Ain Shams Engineering Journal (2018) 9, 161–172

Ain Shams University

Ain Shams Engineering Journal

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A load shedding scheme for DG integrated islanded power system utilizing backtracking search algorithm

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Received 24 September 2014; revised 30 September 2015; accepted 3 October 2015
Available online 11 November 2015

KEYWORDS

Optimal load shedding;
Islanded system;
Voltage instability;
Voltage stability margin (VSM);
Backtracking search algorithm (BSA);
Genetic algorithm (GA)

Abstract In a dispersed generation (DG) integrated distribution system, several technical issues should be resolved if the grid disconnects and forms an islanded system. The most critical challenge in such a situation is to maintain the stability of the islanded system. The common practice is to reject several loads through a load shedding scheme. This study introduces a development of an optimal load shedding scheme based on backtracking search algorithm (BSA). To handle this optimization problem, a constraint multiobjective function that considers the linear static voltage stability margin (VSM) and amount of load curtailment is formulated. It also handles the load priority and various operating conditions of DGs. The performance of the proposed load shedding scheme was evaluated through an extensive test conducted on the IEEE 33-bus radial distribution system with four DG units considering several scenarios such as load shedding under various operating points and at various islands using the MATLAB® software. Moreover, the effectiveness of the proposed scheme was validated by comparing its results with those obtained using the genetic algorithm (GA). The optimization results indicate that the proposed BSA technique is more effective in determining the optimal amount of load to be shed in any islanded system compared with GA.
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1. Introduction

Considering the development of new technologies through the years, the idea of immediately disconnecting all of the dispersed generations (DGs) to prevent equipment damage and eliminate safety hazards is inapplicable. Moreover, some standards and regulations have been created to prevent islanding hazards, and distribution network operator companies have

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Peer review under responsibility of Ain Shams University.

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http://dx.doi.org/10.1016/j.asej.2015.10.001
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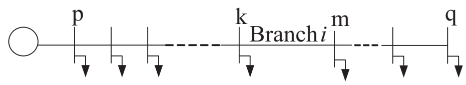

Figure 1 Typical radial feeder of distribution system.

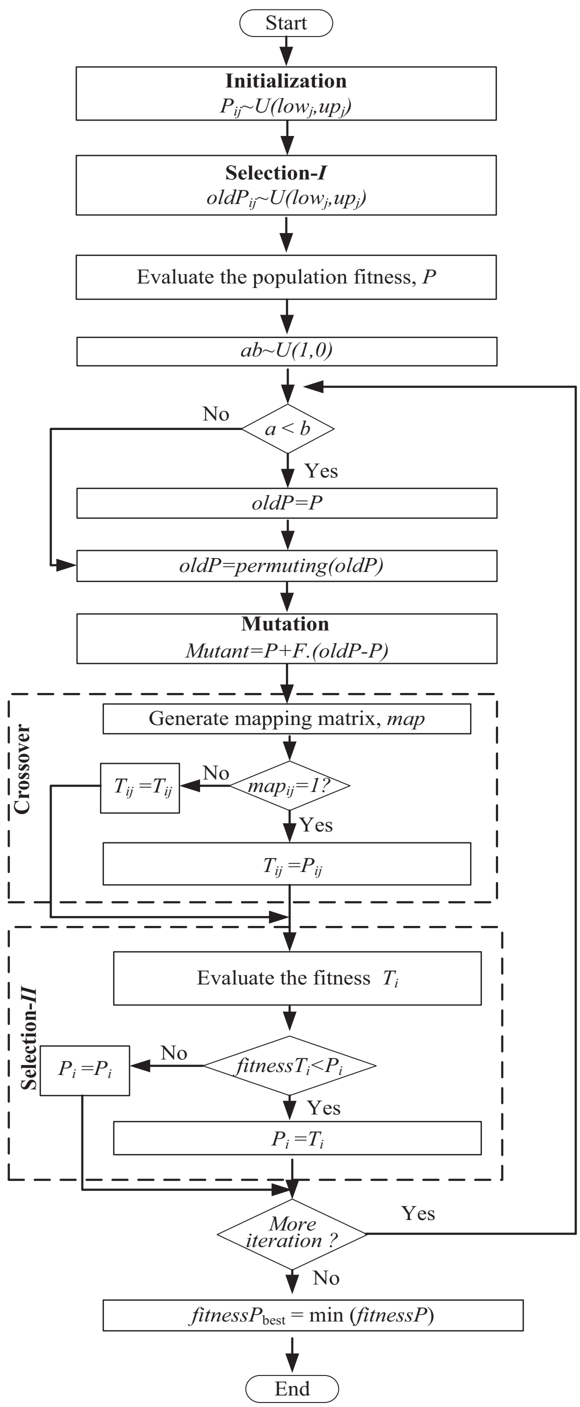

Figure 2 General flowchart of BSA.

the primary duty to protect the network and its customers from the hazards [1]. The technical hurdles to achieve a safe and smooth operation of islanded events are speed governor response, range of operating power, voltage and frequency control, earthling or equivalent protection of the island operation, and resynchronization to the grid. Among these technical hurdles, voltage and frequency control tends to occur more frequently, of which load shedding is considered the most effective technique to overcome the problem.

Generally, automatic load shedding has two types. The first type is under-frequency load shedding (UFLS), which is designed to rebalance load and generation within an electrical island once the unbalanced system is created. The second type is under-voltage load shedding (UVLS), which is utilized to prevent local area voltage collapse and to directly respond to the voltage condition in a local area. The UVLS scheme aims to shed load to restore reactive power relative to demand, to prevent voltage collapse, and to contain a voltage problem within a local area rather than allowing it to spread in a wide area. By contrast, automatic UFLS is designed for extreme conditions to stabilize the balance between generation and load after electrical island formation and to drop sufficient load to allow the frequency stabilization in the island. However, the UFLS is ineffective if instability or voltage collapse occurs within the island. Moreover, the most common factor that contributes to power blackout is voltage instability [2]. Thus, effective load shedding is crucial to prevent total system collapse. Improper load shedding would cause a high number of blackouts.

Various load shedding schemes have been proposed by researchers, in which the most applicable method is optimal load shedding using computational intelligence techniques, such as artificial neural network (ANN), adaptive neuro-fuzzy inference system (ANFIS), fuzzy logic control (FLC), genetic algorithm (GA), and particle swarm optimization (PSO). For instance, [3] suggested controlling the voltage stability during load shedding using FLC. The simulation results indicate that load shedding based on FLC can successfully stabilize and restore the system to the nominal value. However, the principal limitation of this technique is that the rules of FLC should be applied correctly depending upon the system under study. The study in [4] demonstrated the application of GA for determining the optimal load shedding scheme, with and without DGs at the network. This optimization aimed to minimize the sum of curtailed load and system losses. Furthermore, the location and the amount of load to be shed in the power system can be determined based on the GA application according to [5]. However, it is observed that the GA required a longer computation time in determining the amount of load shed, thus limiting its use for online application [6,7]. A new algorithm for the steady-state load shedding strategy was proposed in [8], in which an alliance algorithm considering the effect of demand priorities on the operation of the power system during emergencies was introduced. Differential evolution is subsequently applied for anticipatory load shedding based on voltage stability [9]. An application of bacterial foraging algorithm optimization was likewise presented to evaluate the optimal load shedding scheme with the objective of minimizing the total power losses, voltage stability index value, and total cost of load shed [10]. Although all of these techniques can determine the optimal load shedding scheme, extensive research is still required to enhance the performance of computational intelligence techniques.

Various voltage stability indicators, power losses, and amounts of MW to be shed are used in optimization evaluation. Similar to other indicators, the static voltage

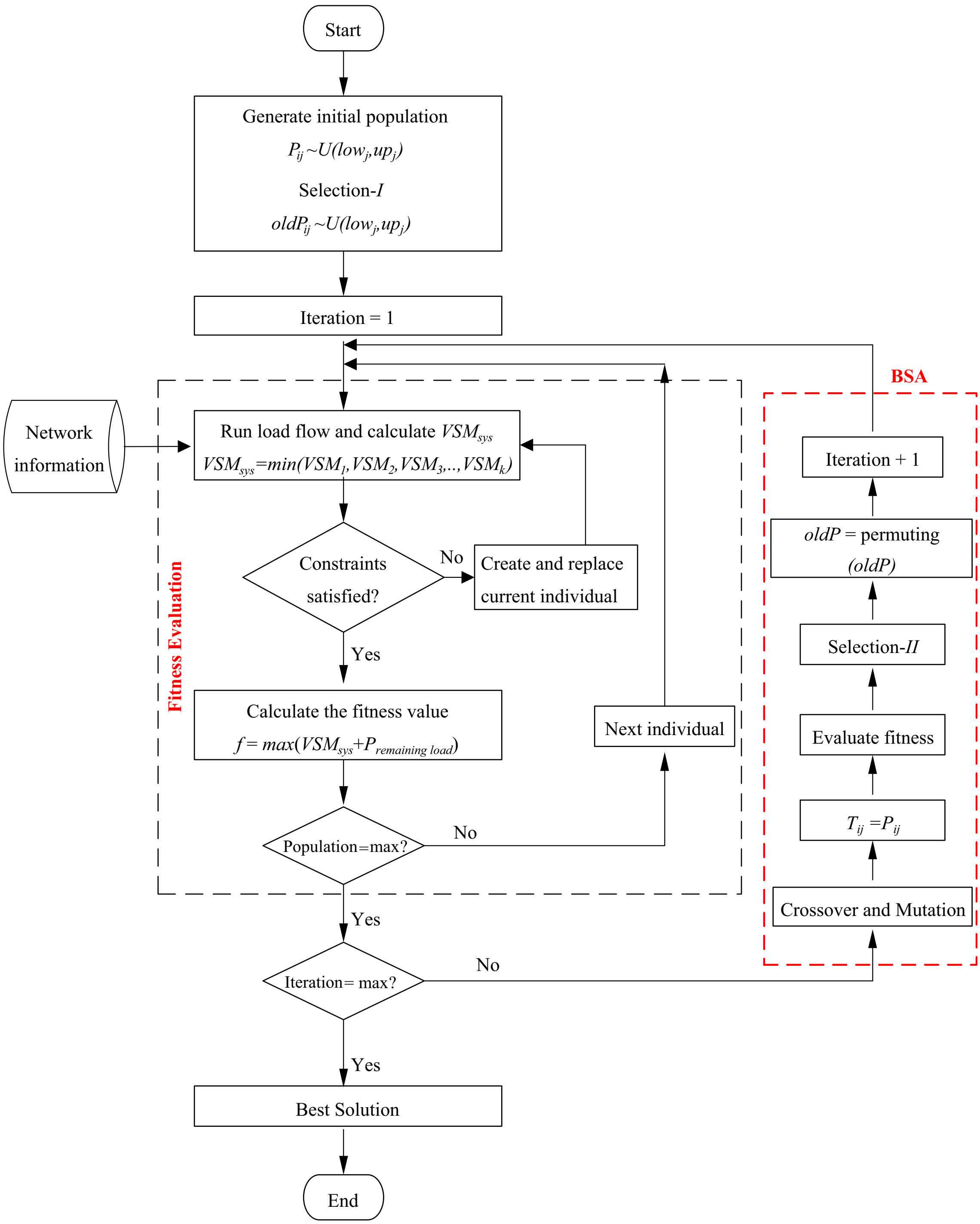

Figure 3 Optimal load shedding scheme using BSA.

stability margin (VSM) proposed in [11] for voltage stability assessment can be used in load shedding schemes. VSM can be used to evaluate critical loads in an islanded system using the system voltage profile. Thus, the load shedding problem can be formulated as an optimization problem using VSM, and an effective optimization technique can provide a reliable solution to the problem. Commonly used optimization techniques such as GA and PSO have limitations in terms of computational time and pre-mature convergence. These limitations may cause non-optimal load shedding scheme. Accordingly, this study adopts an effective optimization algorithm known as the backtracking search optimization algorithm (BSA). BSA is equipped with higher feasibility, solution quality, and convergence speed compared with the original GA and PSO algorithms used in previous load shedding schemes. Therefore, this study describes the development of the optimal load shedding scheme based on BSA in an islanded distribution system. For this purpose, a multi-objective function is formulated

Table 1 Rated maximum power of DGs.

DG	DG types	Maximum active power rating (MW)
1	PV generator	0.03
2	Constant power generator	0.8
3	PV generator	0.6
4	Constant power generator	0.4

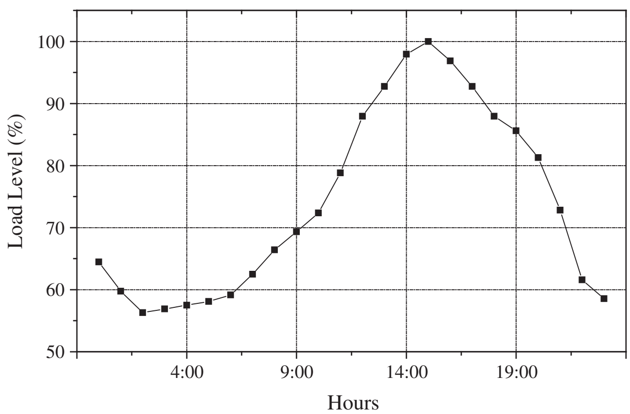

Figure 4 Hourly load profile for individual loads.

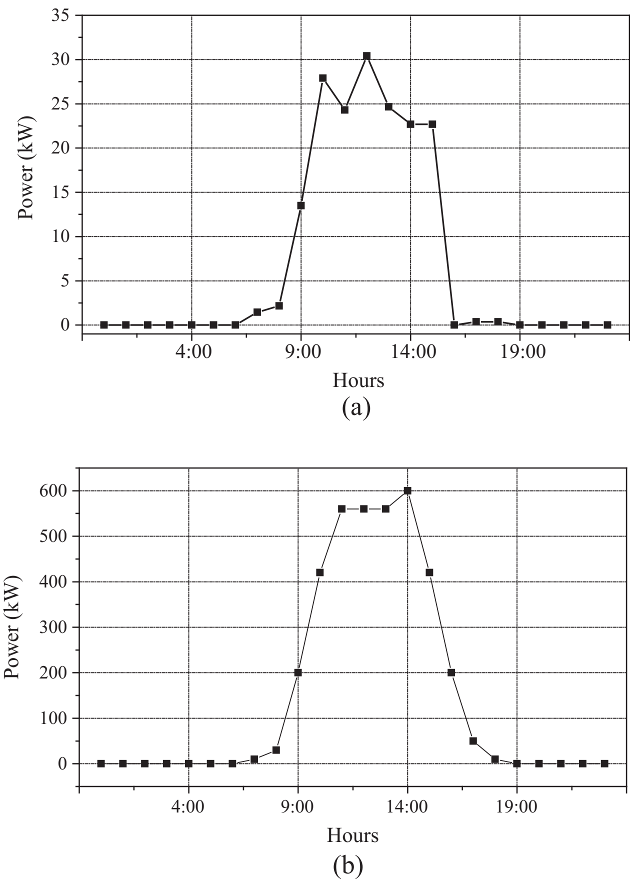

Figure 5 Hourly PV power production: (a) DG1 and (b) DG3.

considering the VSM and the amount of load to be shed. The MATPOWER Newton–Raphson-based power flow algorithm in MATLAB® is utilized to evaluate the formulated multiobjective optimization problem. The proposed methods consider various system constraints, such as load priority, voltage, and power generation limits.

2. Tools and methods used in the proposed method

This section describes the overview of various tools and methods (VSM index and BSA) that are used to develop the proposed load shedding scheme for the islanded power system. The first stage of the proposed method involves problem formulation. The main concept behind the VSM is given in Section 2.1. Meanwhile, the main steps of the BSA are summarized in Section 2.2.

2.1. Voltage stability margin

VSM aims to evaluate the closeness of the system to voltage collapse. Thus, VSM can be used as an indicator to obtain the optimal load shedding scheme. It is derived from a typical radial feeder of a distribution system as depicted in Fig. 1, in which branch i is connected between buses k and m. Given the magnitude and angle of these bus voltages, the loading index (L_i) of branch i can be expressed as follows [11–13]:

$$L_i = \left(2\frac{V_m}{V_k}\cos\delta_{km} - 1\right)^2 \quad (1)$$

where V_m represents the voltage at bus m, V_k represents the voltage at bus k and δ_{km} represents the angle between bus k and bus m.

Table 2 Percentage load priority limits for the IEEE 33-bus radial distribution system.

Bus number	Percentage (%)	Bus number	Percentage (%)
1	0	18	34
2	34	19	60
3	23	20	53
4	64	21	20
5	15	22	50
6	43	23	4
7	35	24	15
8	21	25	10
9	5	26	59
10	21	27	2
11	0	28	28
12	52	29	15
13	11	30	55
14	47	31	25
15	57	32	30
16	61	33	3
17	37		

The L_i index shown in Eq. (1) estimates the maximum load level of a single line section. Given its linear relationship, it can be utilized to represent the voltage stability at any loading level of any line section in the system. Similar to other voltage stability indices, L_i also varies between unity (at no load) and zero

Table 3 Overall power demand and supply in islanded system.

Island	Maximum amount of load demand (MW)	Available DG	Maximum amount of DG supply (MW)
A	3.715	ALL DG	1.83
B	1.405	DG1, DG2	0.83
C	2.335	DG1, DG2, DG3	1.43
D	2.325	DG1, DG2, DG4	1.23

Table 4 GA and BSA parameter settings.

Parameter	GA	BSA
Population size	50	50
Maximum iteration	1000	1000
Cross Probability	0.96	–
Mutation rate	0.08	–

(at voltage collapse point). Meanwhile, the VSM of the feeder is considered as the product of loading indices of all of the feeder branches, which can be addressed as

$$\mathrm{VSM} = \prod_{i=\Omega} L_i \tag{2}$$

where Ω represents a set of branches constituting the feeder (from source bus p to end bus q). Thus, the overall system VSM (VSM_{sys}) consisting of multiple feeders can be evaluated as

$$\mathrm{VSM}_{sys} = \min(\mathrm{VSM}_1, \mathrm{VSM}_2, \mathrm{VSM}_3, \ldots, \mathrm{VSM}_s) \tag{3}$$

where s is the number of feeders in the system.

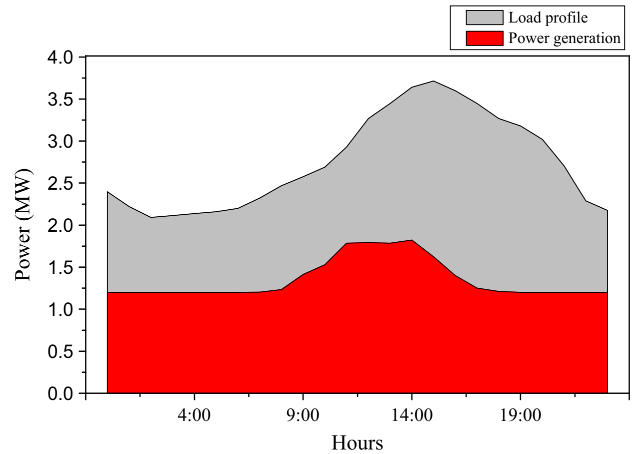

Figure 7 Daily load profile and power generation for island A.

Some loads in the system should be curtailed to reduce the loading level of feeders and increase VSM_{sys} to an acceptable level. The optimum amount of the load to be shed from the system can be determined by using a suitable optimization algorithm, such as BSA. The next section describes the main BSA steps in the development of the proposed load shedding scheme.

2.2. Backtracking search optimization algorithm

BSA is a new evolutionary algorithm (EA) proposed by [14] to handle numerical optimization problems. The development of BSA is based on random mutation strategy. The general flowchart of BSA consists of five main processes, namely, initialization, selection-*I*, mutation, crossover, and selection-*II*

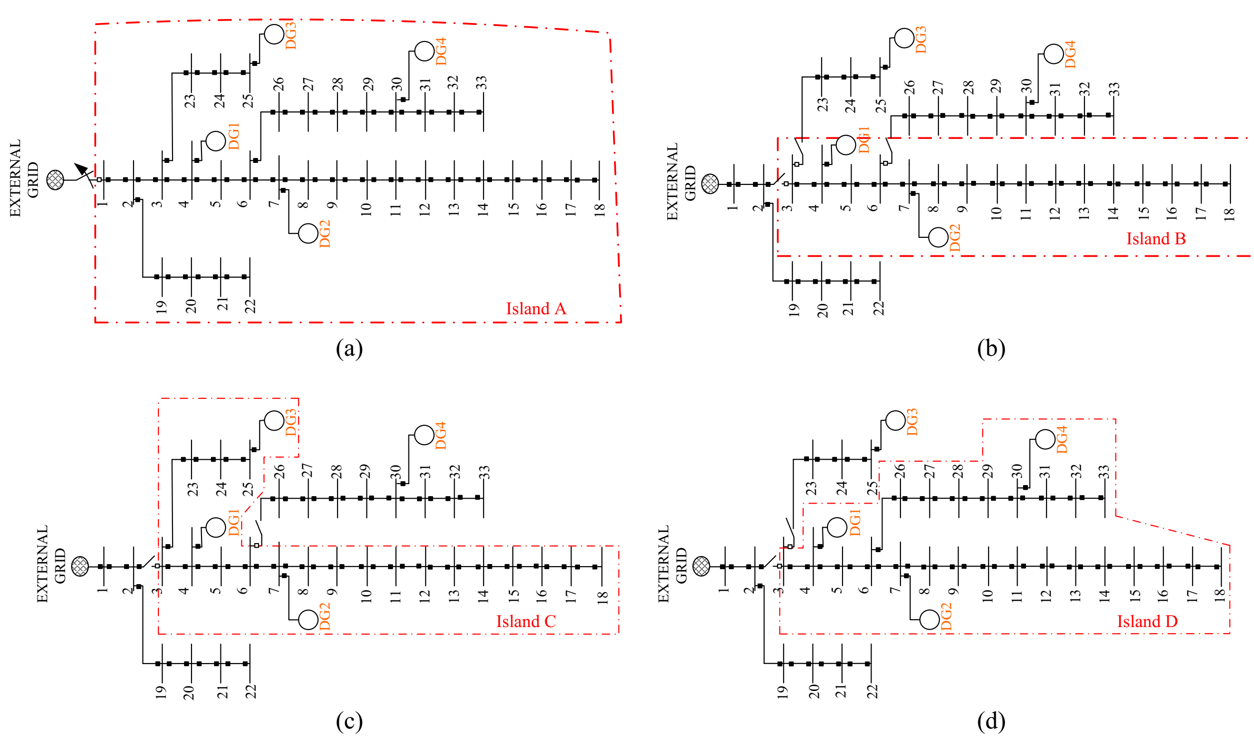

Figure 6 Single line diagram of islanded systems, (a) power island A, (b) power island B, (c) power island C, and (d) power island D.

Table 5 Summary of load shedding performance at hour 9.00.

Island	Load demand (MW)	Power mismatch (%)	Load curtailment (MW)		Total remaining load after optimization (MW)	
			BSA	GA	BSA	GA
B	0.974	16	0.171	0.222	0.803	0.752
C	1.619	37	0.655	0.7	0.964	0.919
D	1.612	25	0.454	0.529	1.158	1.083

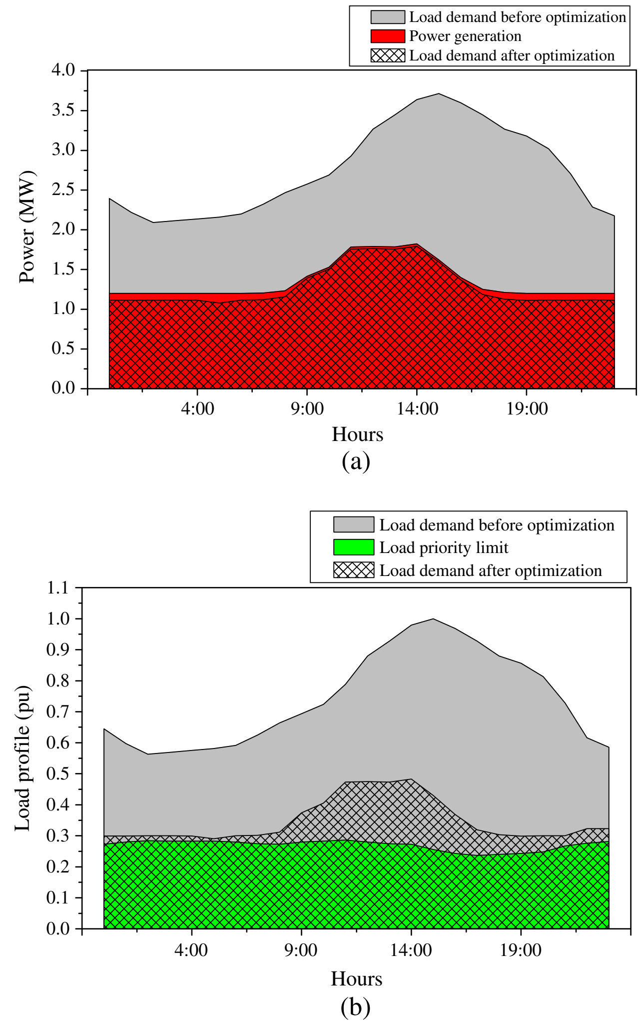

Figure 8 Proposed load shedding scheme performance for island (a) generation and load mismatch and (b) optimum load profile with load priority limits.

(see Fig. 2). Similar to other heuristic optimizations, the first process of the BSA is the initialization of individual parameters to be optimized. This process can be expressed as

$$P_{ij} \sim U(low_j, up_j) \tag{4}$$

where P_{ij} is the jth individual element in the problem dimension D that falls in ith position in a population dimension N, U represents the uniform distribution, and *up* and *low* respectively represent upper and lower boundaries.

The second process is selection-*I*. This stage aims to determine the search direction based on the historical population *oldP*. The initial *oldP* is represented as

$$oldP_{ij} \sim U(low_j, up_j) \tag{5}$$

However, *oldP* will be re-updated using Eq. (6) in each iteration at the beginning through the if–then rule:

$$if \quad a < b \quad then \quad oldP := P | a, b \sim U(0,1) \tag{6}$$

where a and b represent random numbers between 0 and 1, and := represents the update operation. The update of *oldP* is then completed by randomly changing the order of individuals in *oldP* as shown in Eq. (7). The updated *oldP* acts as a memory in the BSA that helps guide the search direction.

$$oldP := permuting(oldP) \tag{7}$$

After the *oldP* is updated, a trial population, T is subsequently generated through mutation and it is given by

$$Mutant = P + F \cdot (oldP - P) \tag{8}$$

where F is an algorithm-dependent parameter utilized to control the amplitude of the search direction. In this study, the standard Brownian walk is used at the mutant stage, and it is given by $F = 3$. *rand*, where *rand* represents the random value obtained from a standard normal distribution. Meanwhile, the final form of T is generated at the crossover stage that involves two major steps. The first step is to generate a binary integer-value matrix (*map*) of size $\mathrm{N} \times \mathrm{D}$ using the same if–then rule adopted for the update of *oldP*. At the second stage, the individuals of T are manipulated using relevant individuals in P as shown in Eq. (9).

$$if\, map_{i,j} = 1 \quad then \quad T_{i,j} := P_{i,j} \tag{9}$$

Then, the boundary condition of trial population, T is subsequently checked and corrected using the following expression:

$$T_{i,j} = rand.(up_j - low_j) + low_j \tag{10}$$

The final stage of BSA is selection-*II* stage. At this point, the fitness of trial population T is evaluated and original population P is updated using greedy selection.

3. Problem formulation

A multiobjective function consisting of a static voltage stability margin is considered in searching for an optimal load shedding in the islanded system. Thus, the operational constrains and fitness functions are presented in Sections 3.1 and 3.2, respectively. Meanwhile, the application of the BSA for the optimal load shedding scheme is summarized in Section 3.3.

3.1. Operation constraints

The optimal load shedding in the islanded system aims to enhance the voltage stability margin and voltage profile. However, the following constraints should be considered during optimization:

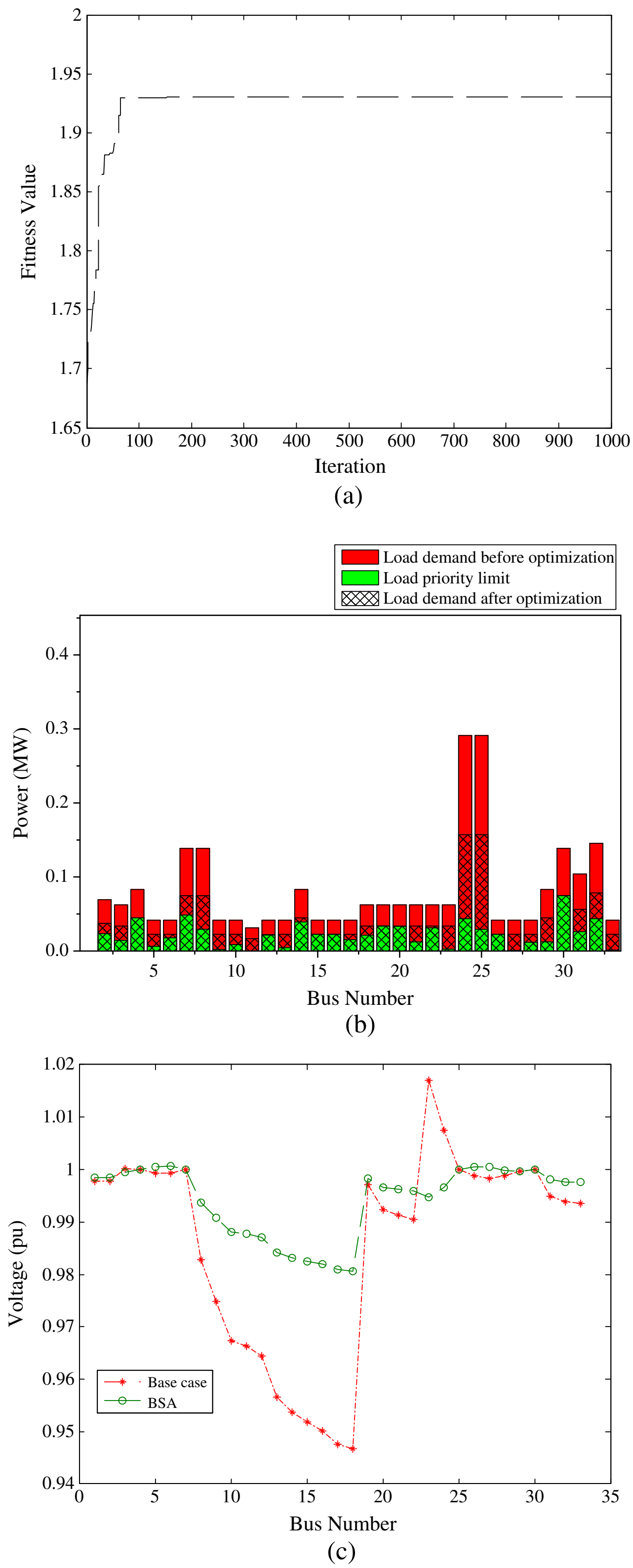

Figure 9 Performance of proposed load shedding scheme at hour 9.00 for island A (a) convergence characteristic, (b) individual load demand after optimization, and (c) voltage profile.

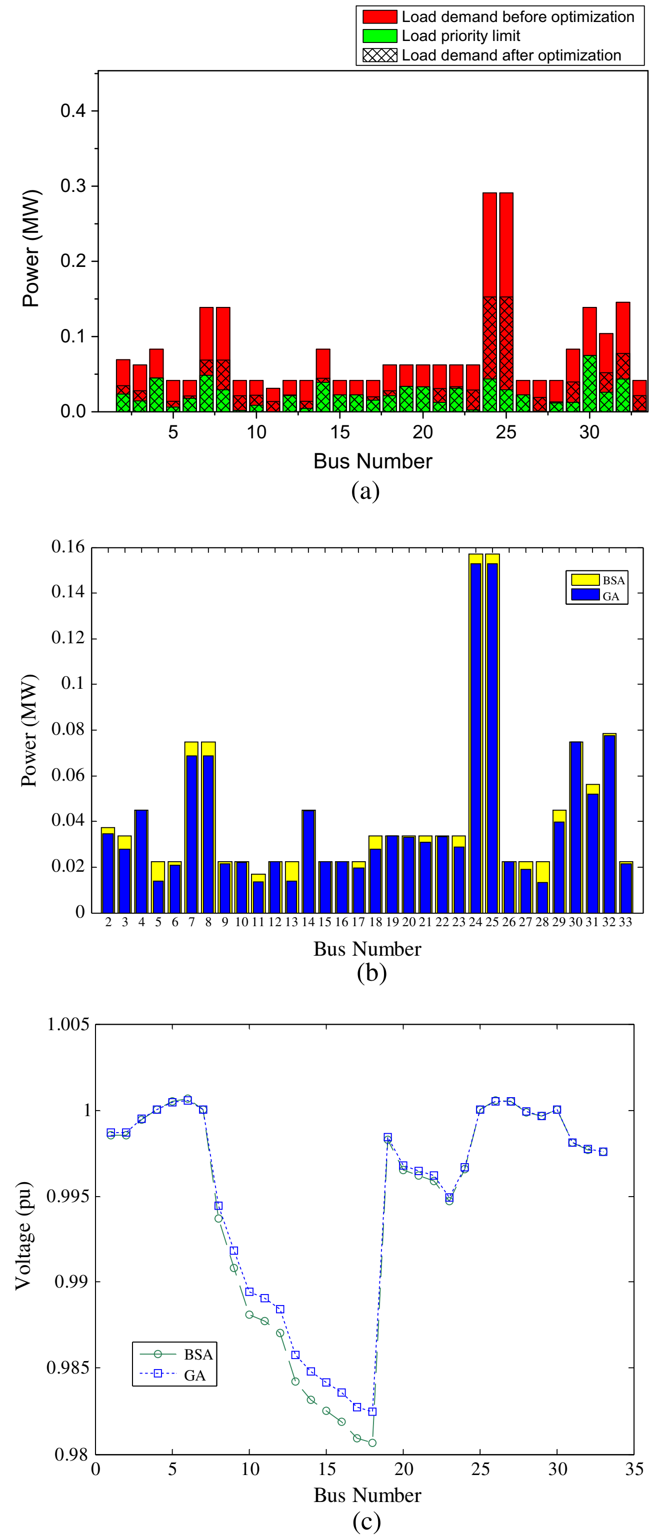

Figure 10 Performance of load shedding scheme at hour 9.00 for island A (a) individual load demand after optimization using GA, (b) comparison of individual load demand after optimization between BSA and GA, and (c) comparison of voltage profile obtained using BSA and GA.

Power flow balance: The total power generation during optimization should be equal to the total consumption as shown in Eq. (11).

$$\begin{aligned}\sum P_{gi} - \sum P_{di} - \sum P_{loss} = 0 \\ \sum Q_{gi} - \sum Q_{di} - \sum Q_{loss} = 0\end{aligned} \quad (11)$$

where P_{gi} and Q_{gi} are the generated active and reactive powers, respectively, and P_{di} and Q_{di} are the active and reactive powers consumed by the load, respectively. P_{loss} and Q_{loss} are the active and reactive power losses in the network, respectively.

Power flow limit: The apparent power S_l that is transmitted through branch l must not exceed the maximum thermal limit S_{l-max} in a steady-state operation:

$$S_l \leq S_{l-max} \quad (12)$$

Bus voltage stability: To prevent the voltage instability of the system, the bus voltage at each bus i must be maintained around its normal value V_i, specified as $[V_{i-min}, V_{i-max}]$, where V_{i-min} is the minimum permissible value of the voltage at bus i and V_{i-max} is the maximum permissible voltage at bus i. These limits can be expressed in terms of the inequality function as

$$V_{i-min} \leqslant V_i \leq V_{i-max} \quad (13)$$

Practically, this deviation can reach up to 10% of the nominal voltage value [13,15].

Load shed limit: The permissible value of load that can be curtailed in the system is limited by the load priority limit. The minimum amount of load that should be maintained for each load is stored in a priority list. Thus, it should be maintained throughout the process in obtaining the optimum load shedding scheme. These limits can be expressed in terms of the inequality function as

$$S_{priority} \leq S_{l-i} \leq S_l \quad (14)$$

where S_{l-i} is the candidate value of the remaining load power, S_l is the load at bus i before load shedding, and $S_{priority}$ is the load priority limit.

Voltage stability margin limit: The VSM_{sys} must be maintained at a certain limit to maintain the voltage profile within the nominal value using Eq. (13). The limit of VSM_{sys} can be given by

$$0 \leq VSM_{sys} \leq 1 \quad (15)$$

However, in practice, the voltage profile must meet the standard values [15]. Thus, the limit of VSM_{sys} can be addressed as

$$0.67 \leq VSM_{sys} \leq 1 \quad (16)$$

Power generator limit: The generator power, P_{gen} must be maintained at its maximum to provide all available power to support the system. The limit of P_{gen} can be given by

$$P_{gen} = P_{max} \quad (17)$$

3.2. Fitness function

The fitness function aims to evaluate the optimal load shedding scheme in islanded systems on the basis of some indices. The constraints of the problems during evaluation should be fulfilled to obtain the best fitness function value. Thus, the overall fitness function is formulated as

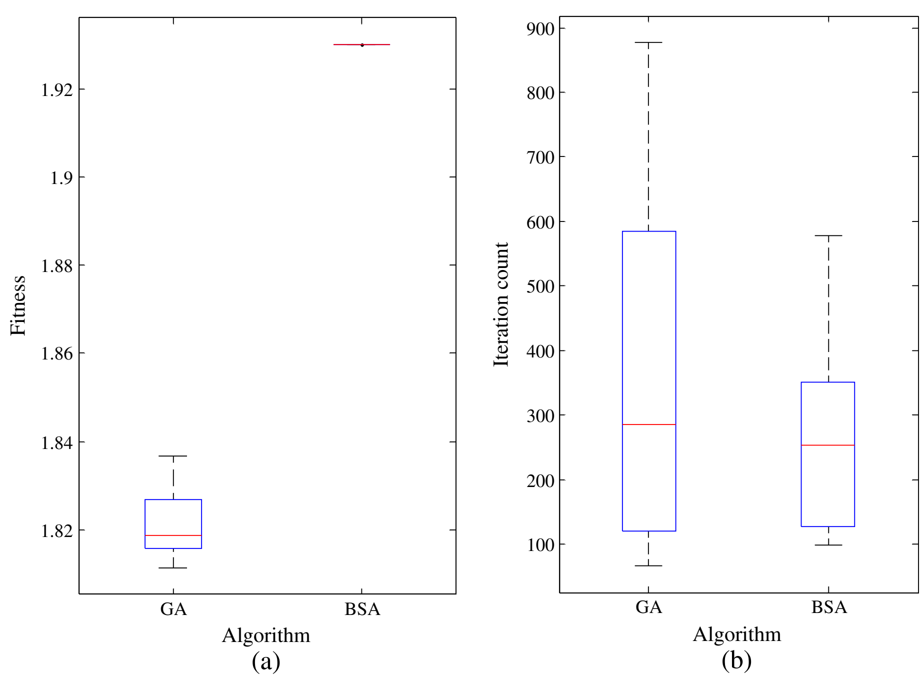

Figure 11 Performance comparisons of GA and BSA in obtaining optimal load shedding in island A at hour 9.00.

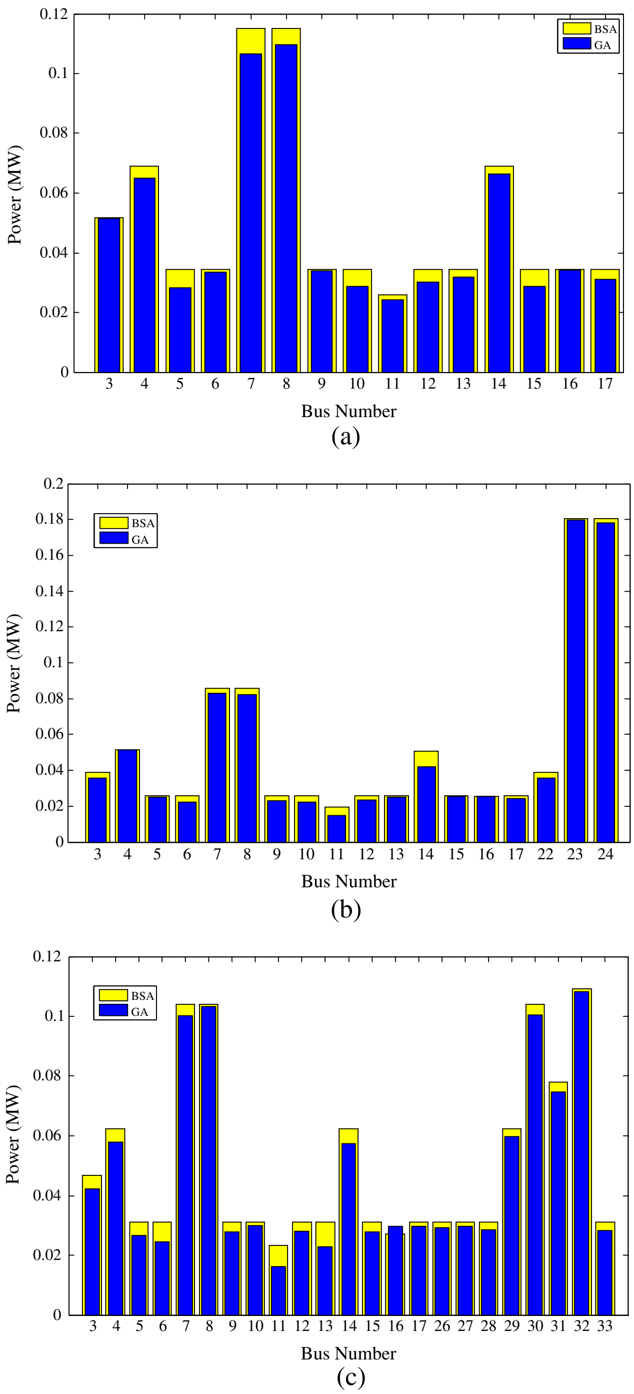

Figure 12 Comparison of individual load demand after optimization by BSA and GA at hour 9.00 for (a) power island B, (b) power island C, and (c) power island D.

$$f = \max(\text{VSM}_{sys} + P_{remaining\ load}) \quad (18)$$

where f is the fitness function, VSM_{sys} is the overall system voltage stability margin and $P_{remaining\ load}$ is the total remaining load.

In this study, BSA is utilized to obtain the optimal load shedding scheme in the islanded system. The solution set considered in this optimization is the load shedding (L_{factor}) vector. The L_{factor} vector contains the amount of load permitted to be shed for each bus where the dimension of L_{factor} vector corresponds to the number of buses in the islanded system under study. The L_{factor} varies between unity and zero. This L_{factor} vector should be in the range of $[S_{priority}, S_l]$. The optimization processes are repeated several times where the maximum f is selected as the best fitness value. The load shedding scheme that corresponds to the maximum f is selected where it generates the optimal amount of the remaining load at that particular hour.

The VSM_{sys} element in Eq. (18) maintains the load shedding scheme, in which it should follow constraints in Eqs. (13) and (16) to avoid the voltage collapse in the islanded system. This element can evaluate the critical load in the islanded system using the system voltage profile. Meanwhile, the $P_{remaining\ load}$ element in Eq. (18) is utilized to ensure that the amount of the remaining load is maximum, such that it has the lowest amount of load to be shed in the islanded system where it can fulfill constraints in Eq. (17).

3.3. Application of BSA for optimal load shedding scheme

The BSA is used with MATPOWER power flow to determine the optimal load shedding scheme in the islanded distribution system. Fig. 3 illustrates a schematic of the procedure involved in solving the optimal load shedding scheme in the islanded system based on BSA.

4. Test system description

In this study, the four DG units are modeled as constant power sources, in which various DG power injections depend on the type and hour of the day. The type of DG and the maximum active power rating of each DG are depicted in Table 1. Figs. 4 and 5 show the individual load profiles and daily PV generator power consumption, respectively, in the load shedding study. The 100% load level at hour 15.00 (Fig. 4) indicates the base case bus power value obtained from the original IEEE 33-bus radial distribution system with four DG units. Moreover, the load priority list that indicates the minimum power (in percentage) that must be maintained is presented in Table 2 for the IEEE 33-bus radial distribution system with four DG units. Any load cannot be curtailed from a bus with a 100% limit. Meanwhile, all loads can be curtailed from a bus with a 0% limit. The load priority limit for a given bus is not a fixed value of power. It varies with the load demand of the bus at a particular hour. In other words, the minimum amount of power ($S_{priority}$) that must be maintained at a given hour is the product of base case load power, percentage load level, and priority limit. $S_{priority}$ is used in the L_{factor} vector as the lower boundary, whereas hourly load demand (S_l) is used as the upper boundary in optimization.

The simulations are based on possible island scenarios as illustrated in Fig. 6. The figure shows that four possible islanded systems can be formed for the IEEE 33-bus radial distribution system with four DG units. Moreover, the optimal load shedding must be performed for each system. The overall maximum amount of load and available DG supply for each islanded system is presented in Table 3.

On the basis of the preceding system conditions, namely, the load demand, load priority limits, and available power from generators at each hour, the proposed BSA-based optimum load shedding is performed for each islanded system as

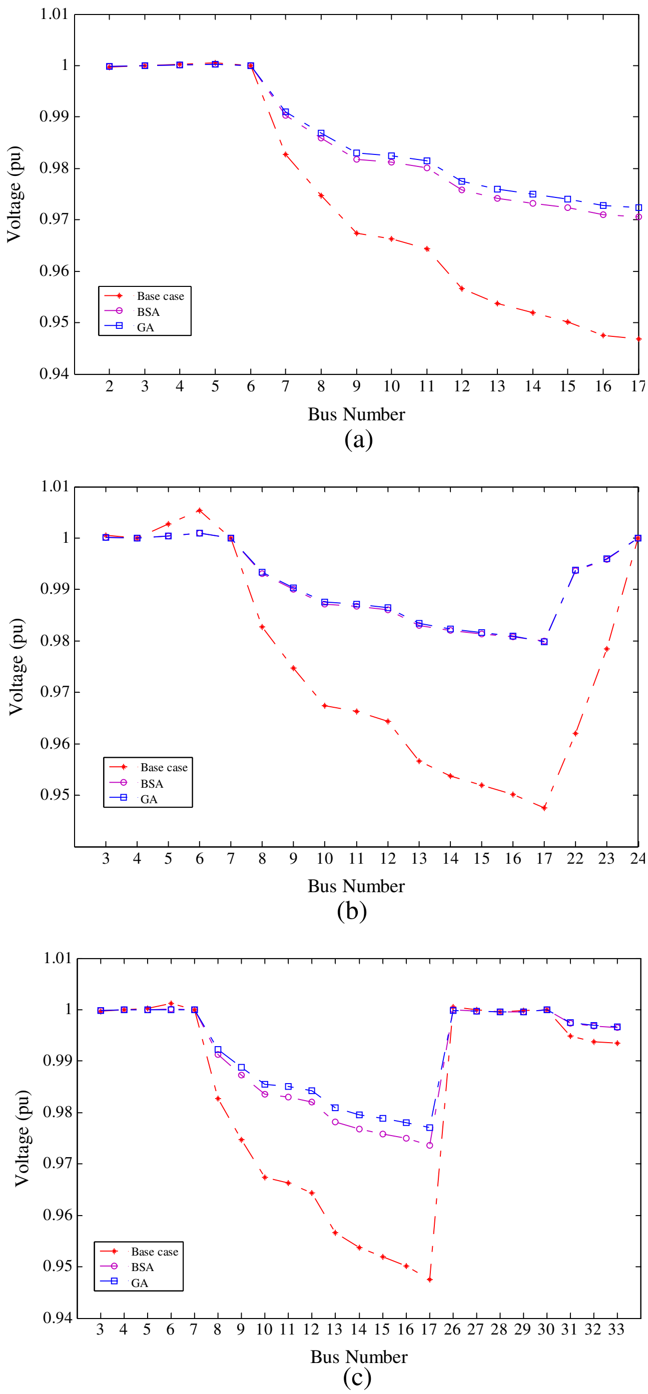

Figure 13 Comparison of voltage profile before and after load shedding at hour 9.00 for (a) power island B, (b) power island C, and (c) power island D.

shown in Fig. 6. The performance of the proposed algorithm is subsequently validated by comparing the performance of the load shedding scheme developed using the GA technique. All of the optimization parameters are standardized to compare the algorithms fairly. Table 4 shows the necessary parameter settings for both optimization techniques used in this study.

Table 6 Performance of BSA and GA in terms of fitness, VSM, and amount of load curtailment at hour 9.00.

Islanding	Fitness		VSM		Load curtailment (%)	
	BSA	GA	BSA	GA	BSA	GA
A	**1.9301**	1.8219	0.9301	0.9365	46	50
B	**1.8877**	1.8278	0.8858	0.8944	18	23
C	**1.9213**	1.8824	0.9213	0.9202	40	43
D	**1.8978**	1.7971	0.8978	0.9107	28	33

5. Results and discussion

5.1. Optimal load shedding for island A using BSA

Island A is formed when the main circuit breaker at bus one in the IEEE 33-bus radial distribution system with four DG units is opened. Power island A contains 32 loads, totaling 3.715 MW real load power, which should be supplied by all four DGs namely, DG1, DG2, DG3, and DG4, (Fig. 6(a) and Table 3). Fig. 7 shows the load demand and available power generation for island A on an hourly basis. The figure shows that the power mismatch between the load demand and power generation is large, that is, 43–63% from valley to peak daily load. To ensure that island A maintains its operation, the proposed optimal load shedding scheme is applied to identify the location and amount of load to shed.

Fig. 8 illustrates the summary of the proposed load shedding scheme performance for power island A. Fig. 8(a) shows that the amount of remaining load after the optimization is close to the amount of power generated during the hourly operation. This result proves that the proposed optimal load shedding scheme based on the BSA technique can decide the optimal amount of load to be shed without cutting excessive load from the system. The difference between power generation and load demand after optimization in Fig. 8(a) shows the power loss in the system (at hour 11:00–14:00). The power loss is low when the PV generators DG1 and DG3 support the system. Conversely, the power loss is high during evening and early morning hours when PV DGs are inactive. Fig. 8(b) shows that the load profile after the proposed load shedding scheme is higher than the load priority limits. The result indicates that the proposed BSA-based load shedding scheme can fulfill the requirement for load priority limit.

The performance at hours 9.00 is analyzed to further evaluate the effectiveness of the proposed load shedding scheme. Fig. 8(b) shows that the load demand at hour 9.00 is 0.69 pu, which is approximately 2.575 MW. However, the available power generation at this hour is only 1.414 MW, and the power mismatch is approximately 45%. This result implies that 45% of the load must be curtailed from the system to operate the system. After applying the optimal load shedding scheme, 1.185 MW is curtailed, leaving only 1.390 MW as the total remaining load. The convergence characteristic for the proposed optimal load shedding scheme using the BSA technique is shown in Fig. 9(a) for this hour. It shows that BSA converges and finds the solution after 90 iterations. Meanwhile, Fig. 9(b) shows that the optimal load shedding scheme can fulfill the entire load priority limit requirement. The scheme did not completely curtail the load from the buses with low priority limits, such as buses 9, 11, 27, and 33. Moreover, Fig. 9(c) shows that the voltage profile of most buses is improved after optimization. For instance, buses 23 and 24 (Fig. 9(c)) show that the amount of load to be curtailed is depending upon the priority load. However, the reduction of the voltage profile at both of the buses is based on the objective function and control variable as stated in Section 3. Thus, the result indicates that all of the bus voltages are now within the acceptable range (i.e., 0.98 pu to 1.01 pu) according to IEEE 18-2002.

5.2. Optimal load shedding for island A using GA

Using the similar procedures, the proposed optimal load shedding scheme is simulated and tested with GA. This study aims to compare and validate the performance of the BSA technique in the proposed load shedding scheme. For this study, the performance at hours 9.00 is further analyzed. The performance of the load shedding scheme using GA at hour 9.00 is shown in Fig. 10. Fig. 10(a) reveals that the optimal load shedding scheme using GA can fulfill the entire load priority limit requirement. After applying the optimal load shedding scheme, 1.278 MW is curtailed, leaving only 1.297 MW as the total remaining load. The total remaining load suggested by GA is 0.093 MW less than the amount calculated by the BSA technique. This result suggests that BSA is better than GA in obtaining the optimal amount of remaining load, considering that the main objective of this study was to minimize the amount of load to be shed without cutting a substantial load from the system. Fig. 10(b) reveals that GA curtails more load than BSA in the islanded system, in which the difference ranges from 0% to 41%. Moreover, an improvement in voltage profile at most buses is observed after the optimization process by GA (Fig. 10(c)). Slight differences in voltage profile emerge because of the load shedding performed by BSA and GA. Some voltage profiles obtained using GA are higher than those obtained using BSA. This improvement in voltage is due to a larger amount of load curtailment by GA than by BSA in the system.

To evaluate the effectiveness of the proposed algorithm, the performance of the two optimization algorithms at hour 9.00 for island A is evaluated (Fig. 11). Given their different searching patterns and convergence characteristics, the capabilities of BSA and GA are examined with 15 repetitions of the optimization process. Moreover, the algorithms are compared in terms of convergence rate (number of iterations required to converge) and optimal solution quality (fitness value). Fig. 11(a) shows that BSA outperforms GA with higher fitness value. Fig. 11(b) shows that the BSA has better performance than GA in terms of convergence rates because the former is more consistent than the latter with smaller inter-quartile range.

5.3. Optimal load shedding for other islanded systems

Similar to the load shedding procedures adopted to island A, optimization procedures are applied on the remaining islanding scenarios, namely, islands B, C, and D. The performance at hour 9.00 is further analyzed. The statistical results at hour 9.00 for load demand, power mismatch, load curtailment and total remaining load after the optimization using BSA and GA are summarized in Table 5. The table shows that the proposed load shedding scheme using BSA performs better than that using GA with less amount of load curtailed in all of the islanded cases. Meanwhile, Fig. 12 shows that the GA-based scheme curtails more load than the BSA-based scheme in the islanded systems in which the difference for islands B, C, and D ranges from −1% to 18%, −1% to 24%, and −10% to 31%, respectively. Moreover, an improvement in voltage profile at most buses can be observed after the optimization (Fig. 13). Slight differences exist in voltage profile because of load shedding performed by BSA and GA. Some of the voltage magnitudes obtained using GA are higher than those obtained using BSA. As previously mentioned, this difference in voltage profile is attributed to the larger amount of load curtailment by GA than by BSA in the system.

Table 6 shows the statistical results for fitness value, VSM, and load curtailment at hour 9.00. For all of the island cases, BSA has obtained the optimal load shedding results with a higher amount of fitness value as indicated in bold. This table shows that the VSM and the amount of load curtailment obtained using BSA are considerably lower than those obtained using GA. This result proves that the proposed optimal load shedding scheme based on BSA can decide the optimal amount of load to be shed without cutting a substantial load from the system.

6. Conclusion

This study describes a novel of optimal load shedding scheme based on the BSA. The problem was to maximize the static VSM and the total remaining load in the islanded system in order to stabilize the system and prevent voltage collapse. To evaluate the performance of the proposed optimal load shedding scheme technique, various evaluation techniques were used. The performance evaluation method considered comparative study between the conventional GA techniques. The optimization results show that the proposed BSA technique is more effective in determining the optimal amount of load to be shed in any islanded system compared with GA.

Acknowledgments

The authors wish to acknowledge the Ministry of Education, Malaysia, and Universiti Teknikal Malaysia Melaka, Malaysia for supporting this study and Universiti Kebangsaan Malaysia, Malaysia for supporting this research financially under Grants ETP-2013-044 and ERGS/1/2013/TK02/UKM/03/1.

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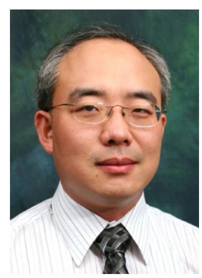

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