20	0	0	0	0	455	281.0714286	0	130	25	0	0	0	0	0
4	455	349.285	349.285	130	0	20	0	0	10	0	455	349.2857143	0	130	25	0	25	0	0	0
5	455	375.357	375.357	130	0	0	25	0	0	0	455	375.3571429	0	130	25	20	25	0	0	0
6	455	416	416	129.999	0	0	25	0	0	0	455	416.0000001	416.0000001	0	25	20	25	0	0	10
7	455	439.375	439.375	130	25	0	25	0	0	0	455	439.375	439.375	0	25	20	0	0	0	0
8	455	424.722	424.722	130	25	0	0	0	0	0	455	424.7222222	424.7222222	0	25	0	0	0	0	0
9	455	427.338	427.338	0	25	0	0	0	0	0	455	427.3382684	427.3382684	0	25	0	0	0	0	0
10	455	435.822	435.822	0	25	0	0	0	0	0	455	435.822	435.822	0	25	0	0	0	0	0
11	455	452.92	452.92	0	25	20	25	0	0	0	455	452.92	452.92	129.9999999	25	0	25	0	10	0
12	455	455	455	0	58.137	20	25	0	10	0	455	455	455	130	58.137	0	25	0	10	0
13	455	421.9	421.9	0	0	20	25	0	0	0	455	421.9005001	421.9005001	129.9999994	25	20	25	0	0	0
14	455	388.674	388.674	0	0	0	0	0	0	0	455	388.674	388.674	130	0	20	0	0	0	0
15	455	324.894	324.894	129.999	0	0	0	0	0	0	455	324.894	324.894	129.9999999	0	20	0	0	0	0
16	455	246.82	246.82	130	0	0	0	0	0	0	455	246.82	246.82	130	0	0	0	0	0	0
17	455	233.0955	233.0955	130	0	0	0	0	0	0	455	233.0955	233.0955	0	0	0	0	0	0	0
18	455	291.084	291.084	130	0	0	0	0	0	0	455	291.084	291.084	0	0	0	0	0	0	0
19	455	329.351	329.351	129.999	0	0	0	0	0	0	455	329.3510001	329.3510001	0	0	0	25	0	0	0
20	455	439.491	439.491	0	0	0	0	0	0	0	455	439.491	439.491	0	0	0	25	0	0	0
21	455	439.166	439.166	0	0	0	25	0	0	0	455	439.1666668	439.1666668	0	0	0	25	0	0	0
22	455	430	430	0	0	0	25	0	0	0	455	430	430	0	0	0	0	0	0	0
23	455	455	455	0	0	20	25	0	0	0	455	455	455	0	0	0	0	0	0	0
24	454.9999997	455	455	0	0	20	0	0	0	0	0	0	0	0	0	20	0	0	0	0

Table 21 (continued)

Hour	Generation schedule of committed units (GU61-GU80)																			
	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	455	218.2142857	0	0	0	0	0	0	0	0	455	218.2142857	0	0	0	0	25	0	0	0
2	455	225.3571429	0	130	0	0	0	0	0	0	455	225.3571429	0	130	25	0	25	0	0	0
3	455	281.0714286	0	130	0	0	0	0	0	0	455	281.0714286	0	130	25	0	25	0	0	0
4	455	349.2857143	0	130	0	0	0	0	0	0	455	349.2857143	0	130	25	0	25	0	0	0
5	455	375.3571429	0	130	0	20	25	0	0	0	455	375.3571429	0	130	25	0	0	0	0	0
6	455	416.0000001	0	129.9999998	0	20	25	0	0	0	455	416.0000001	0	129.9999998	25	20	0	0	0	0
7	455	439.375	439.375	0	0	20	25	0	0	0	455	439.375	0	0	25	20	0	0	0	0
8	455	424.7222222	424.7222222	0	0	0	0	0	0	0	455	424.7222222	424.7222222	0	0	20	0	0	0	0
9	455	427.3382684	427.3382684	0	25	0	0	0	0	0	455	427.3382684	427.3382684	0	0	0	0	0	0	0
10	455	435.822	435.822	0	25.00000001	0	0	0	0	0	455	435.822	435.822	0	0	0	25	0	0	0
11	455	452.92	452.92	0	25.00000002	0	0	0	0	0	455	452.92	452.92	0	0	0	25	0	0	0
12	455	455	455	130	58.13714286	0	25	10	0	0	455	455	455	0	0	0	25	0	0	0
13	455	421.9005001	421.9005001	129.9999994	25	0	25	0	0	0	455	421.9005001	421.9005001	129.9999994	0	0	0	0	0	0
14	455	388.674	388.674	130	25	0	25	0	0	0	455	388.674	388.674	130	0	0	0	0	0	0
15	455	324.894	324.894	129.9999999	0	0	25	0	0	0	455	324.894	324.894	129.9999999	0	0	0	0	0	0
16	455	246.82	246.82	130	0	0	0	0	0	0	455	246.82	246.82	130	0	0	0	0	0	0
17	455	233.0955	233.0955	130	0	0	0	0	0	0	455	233.0955	233.0955	130	0	0	0	0	0	0
18	455	291.084	291.084	0	0	0	0	0	0	0	455	291.084	291.084	0	0	0	0	0	0	0
19	455	329.3510001	329.3510001	0	0	0	0	0	0	0	455	329.3510001	329.3510001	0	0	20	0	0	0	0
20	455	439.491	439.491	0	0	0	0	0	0	0	455	439.491	439.491	0	0	20	0	0	0	0
21	455	439.1666668	439.1666668	0	0	0	0	0	0	0	455	439.1666668	439.1666668	0	0	20	0	0	0	0
22	455	430	430	0	0	0	0	0	0	0	455	430	0	0	0	0	0	0	0	0
23	0	0	0	0	52	0	0	0	0	0	0	0	0	130	0	0	25	0	0	0
24	0	0	0	129.9999995	117.0000003	20	0	0	0	0	0	0	0	129.9999995	0	0	25.00000051	0	0	0

Table 21 (continued)

Hour	Generation schedule of committed units (GU81-GU100)																			
	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	0	0	0	0	0	0	0	0	0	0	0	0	218.2142857	130	0	0	0	0	0	0
2	0	0	0	0	0	20	0	0	0	0	0	0	225.3571429	130	0	0	0	0	0	0
3	0	0	0	0	0	20	0	0	0	0	0	0	281.0714286	130	25	20	0	0	0	0
4	0	0	0	0	0	20	0	0	0	0	0	0	349.2857143	130	25	20	0	0	0	0
5	0	0	0	130	0	0	0	0	0	0	0	0	375.3571429	130	25	20	0	0	0	0
6	0	0	0	129.999	25	0	0	0	0	0	0	0	416.0000001	129.9999998	25	0	0	0	0	0
7	0	0	0	130	25	0	0	0	0	0	0	0	439.375	0	25	0	0	0	0	0
8	0	0	424.7222222	130	25	0	0	0	0	0	0	0	424.7222222	0	25	0	0	0	0	0
9	455	427.338	427.3382684	129.999	25	0	0	10	0	0	0	0	427.3382684	0	25	0	0	0	0	0
10	455	435.822	435.822	0	25.00000001	0	0	0	0	0	455	435.822	435.822	0	25.00000001	0	0	0	0	0
11	455	452.92	452.92	0	25.00000002	20.00000001	25	0	0	10	455	452.92	452.92	0	0	0	0	10	0	0
12	455	455	455	0	0	20	25	0	0	0	455	455	455	0	0	0	0	0	0	0
13	455	421.9	421.9005001	0	0	20	25	0	0	0	455	421.9005001	421.9005001	0	0	0	0	0	0	0
14	455	388.674	388.674	0	0	0	0	0	0	0	455	388.674	388.674	0	0	0	0	0	0	0
15	455	324.894	324.894	129.999	0	0	0	0	0	0	455	324.894	324.894	0	0	0	0	0	0	0
16	455	246.82	246.82	130	0	0	0	0	0	0	455	246.82	246.82	0	0	0	0	0	0	0
17	455	233.0955	233.0955	130	0	0	0	0	0	0	455	233.0955	233.0955	0	0	0	0	0	0	0
18	455	291.084	291.084	130	0	0	0	0	0	0	455	291.084	291.084	130	0	0	0	0	0	0
19	455	329.351	329.3510001	129.999	25	0	0	0	0	0	455	329.3510001	329.3510001	129.9999997	0	20	0	0	0	0
20	455	439.491	439.491	0	25.00000002	0	0	0	0	0	455	439.491	439.491	129.9999999	25.00000002	20	0	0	0	0
21	455	439.166	439.1666668	0	25.00000009	0	25	0	0	0	455	0	0	129.999999	25.00000009	20	0	0	0	0
22	455	0	0	0	25	0	25	0	0	0	0	0	0	130	25	0	0	0	0	0
23	0	0	0	0	52	0	25	0	0	0	0	0	0	0	52	0	25	0	0	0
24	0	0	0	0	117.0000003	20	0	0	0	0	0	0	0	0	117.0000003	0	25	0	0	0

Table 22 Overall cost for generation of each unit without renewable energy sources

Generating units	Generation cost ($)
5-Unit	9010.1
6-Unit	13489.93957
10-Unit (5% SR)	557533.12
10-Unit (10% SR)	563937.6875
19-Unit	208510
20-Unit	1125200
40-Unit	2253700
60-Unit	3388100

Table 23 Overall cost for generation of each unit with renewable energy sources in winter

Generating units	Generation cost ($)	% cost saving
5-Unit	8572.9	4.85
6-Unit	12977	3.8
10-Unit (5% SR)	536200	3.83
10-Unit (10% SR)	539110	4.4
19-Unit	207560	0.46
20-Unit	1084100	3.65
40-Unit	2189400	2.85
60-Unit	3294600	2.76
80-Unit	5591700	–
100-Unit	5529900	–

Table 24 Overall cost for generation of each unit with renewable energy sources in summer

Generating units	Generation cost ($)	% Cost saving
5-Unit	8226.6	8.7
6-Unit	12229	9.35
10-Unit (5% SR)	529980	4.94
10-Unit (10% SR)	534050	5.3
19-Unit	207180	0.65
20-Unit	1076400	4.34
40-Unit	2176900	3.41
60-Unit	3297500	2.67
80-Unit	5578000	–
100-Unit	5530800	–

Table 25 Overall cost for generation of each unit with renewable energy sources in Autumn & Spring

Generating units	Generation cost ($)	% cost saving
5-Unit	7880.4	12.5
6-Unit	11720	13.12
10-Unit (5% SR)	526480	5.57
10-Unit (10% SR)	529890	6.04
19-Unit	205610	1.4
20-Unit	1075300	4.43

Conclusions

In this research work, the authors have successfully presented the fusion of Harris Hawks optimizer with SCA optimization technique and evaluated performance of the suggested hybrid optimized method for standard benchmark problem unit commitment problem, which consists of thermal generating units and along with PV generating units. The proposed research focuses on invention of hybrid variant of Harris Hawks optimizer (HHO) and sine–cosine algorithm (SCA) using memetic algorithm approach, named as intensify Harris Hawks optimizer. The efficacy of the suggested algorithm was tested for 4-generating unit system, 5-generating unit system, 6-generating unit system, 7-generating unit system, 10-generating unit system, 19-generating unit system, 20-generating unit system, 40-generating unit system and 60-generating unit system. After successful experiment, it was observed that the suggested optimizer is too much effective to solve continuous, discrete and nonlinear optimization problems.

After verification, it builds up the effective outcomes of the suggested hybrid improvement optimization which are more effective to other newly defined meta-heuristics, hybrid and heuristics method and advancement search calculation and suggested algorithm recommends for the efficiency of this algorithm in the search area of meta-heuristics type optimization algorithms which are nature inspired. The other existing optimization techniques have good development prospect, but their research is still at initial condition and included so many problems which need to be solved or in other instance, there are several uncertainties, such as, how to adequately stay away from nearby or local optimum? What is the most effective method to consummately consolidate the upsides of distinctive enhancement calculations? How to successfully set the boundaries or parameter of a calculation? What are the compelling cycle of iteration stop conditions? etc. The most significant issue is that it comes up short on a bound together and complete hypothetical framework. So, using this novel proposed methodology, those problems are easily solved. The proposed optimization algorithm is useful to overcome those problems.

Supplementary information

The online version contains supplementary material available at https://doi.org/10.1186/s43067-020-00026-3.

Additional file 1. Test data for standard Unit Commitment Problems.

Abbreviations

TFC: Total cost of fuel; $F_{\text{cost}\,n}(P_{nt})$: Cost of fuel for a particular generating unit *n*th at that particular time '*t*' hour; $SUC_{n,t}$: Cost of start-up for *n*th unit within '*t*' hours; SDC_{nt}: Cost of Shutdown for *n*th unit within '*t*' hours; U_{nt}: Unit status at time t; A_n : Coefficient of cost for *n*th unit; B_n: Coefficient of cost for *n*th unit; C_n: Coefficient of cost for *n*th unit; HSU_n: hot start for *n*th unit; CSU_n: cold start for *n*th unit; $P_{n,t}^{MAX}$: Maximum electrical power generation by unit *n*; P_n^{MIN}: Minimum electrical power which generation by unit *n*; $P_{n,t}$: Electrical power generation of unit *n*th at the time span '*t*'; PD_t: load demand at '*t*' hours; INS_n: initial status of unit *n* at time '*t*'; $T_{n,t}^{OFF}$: Initial OFF status for *n*th unit at time '*t*'; $T_{n,t}^{ON}$: Initial ON status for *n*th unit at time '*t*'; T_n^{UP}: UP condition for *n* no. of power generating unit; T_n^{DW}: DOWN condition for *n* no. of power generating unit; *K*: incremental cost for shut down of unit; PD_n: Power demand for *n*th unit; SR_t: spinning reserve necessity; T_n^{COLD}: Time span for COLD start of n no. of generating unit; Np: Population number; *t*: No. of hours; NU: No. of generators.

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Authors' contribution

AN analyzed and interpreted the data regarding the optimal scheduling of each power generating unit during 24 h and overall cost for power generation of each unit with renewable energy sources in summer, winter, autumn and spring and also drafted the work or substantively revised it and was a major contributor in writing the manuscript. VK have made substantial contribution to the conception and design of the research work and the creation of MATLAB coding (Software) used in the work. All authors have read and approved the manuscript, and the content of the manuscript has not been published or submitted for publication elsewhere.

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Availability of data and material

The datasets used and/or analyzed during the current research study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare that they have no competing interests.

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