Islanded microgrid congestion control by load prioritization and shedding using ABC algorithm

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ABSTRACT

The continued growth in load demand and the gradual change of generation sources to smaller distributed plants utilizing renewable energy sources (RESs), which supply power intermittently, is likely to strain existing power systems and cause congestion. Congestion management still remains a challenging issue in open access transmission and distribution systems. Conventionally, this is achieved by load shedding and generator rescheduling. In this study, the control of the system congestion on an islanded micro grid (MG) supplied by RESs is analyzed using artificial bee colony (ABC) algorithm. Different buses are assigned priority indices which forms the basis of the determination of which loads and what amount of load to shed at any particular time during islanding mode operation. This is to ensure as minimal load as possible is shed during a contingency that leads to loss of mains and ensure a congestion free microgrid operation. This is tested and verified on a modified IEEE 30-bus distribution systems on MATLAB platform. The results are compared with other algorithms to prove the applicability of this approach.

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1. INTRODUCTION

The electrical power market deregulation and the gradual evolution of the grids towards smart grid (SG) is currently being witnessed in an effort to supply power to the increasing population and flourishing industries. The RESs in the SGs are expected to be more resilient with the ability to survive system difficulties during contingencies [1, 2]. However, this change from conventional monopolistic system to deregulated system may make the system to operate beyond its voltage and thermal limits hence transmission and distribution system congestion [3]. Congestion can be defined as difference in the scheduled and the actual power flow in a given line without violating the set limits [4]. It is a condition where more power is scheduled to flow across transmission, distribution lines and transformers than what those lines can carry [5]. Operation in islanded mode is recommended in order to prevent total blackouts in the power system [6]. This ensures power is supplied to customers reliably in a safe way and maintains the system security.

The methods used for congestion management (CM) can be classified into two; Cost free and non-cost-free methods [7]. The cost-free method includes use of FACTS devices, outaging congested lines, and the operation of transformer taps. On the other hand, the non-cost-free methods include shedding of some loads, generator rescheduling among others. The increase in competitive pressure in the electrical power industry necessitates removal of overloads through load shedding bearing in mind the economic and the cost of shedding the load [8]. In addition to the above conventional methods, evolutionary algorithms like ABC, particle swarm optimization (PSO), ant colony optimization (ACO), cuckoo search algorithm (CS), harmony search algorithm (HS), shuffled frog leaping algorithm (SFLP), simulated annealing algorithms (SA) among others are also increasingly being used in CM [9-11].

A number of studies on CM have been done so far. For instance, reference [12] proposes two measures that can be used to control congestion; generator rescheduling and loss reduction of real power. In [13], the author proposes the use of FACTS devices in the management of congestion at transmission level. In [14], rescheduling of sensitive generators and load shedding is proposed for CM using PSO algorithm. In [15], the author used the sensitivities of overloaded lines together with the cost of power generation and load shedding in CM. The load-shedding schedule and new power generation for affected buses was calculated using line sensitivities and the cost.

It is challenging to control the power produced in an islanded MG by RESs because these sources produce power intermittently. Load shedding is the main method of controlling system stability in this case and avoid any danger within the MG [16]. Optimal shedding of connected loads assists in reducing the difference between the power that DGs can supply and the connected loads [17]. In [18], ABC algorithm is used for overload control by rescheduling generators. The author uses generator sensitivity factors in selecting the generators that participate in real power rescheduling. In [19], ABC and PSO algorithms were used in generator rescheduling based on bus and generator sensitivity factors for CM in a system with wind energy resources only. In [20], the authors used PSO in generation rescheduling and load shedding in CM. In [21], congestion alleviation in a deregulated power system is proposed using cuckoo search algorithm. This was tested on IEEE 30-bus system. A modification of ABC algorithm is applied in the determination of the DG power output and their location in reference [22]. This was tested on 33 bus system.

Through load shedding, the amount of power demand that can be curtailed so as to mitigate CM problem is determined. From the literature, extensive research on CM on MGs has been done. However, CM using load shedding algorithms still remains an open issue and needs further research. In this paper, the CM problem in an islanded MG supplied with RESs is analyzed. This is formulated as an optimization problem. ABC algorithm is used in the determination of the optimal amount of load to be shed and from which buses based on their priority index. This rest of this paper is organized as follows; section 2 discusses the proposed congestion management method, its mathematical formulation and how ABC algorithm will be applied; section 3 analysis the simulation results and 4 summarizes and concludes this paper.

2. PROPOSED CM SCHEME IN AN ISLAND WITH RESs

This simulation assumes that MG is suddenly switched to island operation mode due to a contingency that leads to loss of mains. After a utility grid disturbance that lead to islanding mode, the power in the MG is allocated to the loads as per their priority index. Figure 1 below is a sketch of a MG with RESs that was used for CM analysis in this study. The loads and buses within the islanded MG were given priority indices, and then ABC algorithm was modified and applied in shedding loads in order to ensure the system is not stretched beyond its limits. Figure 2 is the proposed load shedding power flow for this study.

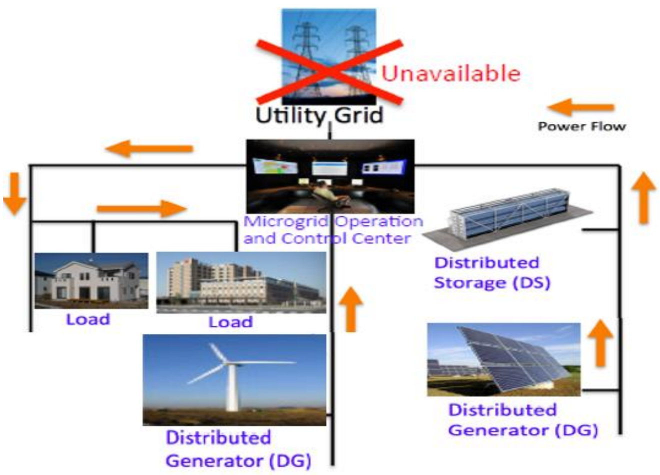

Figure 1. Micro grid with RESs

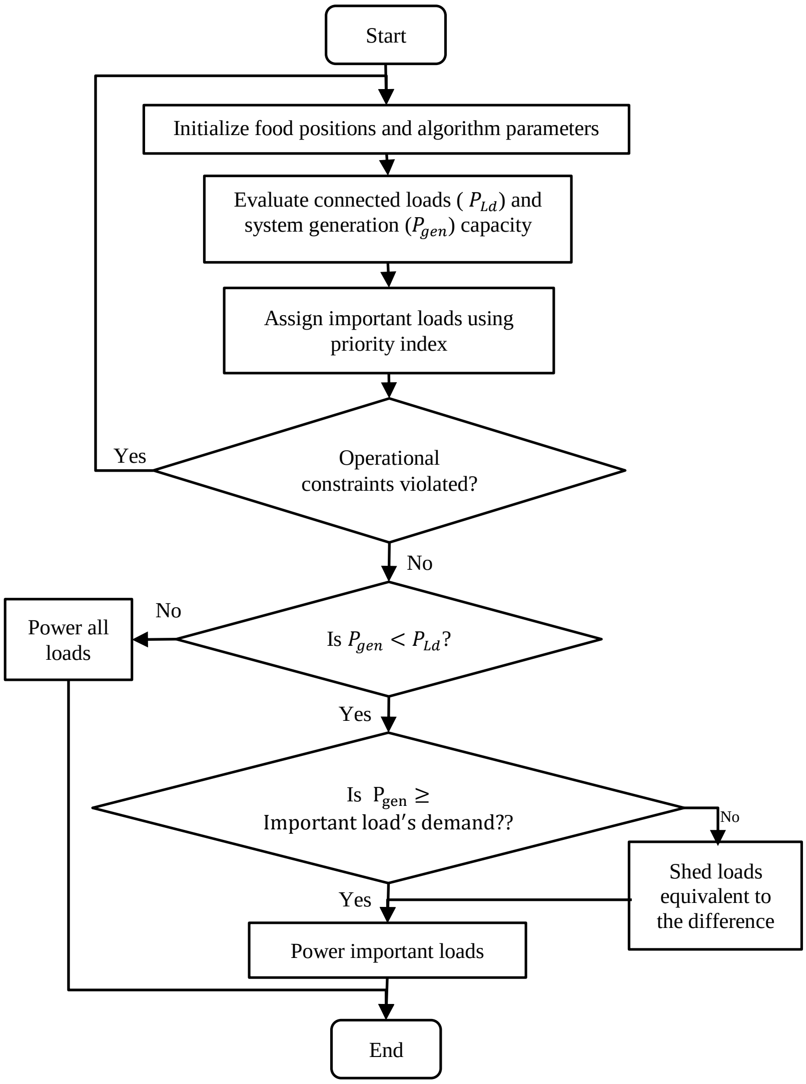

Figure 2. Load shedding power flow for CM

2.1. Mathematical problem formulation

The main objective of this paper is to alleviate elements of system congestion in an islanded MG through minimizing overloads by optimal load shedding using ABC algorithm. This is expressed the expressions 1-3 below;

$$Minimize\ F_1 = \sum_{i=1}^{OL} (S_i - S_i^{max})^2 \tag{1}$$

$$Minimize\ F_2 = \sum_{i=1}^{NG} \left(P_i + Q_i P_{gi} + R_i P_{gi}^2\right) + \left|e_i * \sin(f_i * (P_{gi} - P_{min,i}))\right| + \sum_{k=1}^{PL} \left(P_k' + Q_k' L_{shd,k}\right) \tag{2}$$

$$Minimize\ P_l = F\left(P_{g,slack}\right) \tag{3}$$

where P_l is the system real power loss, S_i^{max} is the maximum capacity of line i, OL is the number of the lines that are overloaded ,$L_{shd,k}$is the amount of load to be shedded at bus k, P_{gi} is the power generated by generator i, S_i is the power flow on line i, NG is the number of participating generators, $P_{min,i}$ is the minimum power generated by generator i, f_i and $e_i$are the generator coefficients for generator.
Subject to the equality and inequality constraints (4-10) below:
Equality constraints,

$$P_{gi} - P_{di} = \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij}) \quad (4)$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) \quad (5)$$

where $|V_i|\ and\ |V_j|$ are voltage magnitudes.
The distributed generation RESs constraints

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max} \quad (6)$$

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

where $P_{gi}^{min}\ and\ P_{gi}^{max}$ are Real power generation limits of the RES $i\ and\ Q_{gi}$ is the VAR generated by RES i
Voltage constraint

$$V_{gi}^{min} \leq V_{gi} \leq V_{gi}^{max} \quad (8)$$

$$V_{di}^{min} \leq V_{di} \leq V_{di}^{max} \quad (9)$$

where V_{gi} and $V_{di}$is voltage magnitude at generator and load bus *i* respectively.

$$\sum_{i=1}^{NG} P_{gi} = \sum_{k=1}^{ND} P_{dk} + P_l \quad (10)$$

where P_{dk} is the real power load at bus k, NG and ND are the sets of generator and load buses respectively.

2.2. ABC algorithm

Swarm intelligence algorithms are the currently preferred approaches in solving dynamic optimizationNP-hard problems in engineering [23]. ABC algorithm is a meta-heuristic optimization algorithm that was proposed by Karaboga from Erciyes University of Turkey [24]. This algorithm mimics the foraging movement of a swarm of bees in search of nectar around the hive as shown in Figure 3 [22]. In this algorithm, the location of food sources represents a possible solution to an optimization problem being solved. The quantity and quality of nectar indicates the fitness of that particular solution.

It has a superior performance in solving engineering problems when compared to other algorithms. For instance, it can handle both continuous and discrete variables. It is mostly applied to optimization problems in power systems that are not smooth. It is divided into three groups as observed from the behavior of a swarm of bees where each group performs a particular function as highlighted below [25];

- The employed bees. They are equal to the possible solutions of the problem. This group continuously updates the rest of the bees in the hive about the quantity, quality and the direction of the food source through the performance of a waggle dance. The duration of the waggle dance depends on the quality and quantity of food source.
- The onlooker group of bees. These bees pick on a food source to exploit based on the information provided by the employed bees waggle dance. More onlookers move to food sources with high fitness and few to food sources with lesser fitness values.
- The scout bees. These bees work is to look for new sources of food for exploitation. They randomly choose food sources around the hive.

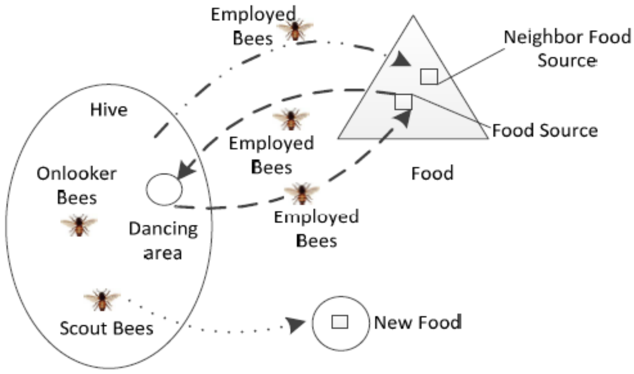

Figure 3. ABC search behavior

2.3. ABC algorithm steps

The initial phase where random population is generated. The solution size is taken to be equal to the number of employed bees. Each of the above solution is a vector of dimension *D*. This dimensional vector D corresponds with the number of parameters being optimized. The fitness (quality) of a food source can be expressed by (11):

$$fitness_i = \frac{1}{1 + f_i} \tag{11}$$

where objective function f_i is the problem formulation target.

The above generated initial population of possible solutions is then sequentially subjected through the three categories of bees in cycles till the specified maximum cycle number (MCN) is reached. Employed bees keeps on modifying the memories of the food locations (solutions) based on the visual observations and nectar quality. The employed bees share the food source information with the rest of the bees in the hive through waggle dance.

The onlooker bee will choose a preferred food source based on the amount of nectar available and as per the probability guided by the equation below [26];

$$p_i = \frac{fitness_i}{\sum_{j=1}^{ts} Fitness_j} \tag{12}$$

where ts is the number of employed bees (= number of the sources of food) and $fitness_i$ is the fitness value of the i^{th} solution.

The onlooker bee then compares the food sources from the information given by employed bees and then chooses a neighbor food source if it is better than the current one using the following equation;

$$X_{ij}^{new} = X_{ij}^{old} + Q_{ij}(X_{ij}^{old} - X_{kj}) \tag{13}$$

where $Q_{i,j}$ is a random number that lies between -1 and 1, $X_{k,j}$ is the neighbouring food source that can be randomly selected and X_{ij}^{old} and X_{ij}^{new} are old and new food sources respectively.

If the food source does not improve after a number of trials, it is abandoned and the associated bee becomes a scout. These steps are continuously repeated until the maximum cycle or stopping criteria is met. Then, the food with the highest fitness value is selected and printed.

3. RESULTS AND DISCUSSIONS

IEEE 30-bus is used to test applicability of this approach in congestion management. This system has a total of six generators, 41 lines, 24 load buses and 21 loads. It has a total of 283.400MW active and 126.200 MVAR reactive loads connected to the system. This is shown in Figure 4. The simulation was carried out on MATLAB/SIMULINK platform on an AMD 4C+6G 2.10 GHz processor with 4GB RAM. The control parameters for ABC algorithm were set as shown in the Table 1.

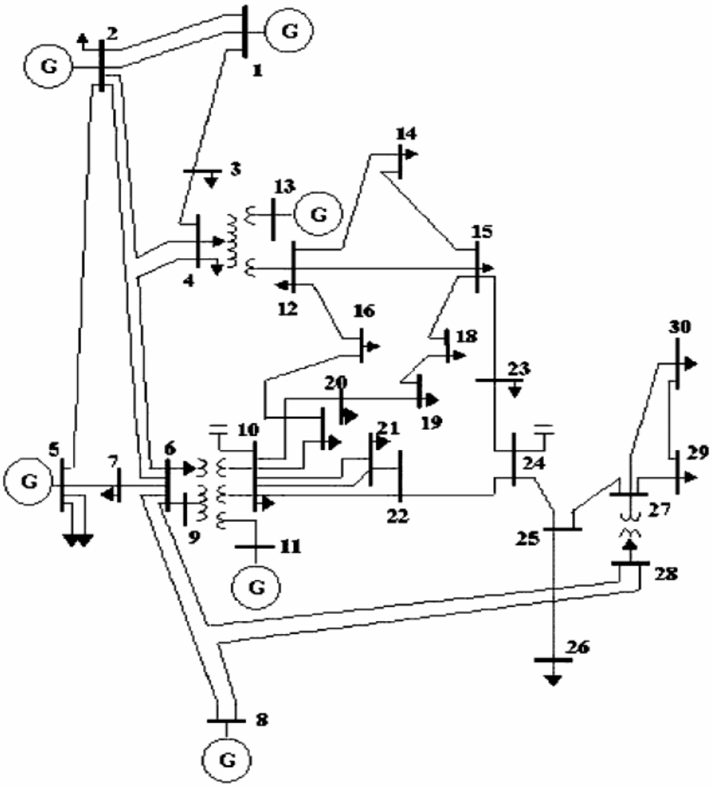

Figure 4. IEEE standard 30 bus system

Table 1. ABC parameter settings

S/N	Parameter	Value
1	Colony size	40
2	Employed bees	20
3	Limit value	100
4	Number of onlooker bees	20
5	MCN	100

Two test cases were simulated and Newton Raphson power flow run to test the congestion status in the island. The test cases done are shown in Table 2. In this case, congestion is simulated by creating an outage on lines 1-2 and 1-7 and overloading the lines.

Table 2. Test cases description

Test case	Contingency Description
1	Outage of line 1-2
2	Outage of line 1-7 with increase in load at all buses by 50%

3.1. Case 1

The outage of line 1-2 brings congestion between lines 1-7 and 7-8 of the modified system. The total system loss increases to 16.069 MW from 7.376 MW. This is compared with the CM using firefly algorithm as shown in the Table 3.

Table 3. Total system loss for case 1

	MW	MVar
Normal condition	7.376	-15.043
Outage of line 1-2 contingency	16.069	21.303
After load shedding (20.552MW) using ABC algorithm	11.649	4.305
Using Firefly algorithm	13.10	Not given

From the load flow, the power flowing between the two congested lines becomes 147.509 and 136.348 MW respectively against the set limit of 130MW. This condition is alleviated by shedding 20.552 MW load from the buses with least priority indices using ABC algorithm. After load shedding, the power flow between the two congested lines comes down to 122.537 MW and 114.093 MW which is well within the limit. This is as shown in Table 4. The Figure 5 shows the voltage profiles at various buses for normal, during the fault and after load shedding using ABC algorithm. There is a great improvement in the voltage profiles on the system buses after load shedding.

Table 4. Power flow for case 1

Congested line	Actual power flow (MW)	Power flow after load shedding using ABC	Line limit (MW)
1-7	147.348	122.537	130
7-8	136.348	114.093	130

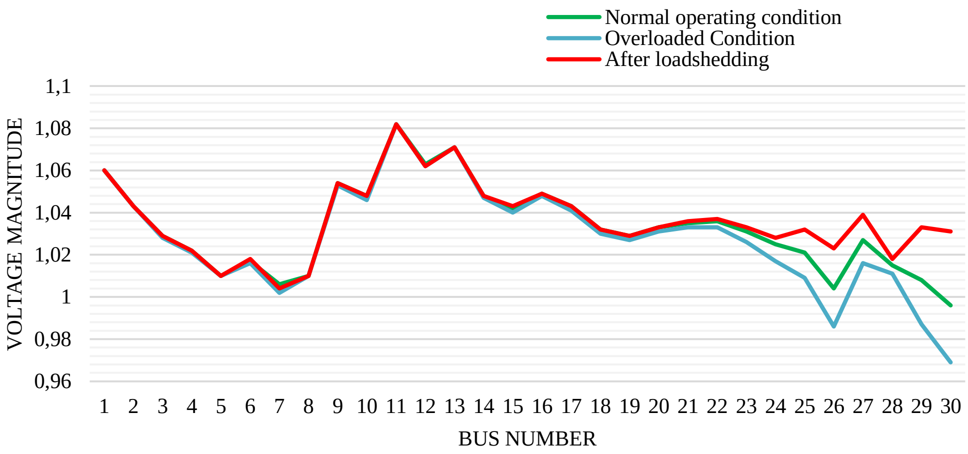

Figure 5. Voltage profile for test case 1

3.2. Case 2

In this section, the system loads were increased by 50% and then line 1-7 outaged. This caused congestion on lines 1-2, 2-8 and 2-9 of 313.914MW, 98.411MW and 104.769 MW respectively against the set limits of 130MW for line 1-2 and 65MW for lines 2-8 and 2-9. In this study, the total power Flow violation on the lines due to congestion is 257.088MW while it is 251.794MW in the study by reference [4]. This is shown in the Table 5.

The system losses were also monitored during and after load shedding using ABC algorithm. Applying ABC algorithm, 41.268 MW was shed to mitigate congestion levels. The total losses were recorded as shown in Table 6. The total losses decreased from 38.164 during the contingency to 17.485 MW after load shedding. This is compared by the congestion management approach using firefly algorithm in reference [4]. As can be observed from the figure, the total power losses for the two approaches is almost the same. This is elaborated in Figure 6.

Table 5. Congested lines for case 2

Congested line	Actual power flow (MW)	Line limit (MW)
1-2	313.914	130
2-8	98.411	65
2-9	104.769	65

Table 6. Total losses for case 2

	MW	MVar
Normal condition	7.376	-15.043
Outage of line 1-7 and 50% load increase	38.164	97.773
After load shedding (41.268MW) using ABC algorithm	26.770	54.706

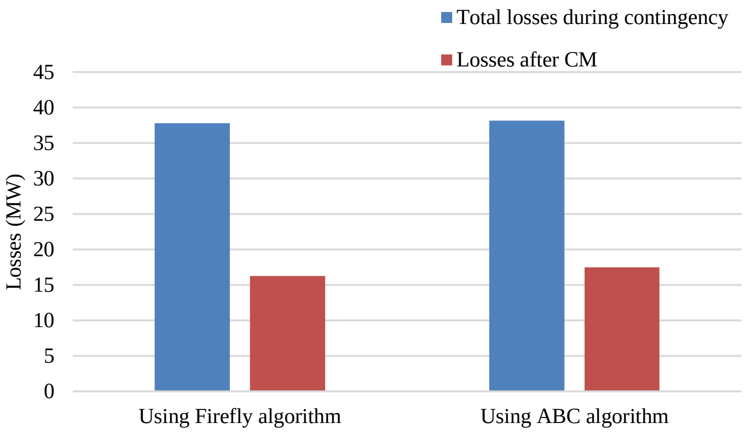

Figure 6. System losses comparison for case 2

The CM by load shedding using ABC algorithm was compared with CM by generator rescheduling using FFA, PSO, RSM and SA as reported in [4]. The power flows comparison is as shown in Table 7. The voltage profiles before, during the contingency and after CM by load shedding using ABC algorithm were monitored. The CM by load shedding using ABC algorithm improves the voltage profiles within the islanded MG. This is shown in Figure 7.

Table 7. Comparison of various algorithms in CM

Power flow (MW)	FFA	PSO	RSM	SA	ABC
Line 1-2	130	129.7	129.91	129.78	204.225
Line 2-8	62.713	61.1	52.36	51.47	59.509
Line 2-9	64.979	64.67	55.43	54.04	63.396

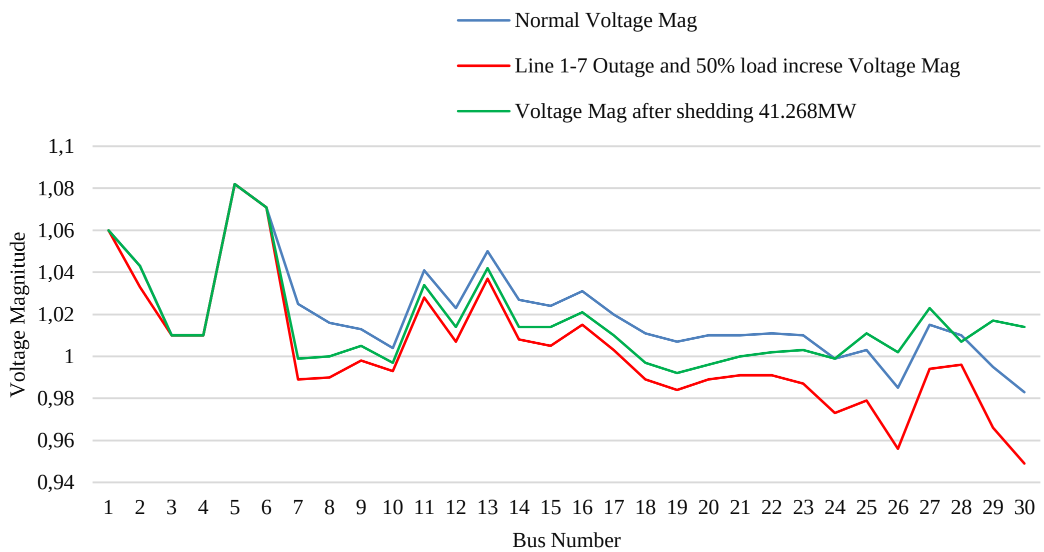

Figure 7. Voltage profiles for case 2

Convergence characteristics for this case was also monitored before the contingency, during the contingency and after load shedding. The iteration converged 14 iterations before the contingency, after 35 iterations during the contingency and converged after 29 iterations after load shedding. This is shown in the Figure 8.

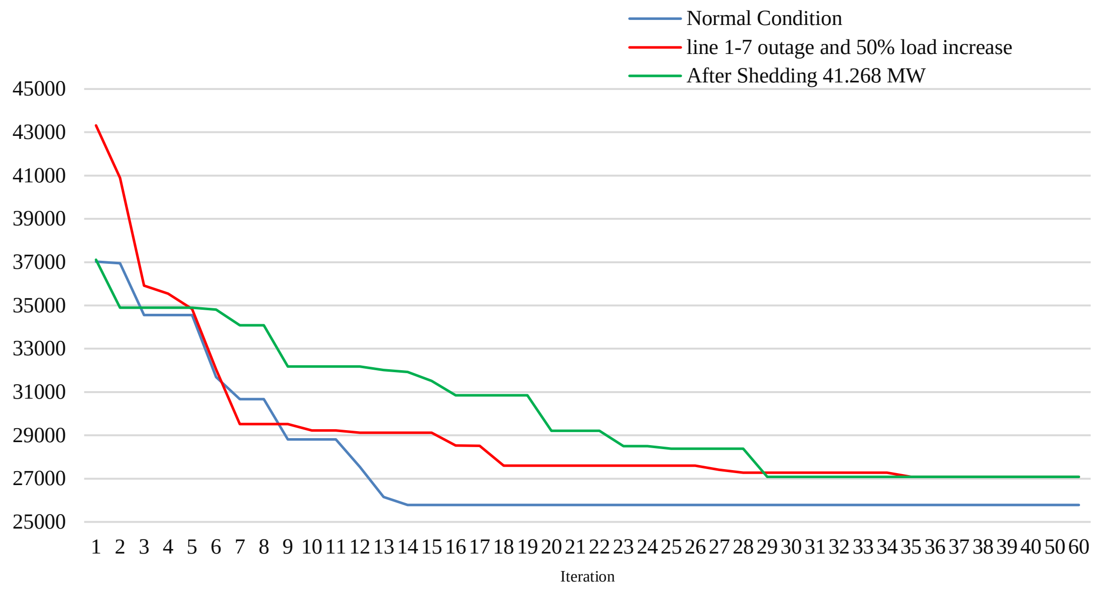

Figure 8. Convergence characteristics

4. CONCLUSION

This paper has presented an approach for congestion management on an islanded MG with RESs. Here, load shedding using ABC algorithm has been successifully employed for congestion management in an islanded microgrid. Various loads and buses were chosen for shedding based on their priority index to help mitigate the congestion problem. This was tested and validated on a modified IEEE 30 bus system with contingencies and sudden load increase in the micrgrid introduced. The results were compared with those from other algorithms like firefly algorithm and PSO as reported in the literature. The results show a great superiority of this approach over these algorithms. As it can be observed, this proposed method can greatly improve the system stability of the islanded MG through the minimization of the load shed and maintain the voltage profile within the required limits. This is due to superior convergence characteristics of ABC algorithm. This approach can therefore berecommeded in the solution of optimization problems in engineering and other fields as well.

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