Intentional Islanding Solution Based on Modified Discrete Particle Swarm Optimization Technique

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***Abstract*— Implementation of intentional islanding can prevent the power system blackout by partitioning the system into feasible sets of islands. The main challenge in determining the optimal islanding solution is the selection of transmission lines to be disconnected (cutsets) to form islands. The islanding solution must be the optimal solution and should not destabilize or cause the system to collapse. Therefore, this work developed a Modified Discrete Particle Swarm Optimization (MDPSO) with three- stages mutation technique to determine the optimal intentional islanding solution. An initial solution based heuristic method is used to assists the MDPSO technique to find the optimal islanding solution with minimal power disruption as its objective function. The post- islanding generation-load balance and transmission line power flow analysis are assessed to ensure the steady state stability is maintained in each island. The load shedding algorithm is carried out if generation-load balance criteria are violated. The proposed technique is tested on a modified IEEE 30-bus and IEEE 39-bus system. The results obtained show that the proposed technique produces an optimal intentional islanding solution with lower power flow disruption compared to other existing methods.**

Keywords—intentional islanding, MDPSO technique, minimal power flow disruption, heuristic method

I. INTRODUCTION

Severe disturbances in transmission lines or line outages can cause sequence tripping which could result in partial or total power system blackout. In most cases, the cascading tripping of transmission lines will cause the occurrence of unintentional islanding (known as passive islanding). Unintentional islanding which are usually uncontrollable, always produces unbalanced islands [1]. These unbalanced islands will subsequently lead to catastrophic system blackout due to its inability to maintain stable system operation. Therefore, intentional islanding (also known as network splitting) is preferred in order to prevent passive islanding which can lead to total system blackout. Intentional islanding is performed to partition the system into few standalone islands. The crucial part in implementing intentional islanding is determining the proper set of transmission lines that needs to be disconnected to form the islands. The process becomes more challenging when the system size is increases as the search space of possible islanding solution increases proportionally.

The implementation of intentional islanding in transmission lines has drawn a great attention in recent years. Various approaches have been proposed by previous researchers for intentional islanding implementation. One of the earlier method is the graph partitioning approach using ordered binary decision diagrams (OBDD) method introduced in [1]-[2] to find proper islanding strategies. A generator grouping method using slow coherency approach is introduced in [3]. The proposed approach identifies the weakest connection in the network to determine the proper splitting solution. This method is then improved in [4] using minimal flow-minimal strategy determination approach which leads to the islanding solution with less number of transmission line cutsets. A numerical approach (linear programming) using piecewise linear AC power flow is introduced in [5] to find a proper islanding solution. Voltage and reactive power are the main constraints considered in forming the islands and mixed integer linear programming (MILP) [6] is used to find the possible islanding solutions. Other technique such as heuristic technique using ant mechanism is proposed in [7] where the probabilistic search approach is used to find the best islanding solution. Besides, meta-heuristic approach has been proposed by the authors in [8]-[9] to reduce the computational complexity in obtaining the islanding solution.

Different from previous work, this paper proposes a Modified Discrete Particle Swarm Optimization (MDPSO) technique to find the optimal islanding solution using minimum power flow disruption as its objective function. Intentional islanding is a discrete problem in nature; therefore discrete optimization approach is more suitable to use in this study. The graph theory approach is utilized in this work to represent the physical connection of power system network during the islanding implementation. In order to narrow down the huge search space of possible islanding solution to the smaller scope, heuristic methods is used to aid the optimization algorithm in finding an optimal islanding solution. Other constraints such as generation- load balance, generators coherency and transmission line capacity. Subsequent to islanding execution, the power imbalance in each island is calculated, network reordering is carried out and load shedding is executed if necessary. The power flow analysis is also performed to ensure the line loading capacity is not violated during islanding solution. proportionally.

The remainder of the paper is organized in the following order. Proposed algorithm is reviewed in Section II. Detailed explanation of the methodology used to find the optimal intentional islanding solution is discussed in Section III. In Section 4, the proposed algorithm is tested on IEEE 30-bus and 39-bus systems to demonstrate its performance. Finally, conclusion remarks for this work are carried out in Section 5.

II. PROPOSED ALGORITHM

This paper presents a meta-heuristic technique namely Modified Discrete Particle Swarm Optimization (MDPSO) technique to determine an optimal islanding solution for planning purposes. The main advantage of using meta-heuristic technique is that it has the capability to find optimal solution from a huge possible set of islanding solutions.

The work begins by modelling the test system in the graph theory. This is important to represent the physical connection of the system during islanding execution. Next, a good initial solution is determined using the heuristic method. The initial solution is used in the initialization part of MDPSO technique to assist the optimization algorithm to find an optimal islanding solution and accelerate the convergence process.

The two main constraints considered during initial solution determination are predetermined number of islands and coherent groups of generators. The heuristic method works by grouping the same coherent generators in a group. Then, the nearest adjacent nodes (next node) are assigned to the nearest coherent group. The line that lies in between the different group of generators is the cutsets candidate. The detail explanations of the method can be obtained in [10].

Then, MDPSO technique is carried out to determine the optimal islanding solution. The algorithm will conduct the load shedding scheme if any imbalance between generation and load demand is noticed after intentional islanding execution. Transmission Line Power Flow Analysis is then performed to ensure that no line exceeds their maximum loading capacity after intentional islanding implementation. Fig.1 illustrates the overview of proposed approach.

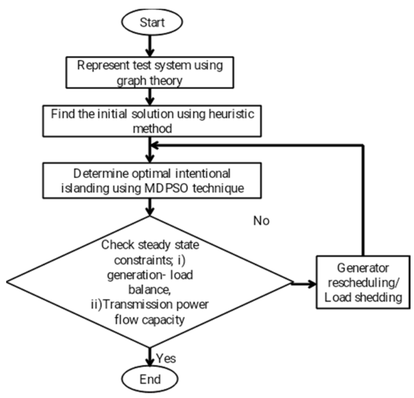

Fig 1. The proposed algorithm

III. METHODOLOGY

The steps involved in determining the final optimal islanding solution by using MDPSO will be elaborated in this section.

A. Modified Discrete Particle Swarm Optimization (MDPSO)

The islanding solution (transmission line to be disconnected) for intentional islanding solution is represented in discrete value (e,g. 1-2, 3-4...etc). Conventional PSO which uses floating point numbers (e,g. 0.225, 0.633, 4.966...etc) in its optimization process does not feasible for intentional islanding problems. Therefore, MDPSO is utilized in determining the optimal islanding solution and all the possible solutions are discovered iteratively. Fig. 2 show the utilization MDPSO technique in this study.

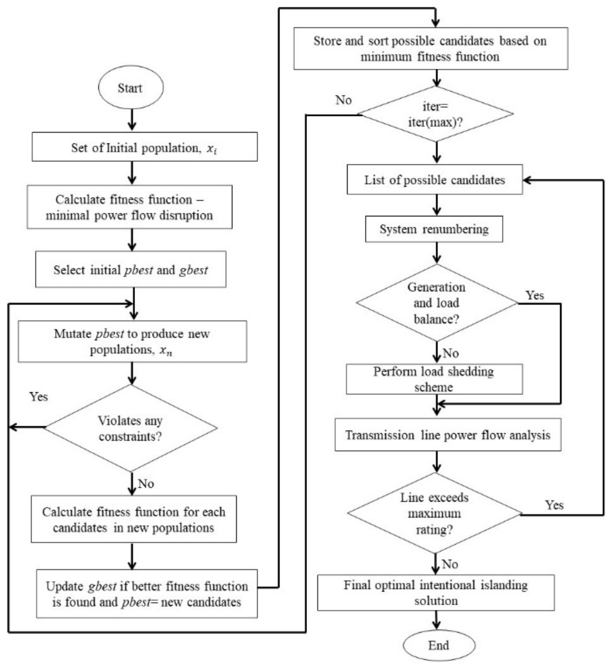

Fig 2. MDPSO Technique

Refer to Fig. 2, the initial solution obtained from the heuristic method is used as initial populations, x_i in MDPSO technique. The fitness value (minimal power flow disruption) is calculated for initial populations as explained in equation (1). This fitness function has been selected as it can produce islands with improved stability compared to the fitness function of minimal power imbalance [11]. Then, the value of *gbest* and *pbest* are specified.

$$\min\left\{ f(x) = \left(\sum_{dt=1}^{dt_{line}} | P_{dt} | \right) \right\} \qquad (1)$$

P_{dt} is the active power flow in the transmission line (disconnected lines), dt and dt_{line} is the total number of lines to be disconnected during islanding implementation.

In MDPSO, the initial populations, x_d is diagonally mutated by replacing a random value, X_{1i} in diagonal manner, from the search space, S to produce new populations, x_n. The solution space, S is the number of edges (transmission line), $ET=\{ET_l\}$ in the system where $l=1,2,3....total\ number\ of\ edges$. Taking into account that there is a possibility that the total number of cutsets may be less or more than the initial population, three-stages of mutation process are introduced.

The three- stages mutation technique are performed in each iteration. The following steps describe the steps taken to implement three-stages mutation technique in MDPSO optimization:

1) Stage 1: The mutation process in the first stage is executed by replacing the single cutsets with single random value, X_{1i} in diagonal manner to produce new populations as shown in Table I. The random value, X_{1i} is selected from the search space, S of the system.

TABLE I. MUTATION PROCESS OF MDPSO TECHNIQUE – STAGE 1

1	Example of initial population from heuristics method	C_1	C_2	C_3	C_4
2	1st cutset is randomly replaced	X_{i1}	C_2	C_3	C_4
3	2nd cutset is randomly replaced	C_1	X_{i2}	C_3	C_4
4	3rd cutset is randomly replaced	C_1	C_2	X_{i3}	C_4
5	4th cutset is randomly replaced	C_1	C_2	C_3	X_{i4}

2) Stage 2: In stage 2, the number of initial cutsets is reduced by one and new populations, x_n are produced by mutate the cutsets diagonally as performed in stage 1. The Mutation process for this stage is explained in Table II.

TABLE II. MUTATION PROCESS OF MDPSO TECHNIQUE – STAGE 2

1	Example of initial population from heuristic technique	C_1	C_2	C_3	C_4
2	1st cutset is randomly replaced	X_{i1}	C_2	C_3	0
3	2nd cutset is randomly replaced	C_1	X_{i2}	C_3	0
4	3rd cutset is randomly replaced	C_1	C_2	X_{i3}	0

3) Stage 3: Finally, another cutsets is added randomly in stage 3 and new populations, x_n are produced by performing mutation process (diagonally replaced) as in stage 1. Table III shows the mutation process implemented in this stage.

TABLE III. MUTATION PROCESS OF MDPSO TECHNIQUE – STAGE 3

1	Example of initial population from heuristic tehcnique	C_1	C_2	C_3	C_4	C_5
2	1st cutset is randomly replaced	X_{i1}	C_2	C_3	C_4	X_{15}
3	2nd cutset is randomly replaced	C_1	X_2	Y_3	Y_4	X_{25}
4	3rd cutset is randomly replaced	C_1	C_2	X_{i3}	Y_4	X_{35}
5	4th cutset is randomly replaced	C_1	C_2	C_3	X_{i4}	X_{45}
6	5th cutset is randomly replaced	C_1	C_2	C_3	C_4	X_{55}

For each new population produced in each stage, the constraints; desired number of islands and coherent groups of generators will be checked and fitness value will be calculated. Then, all the new populations, x_n obtained from three- stages mutation are combined and compare with the initial *gbest*. If a better solution with minimum fitness value is found, the *gbest* is replaced with new value and the old *gbest* is store in possible solutions path. This process is continues until it reaches the predetermined number of iteration. For each iteration, the new populations, x_n are chosen as new *pbest* and will used for next iteration.

B. System Renumbering

Once the optimal islanding solution is found, the load flow analysis need to be performed in each island. Therefore, system renumbering is required. However, only one island has a slack bus when the system is split and other islands contain only PV and load buses. Therefore a slack bus has to be selected from the existing PV buses for islands which do not have slack bus. In this work, the slack bus is selected from the PV bus that has the highest maximum power rating (P_{Gmax}).

C. Load Shedding Scheme

There are two main scenarios that possible to occur after islanding implementation which is surplus of power generation and deficit of power generation. Therefore, the generation and load balance are evaluated in each island using equation in (2).

$$P_{imb} = \left(\sum P_G - P_L \right) \tag{2}$$

where P_G is the generated power in the island and P_L is the accumulation of all load and line losses in that particular island. If the generated power in the island, P_G is more than the load demand (P_L), load shedding execution is not required. However, if power imbalance is noticed in any island after the maximum generator limit for all generators have been exceeded, load shedding scheme will be initiated. In this work, the load shedding scheme is carried out by removing the best load combinations that match the value of the power imbalance.

D. Power Flow Analysis

Power flow analysis is then conducted to determine whether there is any line violates its maximum rating, $P_{tc,max}$ after the islanding execution using equation (3).

$$P_{tc,line} < P_{tc,\max} \tag{3}$$

where $P_{tc,line}$ is the active power flow in line *tc* and $P_{tc,max}$ is the maximum permissible limit of active power flow in line *tc*. This solution is regarded as the optimal islanding solution if the line ratings are not violated. On the other hand, if the transmission line ratings are violated, then the algorithm will find the next best solution for evaluation.

IV. SIMULATION RESULTS

The effectiveness of proposed algorithm is validated on IEEE 30-bus and IEEE 39-bus test systems. Islanding solution with two islands is carried for IEEE 30-bus test system whereas islanding solution with three islands is implemented for IEEE 39-bus test system. The algorithm is coded using MATLAB R2015a on Windows 10, Intel® Core™ i7-5500U CPU at 2.40GHz with 8GB of RAM.

A. Case I: IEEE 30-Bus Test System

The IEEE 30-bus test system has 6 generators and 41 transmission lines. The system is modelled using graph theory approach and initial solution (cutsets) of intentional islanding solution is obtained from heuristic method. To show the effectiveness of the proposed algorithm with load shedding ability during islanding solution, the generator value are modified based on [8].

For this case, the system is separated into two islands based on their coherent groups of generators, G_1={1,2, 5, 13} and G_2={8,11} [8]. Table IV show the initial solution obtained from heuristic method and its corresponding power flow disruption, P_{dp}. The usage of heuristic method helps to reduce the initial solution (cutsets) from possible transmission line combinations, $2^{\text{no.of transmission line}}$ ($2^{41} \approx 2.199 \times 10^{12}$) to only 7 lines as an initial solution.

TABLE IV. INITIAL SOLUTION FOR TEST CASE I: IEEE 30-BUS TEST SYSTEM

Initial solution (cutsets)	$\sum P_{dp}$ (MW)
2-6, 4-6, 6-7,19- 20, 10- 17, 22- 24, 24- 25	38.5766

The initial solution is refined in MDPSO to obtain an optimal islanding solution with minimum total power flow disruption. Table V shows that the final optimal islanding solution of 6 cutsest with lower power flow disruption (27.3818MW) is obtained as compared to the initial solution. Referring to Table II, the system is separated with 13 buses in island 1 and 17 buses in island 2. In island 1, the total generation supply (P_{gen}) is sufficient with the total load demand (P_{load}), therefore load shedding does not required. In island 2, it is noticed that the total load demand (P_{load}) is still more than the total generation supply (P_{gen}) after all generators reached their maximum generation limit. Therefore load shedding scheme is initiated to ensure the generation and load balance is achieved in the islanded area. Load shedding scheme is executed by shedding loads at bus 21 and bus 24 (26.2 MW) to fulfilled the generation and load demand balance criterion. The transmission line power flow analysis is carried out in each island to make sure none of the lines violate their maximum allowable capacity after islanding implementation.

B. Case II: IEEE 39-Bus Test System

The proposed algorithm is further demonstrated on modified IEEE 39 bus system to test its effectiveness. This system consists of 10 generators and 46 transmission lines. In order to prove the effectiveness of the proposed algorithm, the generators value are modified based on [9].

For this case, the system is separated into three islands with the coherent group of generators in each island are G_1={30,37,38}, G_2={31,32,39}and G_3={33,34,35,36}[9]. The initial solution obtained from heuristic method and its total power flow disruption, P_{dp} is shown in Table V. The initial solution (cutsets) from possible transmission line combinations, $2^{\text{no.of transmission line}}$ ($2^{41} \approx 2.199 \times 10^{12}$) is reduce to only 5 lines as an initial solution.

TABLE V. INITIAL SOLUTION FOR TEST CASE II: IEEE 39 TEST SYSTEM

Initial solution of Islanding cutset	$\sum P_{disruption}$ (MW)
1-39, 3-4, 14-15, 17-18, 17-27	451.8817

As in previous study case, the initial solution is refined in MDPSO to obtain an optimal islanding solution with minimum total power flow disruption. Referring to Table VII, the system is separated with 11 buses in island 1, 14 buses in island 2 and 14 buses in island 3. The total generation supply (P_{gen}) in island 1 and island 3 are sufficient with their total load demand (P_{load}), therefore load shedding does not required. However, the total load demand (P_{load}) in island 2 is still more than the total generation supply (P_{gen}) after all generators reached their maximum generation limit. Thus, load shedding scheme is initiated to obtain the generation and load balance in the islanded area. Load shedding scheme is executed by shedding loads at bus 7 (233.8 MW) to fulfilled the generation and load demand balance criterion. Then, the transmission line power flow analysis is carried out to make sure none of the lines violate their maximum allowable capacity. The final optimal islanding solution of 5 cutsets with lower power flow disruption (310.9092MW) is obtained in this study case.

C. Comparative Validation and Discussion

A comparative study is carried out to validate the performance of the proposed algorithm with other published work which has the same coherent group of generator and desired number of islands. The detail of the comparison findings are illustrates in Table VIII.

Referring to Table VIII, the proposed algorithm is able to find the optimal intentional islanding solution with lower total power flow disruption as compared to methods in [8] and [9]. In Case I, the MDPSO technique found islanding solution with lower total power flow disruption of 27.3818 MW (improvement of 20.74%) better than method in [8]. Meanwhile, in Case II, the proposed algorithm able to determine islanding solution with lower total power flow disruption of 293.5568 MW (improved by 61.4%) as compared to method in [9]. Based on the results obtained, it is proven that the MDPSO technique has the ability to solve the combinatorial explosive problem through the mutation process to find an optimal intentional islanding solution with lower power flow disruption.

TABLE VI. OPTIMAL INTENTIONAL ISLANDING SOLUTION FOR IEEE 30-BUS TEST SYSTEM

Islands	Buses Info	Optimal Islanding Solution	$\sum P_D$	Active Power				Load Shed
				Pre-islanding		Post- islanding		
				Total Pgen	Total Pload	Total Pgen	Total Pload	MW
Island 1	1~5, 7 12~16, 18, 23	2-6, 4-6, 6-7,16-17, 18-19, 23- 24	27.3818	69.237	68.3	69.237	68.3	-
Island 2	6, 8~11, 17, 19~22, 24~30			50	69.2	43.724	43.0	26.2

TABLE VII. OPTIMAL INTENTIONAL ISLANDING SOLUTION FOR IEEE 39-BUS SYSTEM

Islands	Buses Info	Optimal Islanding Solution	$\sum P_D$	Active Power				Load Shed
				Pre-islanding		Post- islanding		
				Total Pgen	Total Pload	Total Pgen	Total Pload	MW
Island 1	1-3,25-30, 37-38	1-39, 3-4, 3-18, 14-15, 17-27	293.5568	1471.215	1455.5	1471.215	1455.5	-
Island 2	4-14,31-32, 39			2222.93	2376.5	2150.746	2142.7	233.8
Island 3	15-24, 33-36			2283.187	2265.1	2283.187	2265.1	-

TABLE VIII. COMPARATIVE VALIDATION FOR OPTIMAL INTENTIONAL ISLANDING SOLUTION

Case Study	Islands	Test System	Technique	Disconnected Lines	Total Power Flow Disruption (MW)
Case I	2 islands	IEEE-30	Ref [8]	2-6, 4-6, 6-7,10-17, 18-19, 22- 24, 24- 25	34.5473
			Proposed approach	2-6, 4-6, 6-7,16-17, 18-19, 23- 24	27.3818
Case II	3 islands	IEEE-39	Ref [9]	1-39, 3-4, 15-16, 16-17	760.5895
			Proposed approach	1-39, 3-4, 3-18, 14-15, 17-27	293.5568

V. CONCLUSION

This paper presents a meta-heuristic technique for intentional islanding solution using Modified Discrete Particle Swarm Optimization (MDPSO) technique assisted by graph theory approach and heuristic method. Graph theory is used to model the system and visualize the physical connection of the network before and after the islanding execution. The heuristic method reduces the huge search space of possible islanding solutions and provides the best initial islanding solution. The MDPSO technique uses this information to determine the optimal islanding solution taking into account other steady state constraints such as generators coherency, generation-load balance and transmission line capacity analysis. The optimization technique uses minimal power flow disruption as their objective function to find the optimal islanding solution. The proposed algorithm is verified using IEEE 30-bus and IEEE 39-bus test system. The results obtained in both test system indicates that the proposed algorithm produced better optimal islanding solution as compared to the existing methods in terms of lower total power flow disruption. Islanding implementation with lower power flow disruption helps to produce balanced and stable islands.

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