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A Modified Artificial Bee Colony for Probabilistic Peak Shaving Technique in Generators Operation Planning: Optimal Cost–Benefit Analysis

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Abstract: In the generation of operating system planning, saving utility cost (*SUC*) is customarily implemented to attain the forecasted optimal economic benefits in a generating system associated with renewable energy integration. In this paper, an improved approach for the probabilistic peak-shaving technique (PPS) based on computational intelligence is proposed to increase the *SUC* value. Contrary to the dispatch processing of the PPS technique, which mainly relies on the dispatching of each limited energy unit in sequential order, a modified artificial bee colony with a new searching mechanism (MABC-NSM) is proposed. The *SUC* is originated from the summation of the Saving Energy Cost and Saving Expected Cycling Cost of the generating system. In addition, further investigation for obtaining the optimal value of the *SUC* is performed between the *SUC* determined directly and indirectly estimated by referring to the energy reduction of thermal units (*ERTU*). Comparisons were made using MABC-NSM and a standard artificial bee colony and verified on the modified IEEE RTS-79 with different peak load demands. A compendium of the results has shown that the proposed method is constituted with robustness to determine the global optimal values of the *SUC* either obtained directly or by referring to the *ERTU*. Furthermore, *SUC* increments of 7.26% and 5% are achieved for 2850 and 3000 MW, respectively.

Keywords: artificial bee colony; integrated resource planning; probabilistic production cost equivalent load duration curve; frequency and duration method; limited energy units

1. Introduction

The main goal of the electric utility is concise for providing electrical as may be demanded by the customers at the lowest possible operating cost, in tandem with maintaining the system security, reliability, and economics of the system. Furthermore, reducing the environmental damage caused by the conventional thermal units, guaranteed consistent supply of energy on the secure condition and reducing the electricity bills of customers are parts of the goal [1–3]. However, load demand variation is largely uncontrollable, with any interruptions very costly. In this regard, the electric utility is required to provide a small capacity of generating units such as gas generators or diesel generators to mitigate the peak load demand [4,5]. This requirement has directly increased the total production cost of energy, operation and maintenance (O&M) cost of the electric utility and build up the level of emission [6,7]. Consequently, electric utilities are required to apply and implement sufficient planning for cost-effective operation and efficient economic decisions on the electricity market [2,8–10]. Finding the least-cost resource options is mainly used to minimize the total electric utility costs by applying the optimization



procedure to acquire energy savings and energy production options [11–14]. Saving utility cost (SUC) is customarily used as a cost-benefit analysis of the integration of renewable energy activities applied to the electric generation system [15,16]. For each set of alternatives investigation in the unit block, it is possible to estimate the SUC at its core; this is about comparative analysis and cost effectiveness. The electric utility had tremendous success using this method to identify the least expensive options for providing a finite amount of electricity to its customers. In electric utility, the SUC considers a wide variety of options, thus providing a shortcut mechanism for evaluating new supply and demand options. As a result of this success, many electric utilities have urged that the SUC must be translated for use in all power system utility sectors involving the generation, transmission, and distribution systems networks. However, this translation has proven by recent analyses that the transmission and distribution (T&D) costs are extremely site-specific and may be a positive or negative influence on the operational planning and much smaller than saving costs obtained from the generation system as proposed in [17–19]. The SUC is obtained based on the generation system, which is usually discussed in terms of their energy and cycling operation and total capacity installation. From the utility perspective, dispatching the limited energy units (LEU) to meet the forecasted load demand over a period of time with certain specified reliability can yield remarkable SUC [20–22]. It is important to note that in the least-cost planning or peak-shaving application in the generation system, the optimal dispatch of limited energy units (ODLEU) does not affect in reliability indices or total capacity installation. This is because the technique is used to adjust or switch the energy generated between the units having different marginal cost instead of changing the pattern of load demand [23–25]. In other words, only two aspects of SUC are calculated, which are the Saving Energy Cost (SEC) and Saving Expected cycling cost (SECC) of the generating system, whenever there is a possibility for the optimal dispatch of LEU performed in such a way that will satisfy the peak load demand imposed with the lowest possible energy and operating cost [26–30].

Given that, generating units either conventional or LEUs are not perfectly reliable and future load levels cannot be forecasted with certainty [31–33]. Hence, the estimation of SUC based on ODLEU is required to apply and implement sufficient planning based on the probabilistic production cost (PPC) model and the reliability analyses to fulfill this requirement [34–38]. The PPC of the generation units based on the equivalent load duration curve (ELDC) can easily be found, if the generation mix only consists of thermal units without energy constraints. This is determined by loading the units under their corresponding *ELDCs*, according to an increase in the fuel cost and the computation of the energy generated by each unit. While, on the other hand, the generation mix consists of a combination of hydroelectric and thermal units with limitation on their emissions level (generally referred to as limited energy units) [39–42]. Although there are several methods used for ODLEU based on PPC of the generation units, the probabilistic peak-shaving technique (PPS) within the framework of ELDC with the Frequency and Duration (FD) approach has shown that the method is superior to the other methods used for simulating multiple limited energy units (hydro and pump storage units). In addition, it is shown that the result of PPC can be obtained within the low computation time [35,43–48]. Generally, in this technique, LEUs needs to fulfill two criteria to fully utilize their energies. First, the compulsory generated energy of the LEU must be less than its assigned energy. The second criterion is related to the thermal unit, which shall not be reduced or peak shaved its energy below its energy limit. The PPS technique is commenced by loading the thermal units, according to the merit order or incremental fuel cost under the base case condition of ELDC, followed by the LEU units arranged corresponding to the decreasing operating hours under the *ELDC*. Subsequently, the LEUs are then optimized by dispatching its energy consecutively or one after the another. However, the PPS technique is identified with some disadvantages in obtaining global ODLEU as well as the optimal value of maximum SUC. In other words, the optimal value of the SUC-based PPS technique can easily be found if each selected thermal unit peak shaved its energy once from optimized LEUs. Hence, the optimal value of the SUC is reported once all LEUs are optimized. On the other hand, for the thermal unit that peak shaved its energy multiple times from optimized LEUs, obtaining the optimal value of SUC cannot be

guaranteed. This problem will be significant as several sequential orders of LEUs have to offload at the same thermal unit. This is because the operation of the peak shaved energy of the thermal unit is non-commutative operations due to its sensitivity to several factors such as its capacity rate and changing of load demand of the thermal unit (after each peak shave processing) and capacity rate of optimized LEU. Figure 1 provides a clear depiction of the peak shaved energy of the selected thermal unit from several optimized LEUs. Figure 1 has shown that the energy reduction of the selected thermal unit in case B is higher compared to case A, although the optimized LEUs are the same for both cases. It should also be noted that the LEU2, which often has minimum operating hours or a small generating capacity rate, will not be able to fully utilize its energy, but it has assisted the LEU1 to do so.



Figure 1. Selected thermal unit that peak shaved its energy from several optimized limited energy units (LEUs) having different affected order.

In conclusion, the conventional optimization of the PPS technique is not economically feasible, due to some optimized LEU not being able to fully utilize their energy. It is worth mentioning that the artificial intelligent optimization technique was not introduced yet for ODLEU based on the probabilistic method; therefore, the ODLEU using the PPS technique has formulated the issue into a multimodal optimization problem to overcome its weakness. The performance of the Artificial Bee Colony (ABC) algorithm is considered a better or similar to several metaheuristic methods such as Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). This is because the ABC algorithm has few control parameters, strong robustness, fast convergence, and high flexibility [49,50]. However, sometimes, the accuracy of the optimal value cannot meet the requirements due to its disadvantages of premature convergence in the later search period. Karaboga and Akay proposed an improved version of the basic ABC algorithm called the modified ABC (MABC) algorithm, while providing a better convergence property for constrained and real-parameter optimization problems. Although the MABC optimization algorithm has more control parameters, the convergence rate is considered to be better compared to the basic ABC algorithm [51]. As far as the author's knowledge is concerned, the obtained optimal value of SUC based on ODLEU using the PPS technique and assisted with intelligence techniques has not been examined so far. Therefore, this paper focuses on providing a proposal for the SUC estimation problem by exploiting this optimization algorithm. For this purpose, determining the optimal value of SUC based on the MABC algorithm is designed in this study. The designed estimator is comprehensively analyzed for different scenarios to obtain the optimal value of SUC. In addition, all results were obtained by an unbiased comparison between the SUC determined directly by the MABC-NSM technique and the SUC indirectly assessed by reference to the energy reduction of the thermal units determined using the MABC-NSM. The proposed MABC-NSM method is also compared with the standard ABC. The results obtained showed that the performance of the proposed MABC-NSM is higher than that of standard ABC algorithms concerning the optimal SUC value. Therefore, the proposed MABC-NSM can utilize the LEUs efficiently and gain more profit for electrical utilities.

The remainder of this paper is organized as follows: Section 2 presented the concepts of the PPS technique, including equations, parameters necessary as input to the subsequent optimization procedure, and the determination of *SUC*. The proposed MABC-NSM algorithm for the estimation of

the *SUC* is presented in Section 3, and Section 4 provides results and discussion. Finally, Section 5 provides the conclusion and outlines possible directions for future research.

2. Determination of SUC Based on PPS Technique

This section briefly discusses the implementation of the PPS technique, which is the key requirement for the determination of *PPC* and total expected start-up cost (*TESC*) of the generation system so that the *SUC* could be obtained by fully utilizing the energy of LEU.

2.1. Determination of Probabilistic Production Cost

The main task of the PPS technique is that the LEU will transfer the maximum amount of its increment energy (E_r) to peak shave some of the energy that should be produced by the thermal unit. The technique is used to adjust or switch the energy generated between the units having different marginal cost instead of changing the pattern of load demand or reducing the total generated energy. The performance of the PPS technique continues in such a way that the *PPC* is minimized and the energy produced is matching with the load demand within an acceptable reliability level. However, the expected energy (E_n) for each generation system is required to be determined according to the initial loading order prior to the PPS procedure. The E_n can be obtained using Equation (1) by referring to the equivalent load duration curve ELDC(x) as given in Equation (2). The *PPC* of the generation system based on the initial loading order can be determined using (3).

$$E_n = T \cdot p_n \int_{sc_{n-1}}^{sc_n} ELDC_{n-1}(x)dx$$
(1)

$$ELDC_{n\neq 1}(x) = p_n \cdot ELDC_{n-1}(x) + q_n \cdot ELDC_{n-1}(x - c_n)$$
(2)

$$PPC_{base} = \sum_{n=1}^{N} (E_n.Gcost_n)$$
(3)

where *T* is the total simulation period in hours, p_n and q_n are the availability and forced outage rate of the capacity of generating units respectively; c_n is the capacity rate of a generating unit, SC_{n-1} and SC_n represent the starting and the end capacity loading point of the generating unit in the system, respectively; $n = \{1, ..., N\}$ is used to represent the total number of all generating units in the system, and Gcost_n represents the operation costs specified for the generating unit. It is worth mentioning that the $ELDC_{n-1}(x)$ in Equation (4) is equivalent to the load duration curve (LDC) in the case that (n = 1). The E_r of the dispatched LEU is determined based on the difference between generated energy by the selected thermal unit before and after the dispatch of LEU, as shown in (4).

$$E_r = T.P_n. \int_{SC_{k-1}}^{SC_k} \left(ELDC_{k-1}(x) - ELDC_{k-1}^{m=1}(x) \right) dx$$
(4)

In Equation (4), *k* is the loading order of selected thermal unit, while SC_{k-1} and SC_k represent the starting and the end capacity loading point of the selected thermal unit involved in receiving the increment energy *Er*, respectively. The $ELDC_{k-1}(x)$ represents the original ELDC obtained from convolving the outage probability of the selected thermal unit with LDC, while $ELDC_{k-1}^{m=1}(x)$ is the extra load subtracted from the original ELDC of the same thermal unit, which is obtained from convolving the outage probability of dispatched LEU with the respective ELDC utilized by the thermal unit as given by (5), where *m* represents the number of off-loading stages of the selected thermal unit.

$$ELDC_{k-1}^{m=1}(x) = p_n ELDC_{k-1}(x+c_n) + q_n ELDC_{k-1}(x)$$
(5)

Determination of the new energy of LEU dispatched to the loading order of the thermal unit subject to its maximum energy limitation, the energy invariance property associated with the increment energy E_r value discharged from the same LEU is expressed as shown in (6). It is worth mentioning that expected energies E_k and E_n of the selected thermal unit and dispatched LEU respectively are computed in the initial loading order.

$$E'_{LEU} = (E_k + E_n) - E'_k \tag{6}$$

The process of finding the optimal value of increment energy E_r continued sequentially under *ELDC* and the *ELDC* of the selected thermal unit with an optimal value of E_r updated simultaneously. However, if the previously adjusted thermal unit is reselected to receive the increment energy E_r , then $ELDC_{k-1}(x)$ is replaced with $ELDC_{k-1}^{m-1}(x)$ and the subsequently forced outage rate of the next LEU (p_n and q_n) and capacity of the next LEU are used in (7) to calculate the new ($ELDC_{k-1}^m(x)$).

$$ELDC_k^{m\neq 1}(x) = p_n ELDC_k^{m-1}(x+c_n) + q_n ELDC_k^{m-1}(x)$$
(7)

where *m* is a number of off-loading stages of the selected thermal unit. Then, both the $ELDC_{k-1}^{m-1}(x)$ and $ELDC_{k-1}^{m}(x)$ are applied in (8) to determine the E_r based on the next LEU loading order, which is located between the E_r based on the previous LEU loading order and the compulsory energy generated by the thermal unit. In the same manner, the E_k and E_k^{m-1} are replaced with new energies E_k^{m-1} and E_k^m in the same thermal unit and used (6) for the determination of new energy E'_{LEU} of the subsequent LEU. The optimization process of the LEU continues until all the LEUs are optimized, and then the PPC_{new} is calculated by (9).

$$E_r^{m\neq 1} = E_k^{m-1} - E_k^m = T.P_n. \int_{SC_{k-1}}^{SC_k} \Big(ELDC_{k-1}^{m-1}(x) - ELDC_{k-1}^{m\neq 1}(x) \Big) dx$$
(8)

$$PPC_{new} = \sum_{n=1}^{L} E_n .COST_n + \sum_{k=1,n=1}^{NE_r} \left(COST_k^{ther} . E_k^m \Big|_{ther}^{ELDC^m} + COST_n^{LEU} . E_r^m \right)$$
(9)

The first item of (9) is the total operation cost of all generating units, excluding the off-loading thermal units affected by E_r . The second and third items are the total operation cost of the thermal unit that is off-loaded by E_r and the total operation cost of the LEU involved in dispatching the increment energy E_r , respectively. $n = \{1, ..., L\}$ is used to represent all generating units, excluding the off-loading thermal units affected by E_r and E_k^m is the compulsory energy generated by the selected thermal unit after off-loading by the LEUs subsequent to the implementation of $ELDC^m$. Here, n and $k = \{1, ..., NE_r\}$ are used to represent the total number of dispatched LEUs. The $COST_k^{ther}$ is the operation cost for the selected thermal unit involved in receiving the increment energy E_r and $COST_n^{LEU}$ is an operation cost for the LEU involved in dispatching the increment energy E_r .

2.2. Determination of Total Expected Start-Up Cost

The total expected start-up cost (*TESC*) refers to the several expenses incurred in order to start thermal units such as the fuel, manpower, wear and tear, and loss of equipment life caused by frequent cycling [52]. In fact, the increasing variable renewable generation on the electric grid is considered as one of the important factors causing thermal units exposed to frequent start-up operation. Therefore, the electric utility is required to determine the expected frequency of start-up of thermal units (*EFS*) over an extended period by forecasting the number of times that the load demand makes a transition

from below to above levels. By referring to Equations (10) and (11), the *TESC* base, according to the initial loading order, can be determined using Equation (12).

$$ELFC_{n\neq 1}(x)(x) = p_n. ELFC_{n-1} + q_n. ELFC_{n-1}(x - c_n) + \frac{1}{\tau}. [ELDC_{n-1}(x - c_n) - ELDC_{n-1}(x)]$$
(10)

The equivalent load frequency curve for the generating unit $ELFC_{n\neq1}$ that can be seen in Equation (10) is made up of two independent contributions. The first part of the equation refers to the load transition resulting from convolution between the two load frequency curves (*LFCs*) in such a way that the p_n and q_n of capacity of the thermal unit is taken into account. In addition, the second one refers to the switching between failures and repair states. Where τ_n is the mean time between failures of the LEU. It is worth mentioning that the $ELFC_{n-1}$ (x) in Equation (10) is equal to *LFC* in the case that (n = 1).

$$EFS_n = p_n \cdot T \left(ELFC_{n-1}(sc_{n-1}) + \frac{ELDC_{n-1}(sc_{n-1})}{\tau_n} \right)$$
(11)

$$TESC_{base} = \sum_{n=1}^{NT} EFS_n.Supc_n \tag{12}$$

Referring to (12), $n = \{1, ..., NT\}$ is used to represent the total number of thermal units in the generation system; the EFS_n for each thermal unit over a period T is determined according to [16], and $Supc_n$ is the start-up cost of the thermal unit. Similarly, in PPC_{new} determining, the performance of PPS technique based on ELDC and ELFC continues in such a way that the $TESC_{new}$ is also minimized. However, obtaining the new EFS of the particular thermal unit ($EFS_k^{m=1}$), which is involved in off-loading its compulsory energy by referring to the increment energy E_r received from the LEUs, is required. The $EFS_k^{m=1}$ value is determined based on changes that occur on ELDC and the ELFC of the selected thermal unit. Therefore, $ELDC_{k-1}^m(x)$ and $ELFC_{k-1}^m(x)$, which have been determined by using (5) and (13) respectively, are used in (14) to calculate the new $EFS_k^{m=1}$ located at the same loading order of the thermal unit.

$$ELFC_{k-1}^{m=1}(x) = p_n \cdot ELFC_{k-1}(x+c_n) + q_n \cdot ELFC_{k-1} + \frac{1}{\tau_n} \left[ELDC_{k-1}(x) - ELDC_{k-1}(x+c_n) \right]$$
(13)

$$EFS_{k}^{m=1} = p_{n}.T\left(ELFC_{k-1}^{m=1}(sc_{k-1}) + \frac{ELDC_{k-1}^{m=1}(sc_{k-1})}{\tau_{n}}\right).$$
(14)

In case the selected thermal unit has peak shaved its energy more than one stage ($m \neq 1$), the same procedure of PPS technique is applied to determine $ELFC_{k-1}^{m\neq 1}(sc_{k-1})$ and $EFS_k^{m\neq 1}$ by using (15) and (16), respectively.

$$ELFC_{k-1}^{m+1}(x) = p_n.ELFC_{k-1}^m(x+c_n) + q_n.ELFC_{k-1}^m(x) + \frac{1}{\tau_n} \Big[ELDC_{k-1}^m(x) - ELDC_{k-1}^m(x+c_n) \Big]$$
(15)

$$EFS_{k}^{m\neq1} = p_{n}.T\left(ELFC_{k-1}^{m\neq1}(sc_{k-1}) + \frac{ELDC_{k-1}^{m\neq1}(sc_{k-1})}{\tau_{n}}\right)$$
(16)

The $TESC_{new}$ is determined using (17) once all the dispatch E_r values based on the subsequent LEU loading order are optimized. The $TESC_{new}$ is specified for the entire thermal units, including the selected thermal units involved in receiving the incremental energy, E_r , from the LEUs. Here, $n = \{1, ..., R\}$ is used to represent all the thermal units excluding the off-loading thermal units affected by E_r , and $k = \{1, ..., NE_r\}$ is used to represent the total number of dispatched LEU.

$$TESC_{new} = \sum_{n=1}^{R} (EFS_n.Supc_n) + \sum_{k=1}^{NE_r} EFS_k^m.Supc_k$$
(17)

2.3. Determination of Saving Utility Cost

The determination of the SUC is performed without causing changes to the reliability of the generating system due to the constant values for the final convolution of ELDC and ELFC. Generally, the utility will calculate the two aspects of SUC, which are the SEC and SECC whenever there is a possibility for the optimal dispatch of LEU performed in such a way that will satisfy the peak load demand imposed with the lowest possible energy and operating cost. Sections 2.1 and 2.2 have explained more elaborately the difference in estimating the PPC and TESC values before and after the optimal dispatch of incremental energy from the LEUs, respectively. In this section, the SEC is determined based on the difference between the two cases of *PPC*, as shown in Equation (18). In a base case condition, the PPC is obtained by using Equation (3) taking into account the base case of ELDC. In the latter case, given in Equation (9), the PPC is obtained based on a new condition of ELDC due to the dispatch of increment energy E_r . As for SECC, it is determined based on the difference between the two cases of *TESC* as given in Equation (19). In the first case, for all of the thermal generating units, the *TESC*_{base} is obtained by taking into account the base case of *ELDC* and *ELFC*, which is basically based on Equation (12). In the second case, the $TESC_{new}$ as given in Equation (17) is obtained based on all of the thermal units inclusive with the new condition of *ELDC* and *ELFC* applied at the particular thermal units involved in peak-shaving or off-loading its compulsory energy by referring to the E_r . Eventually, the SUC of generating systems is defined as the summation of the SEC and SECC as expressed in (20). In addition, Figure 2 has shown the procedure of determination of SUC based on the dispatch increment energy Er from several LEUs using the PPS technique.

$$SEC = PPC_{base} - PPC_{new}$$
(18)

$$SECC = TESC_{base} - TESC_{new}$$
(19)

$$SUC = SEC + SECC \tag{20}$$



Figure 2. Flow chart of saving utility cost determination based on dispatch increment energy E_r from several limited energy units (LEUs) using the probabilistic peak-shaving technique (PPS) technique.

3. The Proposed MABC-NSM Algorithm for Estimation the SUC

The intelligent foraging behavior of honey bee swarms has inspired toward the development of the ABC algorithm. Contrary to the other optimization algorithms, which mainly rely on probabilistic modeling to change a part of the solution in search of a better solution, the ABC algorithm has the ability to remove an entire unproductive population or Food Source Position (*FSP*) and randomly initializes a new one to search for better solutions. With this feature, the ABC algorithm shows a better global search ability and proper convergence than another algorithm does [49–51,53–55]. However, sometimes, the accuracy of the optimal value cannot meet the requirements due to its disadvantages of premature convergence in the later search period. Therefore, this paper proposed a new development approach of the MABC with a new searching mechanism (MABC-NSM) optimization technique constituted with robustness to determine the global optimal solution of the *SUC*. Sections 3.1 and 3.2 discuss in detail the random generation of *FSP* and neighborhood operation of the proposed approach MABC-NSM respectively, which are considered different from the standard ABC algorithm. Eventually, the MABC-NSM algorithm for estimation of the *SUC* is detailed in Section 3.3.

3.1. Problem Formulation

This section presents the proposed method used to determine the maximum solution for the objective function of *SUC*, which is considered as a mixed-integer nonlinear programming (MINLP). The aim of solving the SUC problem is to provide an optimal E_r dispatched from the LEU to the thermal unit obtained based on the approach of the PPS technique within the framework of the *ELDC* and FD approach that is assisted by the MABC-NSM optimization method. Section 2 has discussed the PPS methodology used to dispatch a certain amount of increment energy Er from LEU to replace several amounts of energy that are supposed to be produced by the thermal unit and the determination of saving utility cost has also been discussed. The constraint in this case study is generator operating limits, wherein every thermal unit and hydro or LEU has their upper and lower production limits, which can be evaluated by Equations (21) and (22). As for the transmission line, the constraint is not considered due to simplifying computational procedures into the probabilistic simulation. It worth mentioning that the total maximum energy of each LEU is assumed to be given in this case study. Therefore, water discharge constraints and reservoir water storage limits are not necessary to calculate or consider as constraints.

$$E_{LEUi}^{min} \leq E_{LEUit} \leq E_{LEUi}^{max} \quad i = 1, \dots, I; t = 1, \dots, T$$

$$(21)$$

$$E_{thj}^{min} \le E_{thjt} \le E_{thj}^{max} \quad j = 1, \dots, J; \ t = 1, \dots, T$$
 (22)

where *I* and *j* are indexed for numbers of LEU and thermal units, respectively. E_{LEUit} is a state variable indicating the energy amount of *LEUi* that is generated in time period *t*. In addition, E_{thjt} is the state variable indicating the energy amount of the thermal unit *j* that is generated in time period *t*.

3.2. Representation of Food Source Position for the Proposed MABC-NSM Algorithm.

This section presents a detailed description of the *FSP* initialization scheme for the MABC-NSM algorithm to maximize *SUC*. The *FSP* is a random selection of thermal units that are selected to perform off-loading or peak shaving to accept increment energy E_r dispatched from LEU. Therefore, the total number of randomly selected thermal units is equal to the total number of LEU. It should be noted that a particular thermal unit can be selected more than once, while each LEU can only be discharged once. Hence, the initialization of *FSP* began with selected the loading order or location (k^*) of thermal units by using Equation (23).

$$k^* = k_{min} + (k_{max} - k_{min}).rand(s, 1)$$
(23)

where *s* is the total number of dispatch LEUs, K_{min} and K_{max} are the lower and upper bound of the loading order of the selected thermal unit involved in receiving the increment energy *Er*. Then, the *FSP* is done by selecting the random position of the thermal unit to receive the E_r as shown in Figure 3.

The initialized *FSP* is often used for the initial bee colony (Icol) and scout bee colony (Scol), while on the other hand, the neighboring solution by the MABC-NSM algorithm is required for the employed and onlooker bee colonies.



Figure 3. Initialization of food source position required for initial and scout bee colony $E_{r_{kn}}|_{ESD}$.

3.3. Neighborhood Operation for the Proposed MABC-NSM Algorithm.

There is a difference between the NSM algorithm used for each employed bee and onlooker bees for efficient searching ability with low computational time within the neighborhood operation colony (Ncol). The NSM plays a vital role in increasing the search efficiency by preventing the scout bee activation because the best *FSP* provided by the employed and onlooker bees conveys better information than the random *FSP* generated by the scout bees during the evolution process [20]. Given that, the employed bee colony (*Ecol*) is responsible for exploiting available food sources, gathering required information, and sharing it with an onlooker bee colony (*Ocol*). Thus, each *Ecol* contains a number of new *FSPs* which is known as the Ncol. Similar to the initialization of *FSP* that is discussed in Section 3.1, the thermal units' loading order (k^*) for each Ncol of the best *FSP* either by the Icol or previous *Ecol* is updating to produce a new loading order of k^{**} using Equation (23). Then, the *FSP* is done by simultaneously selecting the random position of thermal unit blocks to receive the E_r .

Once all the *Ecols* have finished with the above exploitation process, they share the information of the *FSP* with the onlookers. Then, each *Ocol* selects a food source according to the traditional roulette wheel selection method. After that, neighborhood operation colony (Ncol) is implemented to find the best *FSP*, and it calculates the nectar amount or the objective function of *SUC* of the neighbor food source. A similar process occurs in *Ocol*, but the number of Ncol generated is twice that of *Ecol*. In the first process, Ncols are generated from the best *FSP* either by the *Ecol* or previous *Ocol* using Equation (24). While in the second process, the Ncols are generated based on Equation (25). The function of Reset is to redo the random selection of the thermal unit and LEU involved in each *FSP* of the onlooker bee colony. This scheme enhances the searching mechanism of the *Ecol* and *Ocol*, thereby reducing the chance of being replaced by the Scol.

$$\vec{k^{***}} = \left(k_{min}^{**} + \operatorname{Reset}\right) + \left(k_{max}^{**} - \left(k_{min}^{**} + \operatorname{Reset}\right)\right).rand(s, 1)$$
(24)

$$\vec{k^{***}} = (k_{min}^{**} + ((k_{max}^{**} - \text{Reset}) - k_{min}^{**})).rand(s, 1)$$
(25)

In such a way, the neighborhood operation (Ncol) of *Ecol* and *Ocol* is performed to explore the optimal solution. However, the *Ecol* becomes a scout bee colony (Scol) to explore a new solution if the current solution is not improved and reached a limit (a predetermined number). At this point, the newly *FSP* discovered is memorized, the scout becomes an employed bee again, and simultaneously

another iteration of the algorithm begins. The whole process is repeated until a maximum cycle number (MCN) is met.

3.4. The Steps of the MABC-NSM Algorithm

The MABC-NSM is presented as a new approach effectively used to avoid the local optimal trap of *SUC* solution.

- (a) Calculate the base case values of *PPC*_{base} and *TESC*_{base} using (3) and (12), respectively. Wherein the thermal units are loaded according to merit order, followed by the LEUs arranged corresponding to the decreasing operating hours under the LDC.
- (b) Specify the total number of the *FSP* and Icol required for initialization process.
- (c) Specify the total number of *Ecol* and Ncol required for the NSM process used in the employed bee colony.
- (d) Specify the total number of *Ocol*, Reset, and Ncol required for NSM process used in the onlooker bee colony
- (e) Specify the total number of limit (limit) required for activating the Scol.
- (f) The initial bee colony (Icol) is implemented in steps (f) until (g), and the SUC_{Icol} is determined using (20) once the two criteria stated earlier and constraints for each dispatched case of $E_{r_{k^*,n}}|_{FSP}^{Icol}$ in an Icol are met. This is followed by the determination of PPC_{Icol}^{new} , $TESC_{Icol}^{new}$, SEC_{Icol} , and $SECC_{Icol}$ using (9), (17), (18), and (19), respectively. Repeat the step (f) and simultaneously record all the information that was obtained above until the Icol reached the specified number stated in step (b). Figure 4a has shown all the process of the Icol.
- (g) Select $E_{r_{k^*,n}}|_{FSP}^{Icol}$ from the colony with the highest value of SUC_{Icol} .
- (h) Apply the NSM for employed bee colony (*Ecol*), which will provide several Ncols for each particular *Ecol* derived from $E_{r_{k^*,n}}|_{FSP}^{Icol}$ obtained from (g). The NSM is implemented in steps (j) until (o) as illustrated in Figure 4b, so that the *Ecol* can be produced with less probability of being replaced by Scol.
- (i) Set the number of *Ecol* as 1.
- (j) Specify k^{**} as the new variables or the locations of the thermal unit using Equation (23) from $E_{r_{k^*,n}}|_{FSP}^{Icol}$ obtained from step (g) or $E_{r_{k^*,n}}|_{FSP}^{Ecol-1}$ obtained from step (m).
- (k) Determine the $SUCN_{col}$, once the two criteria stated earlier and constraints for each dispatched case of $E_{r_{k^*,n}}\Big|_{FSP}^{Ncol}$ in an Ncol are met.
- (l) Differentiate between the values of SUC_{Ncol} and SUC_{Icol} produced by the $E_{r_{k^{**},n}}\Big|_{FSP}^{Ncol}$ and $E_{r_{k^{*},n}}\Big|_{FSP}^{Icol}$ and $E_{r_{k^{**},n}}\Big|_{FSP}^{Icol}$ and $E_{r_{k^{**},n}}\Big|_{FSP}^{Icol-1}$ produced by the $E_{r_{k^{**},n}}\Big|_{FSP}^{Ncol}$ and $E_{r_{k^{**},n}}\Big|_{FSP}^{Icol-1}$, respectively.
- (m) Record the number of *Ecol*, Ncol, and $E_{r_{k^*,n}}|_{FSP}^{Ecol}$ having the same value as the $E_{r_{k^*,n}}|_{FSP}^{Ncol}$ only when it gives the result of SUC_{Ncol} that is higher than the SUC_{Icol} produced by the $E_{r_{k^*,n}}|_{FSP}^{Icol}$ or SUC_{Ncol} is higher than SUC_{Ecol-1} associated with the $E_{r_{k^*,n}}|_{FSP}^{Ecol-1}$; then, the limit is reset to 0 and proceed to step (m(ii)).
 - i. In contrast to the above matter, when only the SUC_{Ncol} is lower than the SUC_{Icol} or SUC_{Ecol-1} , then record the limit which is increased by 1 and perform the subsequent process. Only if the limit has reached the specified number as set in step (e), then stipulate $E_{r_{k^*,n}}|_{FSP}^{Ecol}$ having a similar value as the $E_{r_{k^*,n}}|_{FSP}^{Lcol}$ or $E_{r_{k^{**,n}}}|_{FSP}^{Ecol-1}$ obtained from step (g) or (m) and simultaneously proceed to step (aa).

- ii. Simultaneously, the subsequent process is performed, which increases the Ncol by 1 and then repeat steps (k)–(m) to produce $E_{r_{k^**,n}}|_{FSP}^{Ncol}$ for a particular *Ecol*. If Ncol has not reached the total number specified in step (c), otherwise increase the *Ecol* by 1 and then repeat steps (j)–(m) to produce $E_{r_{k^**,n}}|_{FSP}^{Ncol}$ for a new *Ecol*. Proceed to step (n) if the *Ecol* has reached the predetermined threshold given in step (c).
- (n) Sort the recorded information of *Ecol*, $E_{r_{k^*,n}}|_{FSP}^{Ecol}$, and SUC_{Ecol} , which are obtained in step (m).
- (o) Choose the final arrangement of the employed bee colony, $E_{r_{k^{**},n}}\Big|_{FSP}^{Ecol}$, including the information of SUC_{Ecol} .
- (p) Apply the NSM to obtain several onlooker bee colonies (*Ocol*) originated from an employed bee colony $E_{r_{k^*,n}}|_{FSP}^{Ecol}$ obtained from step (o). The NSM process of the onlooker bee colony encompassed under the steps (r) to (z) is illustrated in Figure 4c.
- (q) Increase the Reset by 1.
- (r) Specify the number of *Ocol* as 1.
- (s) Define $\vec{k^{***}}$ using Equation (24) from the thermal unit of $E_{r_{k^{**},n}}\Big|_{FSP}^{Ecol}$ obtained from step (o) or $E_{r_{k^{**},n}}\Big|_{FSP}^{Ocol-1}$ obtained from step (v).
- (t) Determine the neighboring colony to calculate the new value of *SUC* obtained based on the energy dispatched from the LEU to the $\vec{k^{***}}$ thermal unit. This implies that the neighboring colony contains the value of $E_{r_{\vec{k^{***}},n}}\Big|_{FSP}^{Ncol}$ yielding the SUC_{Ncol} .
- (u) Compare the value of SUC_{Ncol} and SUC_{Ecol} produced by $E_{r \rightarrow k^{***},n} \Big|_{FSP}^{Ncol}$ and $E_{r_{k^{**},n}} \Big|_{FSP}^{Ecol}$ obtained from step (o), respectively, or the value of SUC_{Ncol} and SUC_{Ocol} produced by $E_{r \rightarrow k^{***},n} \Big|_{FSP}^{Ncol}$ and $E_{r \rightarrow k^{***},n} \Big|_{FSP}^{Ocol-1}$ obtained from step (v), respectively.
- (v) Record the number of *Ocol*, Ncol, and $E_{r \rightarrow k^{***,n}} \Big|_{FSP}^{Ocol}$ equivalent to $E_{r \rightarrow k^{***,n}} \Big|_{FSP}^{Ncol}$ once it gives the SUC_{Ncol} result that is higher than SUC_{Ecol} produced based on the $E_{r_{k^{**},n}} \Big|_{FSP}^{Ecol}$ or SUC_{Ncol} is higher than SUC_{Ocol-1} associated with $E_{r \rightarrow k^{***,n}} \Big|_{FSP}^{Ocol-1}$ simultaneously, the limit is reset to 0 and increase the Reset of the onlooker bee colony by 1. The limit for Reset has been specified in step (d), and then proceed to step (v(ii)).
 - i. In contrast to the above matter, when only the SUC_{Ncol} is lower than the SUC_{Ecol} or SUC_{Ocol-1} , then record the limit which is increased by 1 and perform the subsequent process. Only if the limit has reached the specified number as set in step (e), then stipulate $E_{r_{k^{**},n}}\Big|_{FSP}^{Ocol-1}$ having a similar value as the $E_{r_{k^{*},n}}\Big|_{FSP}^{Ecol}$ or $E_{r_{k^{***},n}}\Big|_{FSP}^{Ocol-1}$ obtained from step (o) or (v) and simultaneously proceed to step (bb).
 - ii. The subsequent process increases the Ncol by 1 and then repeats steps (t)–(v) to produce $E_{r_{k^{***},n}}\Big|_{FSP}^{Ncol}$ for a particular *Ocol*, if Ncol has not reached the total number specified in step (d); otherwise, increase the *Ocol* by 1 and then repeat steps (s)–(v) to produce $E_{r_{k^{***},n}}\Big|_{FSP}^{Ncol}$ for the new *Ocol*. If Ncol has reached the total number specified in step (d) then simultaneously proceed to step (w) if *Ocol* reaches half of the predetermined threshold or limit given in step (d).

- (w) Arrange the recorded information of *Ocol*, $E_{r \rightarrow k^{ess},n} \Big|_{FSP}^{Ocol}$, and SUC_{Ocol} obtained in steps (v). All the information is obtained based on *Ocol* in the current Reset.
- Select the last row of the onlooker bee colony $E_{r \rightarrow k^{***,n}} \Big|_{FSP}^{Ocol}$ including the information of *Ocol* and (x) SUC_{Ocol}.
- (y) Repeat the NSM for the onlooker bee colony from step (t) until step (w) as shown Figure 4d to produce $E_{r_{k^{***},n}}\Big|_{FSP}^{Ocol}$, and SUC_{Ocol} . k^{***} is obtained using Equation (25) from the thermal unit of $E_{r \rightarrow k^{***},n} \Big|_{ESP}^{Ocol}$ obtained from step (x).
- Select the last row or arrangement of the onlooker bee colony $E_{r} \in \begin{bmatrix} O_{col} \\ E_{r} \\ E_{r} \end{bmatrix}$, including the information (z) of Ocol and SUC_{Ocol}.
- (aa) Determine a scout bee colony, $E_{r_{k^*,n}}|_{FSP}^{Scol}$ as shown Figure 4e, if the limit recorded in steps (m)(i) or (v)(i) reaches the limit stated in step (e). This is done by performing step (f) to obtain a scout bee colony $E_{r_{k^*,n}}|_{FSP}^{Scol}$ and the SUC_{Scol} .
- (bb) Change the name of $E_{r_{k^*,n}}\Big|_{FSP}^{Scol}$ to $E_{r_{k^*,n}}\Big|_{FSP}^{Icol}$ and proceed to step (h) if the limit reaches the limit specified in step (e) and $E_{r_{k^*,n}}\Big|_{FSP}^{Scol}$ has provided a higher value of SUC_{scol} . This means that $E_{r_{k^*,n}}\Big|_{FSP}^{Icol}$ has the same value as the $E_{r_{k^*,n}}\Big|_{FSP}^{Scol}$. Similarly, SUC_{Icol} has a value equal with SUC_{Scol} . If the limit does not reach the predetermined limit given in step (e), then change the name of $E_{r} \underset{k^{***,n}}{\leftarrow} \Big|_{FSP}^{Ocol}$ to $E_{r_{k^*,n}}\Big|_{FSP}^{Icol}$ and proceed to step (h). This signifies that $E_{r_{k^*,n}}\Big|_{FSP}^{Icol}$ has the same value as $E_{r_{k^{***},n}}\Big|_{FSP}^{Cont}$ obtained from step (z). Similarly, SUC_{Ecol} has the same value with SUC_{Ocol} obtained from step (z), respectively.
- (cc) Halt the ABC process when the last cycle, the maximum cycle number (MCN), is reached, and then proceed to step (dd). Otherwise, proceed to step (h) to the next iteration process of the ABC technique.
- (dd) Report the optimal values of SUC.



Figure 4. Cont.



(d) Figure 4. Cont.



Figure 4. The methodology of the modified artificial bee colony with a new searching mechanism (MABC-NSM) algorithm: (**a**) Initial bee colony (Icol); (**b**) NSM-Employed bee colony (*Ecol*); (**c**) and (**d**) NSM-Onlooker bee colony (*Ocol*) for $\vec{k^{***}}$ and $\vec{k^{***}}$ respectively; (**e**) Scout bee colony (Scol).

4. Results and Discussion

In this section, the test system is first described and then followed by the base case results. The results of *SUC* are selected based on a detailed comparison of standard ABC and the proposed method of MABC-NSM. Furthermore, the comparison of *SUC* results using the proposed algorithm MABC-NSM is also detailed through the impartial comparison between the *SUC* determined directly and the *SUC* indirectly estimated by referring to the energy reduction of thermal units *ERTU*.

4.1. Test System Description

A winter week load cycle of modified IEEE RTS-79 having the maximum peak load demand of 2850 MW and 3000 MW is used to validate the proposed method. The test system is modified with an additional 25 MW and 15 MW hydro units as specified in accordance with the standard stated in [56] with start-up cost data from [57] and operating cost data for the generating units [58]. The maximum total energy assigned to the hydro units is assumed to be 18,969 MWh.

4.2. Base Case Results

Table 1 displays results that convey important information, which will be used as a reference for *SUC* determination expounded in the next subsection. These results are basically obtained based on the framework of the *ELDC* and FD methods without considering the optimal dispatch of the LEU ODLEU (base case condition) for the peak load demand of 2850 MW and 3000 MW considered in the modified IEEE RTS-79. It is noteworthy that in the base case condition, the thermal units are initially arranged according to the merit order or incremental fuel cost followed by the LEU blocks arranged corresponding to the decreasing operating hours as shown in Table 1. The corresponding final results of *PPC* are \$5,658,196 and \$6,343,498 with *TESC* being \$386,426 and \$386,387 for peak load demands of 2850 MW and 3000 MW, respectively. In this case study, the ODLEU has no effect on the reliability indices. Thus, it is not included in Table 1.

Order	Order Installed Capacity (MW)		Expe	ected	Expected	
oraci	mouned cupacity (1111)	q_n	Energy, E	E_n (MWh)	Frequenc	cy Startup
			2850	3000	2850	3000
1	400	0.120	59,136	59136	0.118	0.118
2	400	0.120	59,136	59136	0.118	0.118
3	350	0.080	54,096	54096	0.124	0.124
4	155	0.040	24,998.400	24,998.400	0.161	0.161
5	155	0.040	24,748.240	24,985.270	0.161	0.161
6	155	0.040	23,676.760	24,262.390	1.443	0.794
7	155	0.040	21,534.220	22,931.410	3.394	1.478
8	76	0.020	9926.854	10,566.640	6.910	5.133
9	76	0.020	9426.235	10,019.450	7.454	6.197
10	76	0.020	8667.062	9567.230	7.090	7.328
11	76	0.020	7943.615	8925.590	6.526	7.011
12	100	0.040	9332.288	10,387.810	6.884	6.895
13	100	0.040	8626.770	9381.815	7.339	7.188
14	100	0.040	7962.194	8680.814	6.755	7.362
15	197	0.050	13,367.900	15,064.300	6.407	6.782
16	197	0.050	8574.433	12,077.050	5.724	5.868
17	197	0.050	4598.911	7244.992	3.738	5.544
18	12	0.020	207.845	335.119	2.142	3.485
19	12	0.020	199.437	321.071	2.101	3.007
20	12	0.020	192.766	309.604	2.016	2.945
21	12	0.020	179.543	292.514	1.986	2.941
22	12	0.020	174.686	284.011	1.958	2.742
23	20	0.100	248.169	411.878	1.725	2.475
24	20	0.100	225.784	387.292	1.665	2.430
25	20	0.100	207.270	365.718	1.579	2.276
26	20	0.100	188.385	339.644	1.467	2.144
27	50	0.010	434.186	834.843	1.533	2.256
28	50	0.010	333.928	685.456	1.186	1.994
29	50	0.010	257.064	537.409	0.920	1.752
30	15	0.010	63.699	136.416	0.673	1.393
31	25	0.010	94.758	203.838	0.613	1.323
32	50	0.010	154.653	336.726	0.544	1.189
33	50	0.010	117.972	260.493	0.410	0.925
34	50	0.010	89.060	195.156	0.325	0.688

Table 1. The results of the base case for all generating units based on peak loads of 2850 and 3000 MW for the modified IEEE RTS-79.

4.3. Comparison of SUC Results Using Proposed Method of MABC-NSM and Standard ABC Method

A comparison is made of the results of *SUC* obtained from the proposed method of MABC-NSM and the standard ABC method. To ensure an impartial comparison of the performance of both optimization techniques, the determination of *SUC* and its computation time are used as a reference to obtain the finest parameters setting for the ABC and MABC-NSM techniques. The determination of the finest parameters setting for the ABC and ABC-NSM techniques are performed based on the different peak load demand of 2850 MW and 3000 MW for the modified IEEE RTS-79. In this case study, the parameters settings that are used for this comparison are colony size (*Cs*), the total number of the limit, and the maximum cycling number (MCN).

4.3.1. Parameter Setting for Cs of ABC and ABC-NSM Techniques

The best value of *Cs* is determined subsequent to several iterative runs of all the operators embedded in the ABC and MABC-NSM techniques under the Cs = 100, Cs = 200, Cs = 300, and Cs = 400 associated with the total number of limits, which is set as half of the *Cs* value, as shown in Table 2. Table 2 represents the results of the *SUC*, and it is a computational time for every optimal solution performed by both techniques with several iterative runs of embedded operators corresponding to different selected values of *Cs*. For the peak load demand of 2850 MW, it is observed that the optimal maximum *SUCs* of \$268,676 and \$288,185 are obtained at *Cs* = 100 and *Cs* = 300 with a computational time of 0.25 hour and 1.28 hours for the ABC and MABC-NSM techniques, respectively.

Meanwhile, for the peak load demand of 3000 MW, it is observed that the optimal maximum *SUC* value of \$274,171 and \$287,865 are obtained at Cs = 100 and Cs = 300 with a computational time of 0.33 hours and 1.37 hours for the ABC and MABC-NSM techniques, respectively. In contrast to the ABC technique, it is obvious that the MABC-NSM technique performed much better in providing the optimal maximum *SUC* values of \$288,185 and \$287,865 within 1.28 hours and 1.37 hours at Cs = 300 for the peak load demands of 2850 MW and 3000 MW, respectively. It is important to mention that despite the ABC having a low computation time, it fails to obtain the optimal maximum results of *SUC*. The performance of both optimization techniques is improved because the scout bees are deactivated by not transcending the total number of limit that is set as half of the total number of *Cs* for the purpose of fair comparison. Eventually, it can be observed that Cs = 300 does significantly culminate toward improving the performance of the MABC-NSM technique and hence providing the finest optimal maximum results of *SUC* for every peak load demand in contrast with the ABC technique. Therefore, the Cs = 300 will be used as a reference for the determination of other parameters settings specified in the MABC-NSM technique.

Table 2. Results of saving utility cost (*SUC*) based on different selected values of *Cs* and its computational time for every optimal solution performed by Artificial Bee Colony (ABC) and MABC-NSM techniques for peak load demands of 2850 MW and 3000 MW.

Optimization Techniques Peak Load Dem (MW)		C_s	Limit	SUC (\$)	Iteration	Time (hours)
		100	50	268,676	232	0.25
	2850	200	100	268,676	294	0.31
	2850	300	150	268,676	336	0.40
ABC		400	200	268,676	372	0.45
1120	3000	100	50	274,171	240	0.33
		200	100	274,171	276	0.37
		300	150	274,171	318	0.41
		400	200	274,171	387	0.47
		100	50	267,994	6328	1.20
	2850	200	100	279,612	7463	1.00
		300	150	288,185	8343	1.28
ABC-NSM		400	200	274,112	9510	1.35
		100	50	267,486	6763	1.26
	2000	200	100	279,082	7847	1.33
	3000	300	150	287,865	9849	1.37
		400	200	273,593	9895	1.41

4.3.2. Parameter Setting of Total Number of Limit for the MABC-NSM Techniques

The suitability of the value prescribed for the total *Limit* depends on whether it provides a better solution of the *SUC* considered as the objective function in the MABC-NSM technique at a reasonably low computational time. In relation with the determination of a suitable total *Limit*, the investigation is performed in such a way that the proposed MABC-NSM optimization process is executed at every value of *Limit* = 50, *Limit* = 100, and *Limit* = 150, taking into account the finest *Cs* value that is previously determined in Section 4.3.1 as shown in Table 2. The finest total *Limit* determined by using the MABC-NSM technique is obtained for every peak load demand of 2850 MW and 3000 MW for the modified IEEE RTS-79. By referring to the assessment of all the total *Limits* determined by using the MABC-NSM technique obtained based on all of the peak load demand, from Table 3, it can be observed that the *Limit* = 150 can be considered as the best finest total *Limit* causing the maximum value of *SUC* = \$28,818 per week with a relatively lower computational time of 1.28 hours and *SUC* = \$287,865 per week with a relatively minimum computational time of 1.37 hours, respectively. Furthermore, for all the peak load demands, the *Limit* = 50 resulted in the worst minimum value of *SUC*, as shown in Table 3. The main reason is that the number of iterative processes involved in the NSM easily attains

or reaches the *Limit* = 50, which will cause the activation of scout bees for randomly generating the food sources and adversely impact the insufficient searching results of the *SUC*.

Optimization Technique	Cs	Limit	Peak Load Demand (MW)	SUC (\$)	Iteration	Time (hours)
			2850	267,390	11,986	1.57
	300	50	3000	273,893	10,752	2.09
ABC-NSM			2850	282,149	10,316	1.45
		100	3000	279,893	9976	1.52
			2850	288,185	8343	1.28
		150	3000	287,865	9849	1.37

Table 3. Results of the SUC based on selected values of Cs = 300 and its computation time for every limit specified in MABC-NSM technique for peak load demands of 2850 MW and 3000 MW.

4.4. Results of SUC Obtained Based on Direct Estimation Using the Proposed Method of MABC-NSM

Table 4 represents several results obtained with regard to the objective function of *SUC* determined by using the MABC-NSM optimization technique, taking into account the PPS technique under the framework of *ELDC* and the FD approach. In this case study, the best parameters setting embedded with a population size of 300 and *Limit* = 150 are applied in the MABC-NSM technique to determine the objective function of *SUC* corresponding to the peak-load demands of 2850 MW and 3000 MW for the modified IEEE RTS-79.

Table 4. The results of the objective function of the SUC determined by using the proposed method of
the MABC-NSM for the peak-load demands of 2850 MW and 3000 MW.

Peak Load Demand (MW)	Loading Order		ERTII (MWh)	New EFS.	SEC (\$)	SECC (\$)
Teak Boud Demand (1919)	Thermal	LEU		iten Eron	020 (¢)	0200 (\$)
	15	31	482.911	0.116	23,469	1046
	15	30	319.130	-0.003	15,509	-25
	15	27	1161.248	0.505	56,435	4547
	15	28	1385.276	0.047	67,322	420
2850	15	29	1441.072	0.049	70,034	442
	12	32	404.891	-0.314	17,693	-1449
	13	33	326.158	0.484	14,253	2237
	13	34	358.856	0.123	15,682	570
Total			5879.541		280,397	7788
	16	31	548.245	0.041	26,644	372
	16	30	372.111	0.029	18,084	265
	16	27	1327.933	0.093	64,535	837
	16	28	1344.968	0.163	65,363	1469
3000	16	29	1273.919	0.045	61,911	409
	13	32	395.756	-0.028	17,294	-131
	14	33	311.265	0.470	13,602	2172
	14	34	335.900	0.078	14,678	361
Total			5910.097		282,111	5754

By referring to Table 4, the new values of *PPC* are \$5,377,799 and \$6,061,387 with new values of *TESC* \$378,638 and \$380,633 for the peak-load demand of 2850 MW and 3000 MW, respectively. Consequently, the maximum *SUC* values of \$288,185 and \$287,865 are obtained by the summation of SEC values of \$280,397 and \$282,111, and *SECC* values of \$7788 and \$5754 for 2850 MW and 3000 MW, respectively. From Table 4, it can also be seen that the variations of *SEC* and *SECC* arise in such a way that there are changes of E_n and EFS_n that are imminent in the thermal unit affected by the dispatch increments energy of LEU. Moreover, the negative value of *SECC* and EFS_n originated from changes occurs in *LFC* during the application of ODLEU. Contrary to decreasing the load demand on the selected thermal unit that is shown in column two of Table 4, the number of times that the demand makes a transition from a level below to a level above is increased in comparison with the

base *LFC* condition. The E_n and *EFS_n* have remained the same for the rest of the thermal unit for the peak-load demands of 2850 and 3000 MW, as shown in Table 1.

4.5. Comparison of SUC Results Obtained Based on Direct Estimation and Indirect by Referring to ERTU

For impartial comparison, the MABC-NSM technique with the finest parameters setting is used to determine *SUC* directly and indirectly estimated by referring to the *ERTU*. Section 4.4 has explained in detail the direct estimation of *SUC* using the MABC-NSM technique with the finest parameters setting. In this section, several results were displayed related to the maximum objective function of *ERTU* determined by using the proposed method of MABC-NSM. Again, the *SUC* is reported once all the optimizing LEUs had dispatched based on maximizing *ERTU* or E_r , regardless of the generation operating cost, as shown in Table 5.

Peak Load Demand (MW)	Loading Order		FRTU (MWh)	New FFS.	SEC (\$)	SECC (\$)
Teak Loud Demand (1977)	Thermal	LEU			5EC (\$)	υLee (φ)
	15	31	482.911	0.116	23469	1046
	15	30	319.130	-0.003	15509	-25
	15	27	1161.248	0.505	56435	4547
	15	28	1385.276	0.047	67323	420
2850	15	29	1441.072	0.049	70034	442
	6	32	523.037	-0.005	6485	-38
	10	33	509.975	0.250	8210	897
	10	34	425.517	0.228	6850	818
Total			6248.165		254,315	8107
	16	31	548.245	0.041	26644	372
	16	30	372.111	0.029	18084	265
	16	27	1327.933	0.093	64535	837
	16	28	1344.968	0.163	65363	1469
3000	16	29	1273.919	0.045	61911	409
	13	32	395.756	-0.028	17294	-131
	8	33	372.277	-0.916	5993	-3284
	8	34	332.301	-1.010	5350	-3620
Total			5967.510		265,174	-3683

Table 5. Results of SUC estimated indirect by referring the objective function of *ERTU* based on MABC-NSM for the peak-load demand of 2850 and 3000 MW.

Based on the results shown in Tables 4 and 5, it is evident that robust performance of the MABC-NSM technique has produced the maximum *ERTU* of 6248.165 MWh and 5967.510 MWh for the peak load demands of 2850 MW and 3000 MW, respectively. The obtained results of *ERTU* have achieved 6.27% and 0.97% higher than the *ERTU* results displayed in Table 4 for the peak load demands of 2850 MW and 3000 MW of the test system, respectively, but the *SUC* is decreased by 8.49% and 9.16%, respectively. This indicates that dispatched LEUs based on the maximum *ERTU* is not met with the energy-efficiency concept, nor is it economically feasible. It is important to mention that despite the standard ABC algorithm failing to obtain the optimal globe value of *SUC* as compared with the MABC-NSM algorithm, it is considered higher than the result obtained based on a maximum of *ERTU* for all the peak demand. Therefore, the result based on the standard ABC algorithm that is displayed in Table 6.

From Table 6, it can be easily noticed that the proposed MABC-NSM technique is not only limited to directly determine the maximum value of *SUC*, but also its resilient performance does augment the energy efficiency in terms of the minimum total reduced energy margin for the certain thermal unit peak-shaved by the minimum total E_r of the LEU. The proposed MABC-NSM technique has achieved 10.65% and 5.25% of the *ERTU* higher than the standard ABC technique for 2850 MW and 3000 MW of the test system, respectively. Furthermore, the *SUC* is increased by 7.26% and 5%, respectively.

Item Description	Standard AB	C Technique	MABC-NSN	A Technique
Load Demand (MW)	2850	3000	2850	3000
PPC (\$)	5,405,272	6,075,725	5,377,799	6,061,387
<i>TESC</i> (\$)	370,674	379,989	378,638	380,633
ERTU (MWh)	5313.411	5615.073	5879.542	5910.097
SEC(\$)	252,924	267,773	280,397	282,111
SECC(\$)	15,752	6398	7788	5754
<i>SUC</i> (\$)	268,676	274,171	288,185	287,865

Table 6. Comparison of *SUC* results obtained based on the standard Artificial Bee Colony (ABC) and MABC-NSM algorithm. *ERTU*: energy reduction of thermal units, *PPC*: probabilistic production cost, SEC: Saving Energy Cost, *SECC*: Saving Expected Cycling Cost, *TESC*: total expected start-up cost.

5. Conclusions

This paper has expounded in detail on the modified IEEE RTS-79 test systems used as the case study for the comparative analyses on the results of the saving utility cost (SUC) obtained from the ODLEU performed based on different peak load demands. The PPS methodology is assisted with an optimization technique to dispatch a certain amount of increment energy E_r from the LEU block to replace several amounts of energy that are supposed to be produced by the thermal unit. This paper has successfully achieved all of the specified objectives, which include developing a new approach of the MABC-NSM optimization technique with robustness to determine the global optimal solution of SUC obtained based on the ODLEU. Herein, the optimal value is selected based on a detailed comparison of standard ABC and the proposed method of MABC-NSM. The achievement of the proposed method is related to composing a new approach of a new searching mechanism that is performed via the process of employed and onlooker bees included under the procedure of the MABC-NSM algorithm. The results have also shown that NSM plays a vital role in increasing the search efficacy by avoiding activating the scout bee. This is because the best food source in the population provided by the employed and onlooker bees often carries better information than the random food source generated by scout bees during the evolution process. The other objective which also has been done successfully is related to obtaining the optimal value of SUC through the impartial comparison between the SUC determined directly by using the MABC-NSM technique and the SUC indirectly estimated by referring to the energy reduction of thermal units determined by using the MABC-NSM. The proposed MABC-NSM technique has achieved ERTU values that are 10.65% and 5.25% higher than the standard ABC technique for the test systems of 2850 MW and 3000 MW, respectively. Furthermore, SUC is increased by 7.26% and 5%, respectively. Nevertheless, the transmission line limit is not taken into account as a constraint in the optimization method, which is used to specify the dispatch of energy from the LEU blocks to several thermal units. Future works certainly will require a transmission line limit that can be considered as one of the constraints in the optimization method used for determining the dispatch of the energy from the LEU blocks to the thermal unit. The proposed optimization method used for determining the dispatch of the energy indeed can be performed based on two case studies that are either referring to a specific area or the entire system. Another recommendation is to develop a new technique based on probabilistic production simulation of the power system for obtaining the accurate saving utility cost assisted with an optimization technique for other renewable energy called non-dispatchable technologies, such as wind turbines and solar.

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Abbreviations

The following a	abbreviations are used in this manuscript
ABC	Artificial Bee Colony
Er	Energy Increment
ERTU	Energy Reduction of Thermal Unit
ELDC	Equivalent Load Duration Curve
En	Expected Energy
EFS	Expected Frequency of Start-Up of Thermal Units
FD	Frequency and Duration
FSP	Food Source Position
GA	Genetics Algorithm
Icol	Initial Bee Colony
LEU	Limited Energy Unit
LFC	Load Frequency Curve
MCN	Maximum Cycle Number
MABC-NSM	Modified Artificial Bee Colony With New Searching Mechanism
MINLP	Mixed Integer Nonlinear Programming
Ocol	Onlooker Bee Colony
O & M	Operation And Maintenance
ODLEU	Optimal Dispatch of Limited Energy Unit
PPC	Probabilistic Production Cost
PPS	Probabilistic Peak Shaving
PSO	Particle Swarm Optimization
SEC	Saving Energy Cost
SECC	Saving Expected Cycle Cost
SUC	Saving Utility Cost
Scol	Scout Bee Colony
TESC	Total Expected Start-Up Cost

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