Controlled Islanding Scheme for Power Systems

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Abstract- **System islanding is often considered as the final stage of power system defense plans. The goal is to preserve stable areas of the faulted power systems. The islanding scheme plays an important role in the power system restoration phase as it can make the power system restoration less complex and reduce the overall restoration time. The basis for islanding is not standard but rather depends upon the nature of the utility. Even though the formation of islands is dominated by geographical proximity of the synchronous generators to maintain generation-load balance, there are some factors which can assist in designing a better islanding scheme. These factors are the type and location of the fault and the dynamic performance of every island on the system against the fault. This paper presents an optimization technique to obtain the optimal formation of islands taking into consideration the geographical distribution of the synchronous generators and the dynamic performance of every island in the system against the extreme and credible faults that lead to full system breakdown. In order to show the validity of this algorithm, the Algorithm is applied to IEEE 118 Bus System and a comparison between the proposed islanding scheme and an islanding scheme based on the geographical distribution of the synchronous generators is presented. The results presented in this paper show that taking into the account the type and location of the extreme and credible faults helps to preserve more stable area than that of the traditional islanding scheme.**

I. INTRODUCTION

A major blackout happens when a large area or a complete area of a power system collapses. The main cause of a major blackout is a succession of cascading failures that trip a transmission line or some generation units. A partial blackout may start with a severe fault which can cause a large variation in power flow and busbar voltage, which in turn can cause the outage of generation units or transmission lines. This causes imbalance in the demand and generation of power. This sort of disturbance can be the beginning of a cascading blackout when it spreads uncontrollably in the power system. For economic reasons, most power systems operate at the minimum level required for stability. This makes the likelihood of converting a local blackout to a major blackout very high. This gives rise to the necessity of having an appropriate scheme to prevent a cascading blackout from becoming a major blackout[1].A variety of emergency controls are used to prevent cascading blackouts. These emergency controls are generator tripping, fast valving, load shedding, excitation controls and system islanding [2]. However, system islanding is usually considered as the ultimate control action to preserve as many stable areas as possible. It is well known that many blackouts, including the series of 2003 blackouts, could have been avoided if appropriate defensive islanding operation were taken following the disturbances. Defensive islanding implies intentional separation of the network in controllable islands. It is not like the passive islanding where the system can be unintentionally split in uncontrollable islands.

In literature, reasonable amount of work has been undertaken in the area of islanding. This work can be divided in two categories. The first category is about grouping the generators according to slow coherency and then trying to find the minimum cutting set from interface network between the generator groups using some searching techniques [3-8]. Due to the fact that they were using slow coherency as the main algorithm , their solutions are not only maintaining load generation balances but also providing good dynamic transient performance during islanding operation. The second group presented completely deferent method for system splitting [9-10]. Unlike the first group, their studies are based on steady state stability. The ordered binary decision diagrams are used after simplifying the original power network by graph theory. This helps in narrowing the solution space. As presented in [11], the balanced islands problem is an NP-problem and it is very difficult to find the optimal solution for large power system using searching algorithm. This is due to the fact that these algorithms are not efficient in searching NP-hard searching space. So far, most of the islanding algorithms are optimized in the way that the solution space is reduced by simplifying the power network. This simplification can be achieved either using simplified version of the power network or a part of it. These kinds of simplification could make it possible to lose one of the better solutions that may exist for the original power system. It is desirable to use the original power system data configuration directly. However, this would prolong the computational time. In this paper, the algorithm used is based on dynamic performance and slow coherency of the islands. The islanding problem is treated as an optimization problem where every solution is evaluated according to its dynamic behavior. Also taking into account the types and the locations of more probable extreme faults, which cause inter-area oscillation problems, and the stability of every possible island have enhanced the scheme design. As mentioned before, in the previous work [3-8], before running the algorithm the generators are grouped according to slow coherency. However, in the proposed algorithm, the solution with slow coherency would be avoided so the ultimate solution should not have slow coherency. In general, this paper raises an argument that designing an islanding scheme against most probable contingencies can be better than designing an islanding scheme with contingencies uncertainty.

It is also very much preferred that the solution for power system be a global optimum solution. However; this can not be reached by mathematical methods. All of these factors therefore make it necessary to use a global search technique such as a Genetic Algorithm [12].

II. Simulation Tools

A. Genetic Algorithm (GA)

Genetic algorithm is a global search technique used in optimization problems by imitating the mechanisms of natural selection and genetics. Full description of Genetic Algorithm can be found in [12].

B. Stability evaluation

For the simulation and stability evaluation, PSSENG (a power system simulator) [13] was used to decide whether the system is stable or not since it is able to give clear assessments of the stability or instability of a system. The stability evaluation algorithm on PSSENG, which is based on time domain simulation output, can classify the simulation cases into the following categories:

- Transiently unstable class
- Oscillatory unstable class (including inter-area oscillations cases)
- Poorly damped stable class
- Well damped stable class

For the two unstable classes, the stability index is expressed by the severity index. Unstable cases with a detection of pole-slipping are classified in the transiently unstable class. The time taken for the system to pole-slip is used as the severity index in this class. Other unstable cases, including inter-area oscillations cases, without a detection of pole-slipping, are classified as being in the oscillatory unstable class. In this class, the calculation of the severity index is more complicated than in the previous one. The maximum magnitude of the rotor swing among all other generators is used as the main indicator of the severity index. Moreover, the frequency deviation and generator's active power are also used as auxiliary measurements in addition to the maximum rotor swing of the machine in order to give an accurate severity index. For the stable classes, the examination of the machine's rotor swings can give a decent indication of the stability of the system. The swing amplitudes can help to identify the extraction of the envelopes of the rotor swing curve for all machines. The swing of the envelopes can be approximately defined as an exponential function

$$S(t) = A\, e^{bt} \qquad (1)$$

The value of b is the system time decay which is used as an index for the degree of stability. If b is less than 12s the case is classified as being in the well damped stable class. If it is more than 12s, the case is classified as being in the poorly damped stable class [14].

III. Problem Formulation

A severe fault may lead to blackouts in some local areas. Under certain circumstances, unexpected faults can lead to a major blackout. However, having a prepared scheme to resolve this problem can help to prevent such a transition. In order to produce this sort of scheme or solution, the production of the scheme should be treated as a constrained optimization problem. This will make the produced scheme meet the following requirements:

- Minimum possible power will be tripped in every island to maintain generation load balance
- As many stable islands as possible will be preserved**.**
- Line flows will not exceed loading limits
- System bus voltage will remain within limits

IV. Methodology

A. Algorithm overview

The idea is to produce an optimal islanding scheme that can preserve as many stable areas as possible. This scheme is optimized and assessed against some critical contingencies which are carefully chosen to cause system decent. Figure 2 shows the Algorithm flowchart. Before running the original power system, a list of more likely contingencies is artificially chosen to cause slow system coherency. The solutions produced by GA are tested and evaluated against each contingency in that list. After testing all solutions against all the contingencies, the best solutions are chosen, to contribute in the production of next generation of solutions, according to probabilistic technique. Following that the GA operators are applied to produce a better generation of the solutions.

B. GA Implementation

Encoding

Before applying GA to an optimization problem, an encoding scheme must be decided upon. The encoding scheme should map all possible solutions of the problem into symbol strings (chromosomes).Since the aim of our optimization problem is to obtain the optimal island formation with minimum amount of load shedding, every possible tie line that may aid to form island and loads are considered in the structure of the possible solutions (chromosomes). Therefore, every possible line and loads is numbered from 0 to K, where K = Number of Lines + number of Loads. Each chromosome is composed of S unique integers (S< K) with each integer corresponding to a line or load. For instance, chromosome with a value of 5214309 means that the elements number 5, 2, 1, 4, 3 and 9 are the ones that might trip.

Selection: The Rolette Wheel technique is used as the probabilistic technique to select the chromosomes [12].

Crossover: In this Algorithm the Midpoint technique for exchanging information was applied [12].

Fitness Function: The fitness function provides an evaluation of the chromosomes' performance in the problem domain. In this particular problem, the objective of the fitness function is to grade every possible island with respect to the following aspects:

- Stability class of the island: The stability evaluation algorithm will evaluate the island according to its stability class.
- Amount of load shedding that survives the island: The islands are evaluated in terms of the amount of tripped load they might need to survive. The higher the amount of tripped power, the lower the rank of the chromosome.
- System decay rate: This index is used only for the two stable classes in order to specify the degree of stability. The lower the system decay rate, the higher the rank of the chromosome.
- Severity Index: This index is used only for the two unstable classes to specify the degree of instability. The higher the severity index the lower the rank of the chromosome.

The corresponding fitness function for every island can be written as

$$F = \begin{cases} SC + \dfrac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \dfrac{1}{TDR} & \text{Stable} \\[2ex] SC + \dfrac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \dfrac{1}{SI} & \text{Unstable} \end{cases} \quad (2)$$

Where: SC represents the stability class and is equal to 20 for well damped stable, 10 for poorly damped stable, 5 for oscillatory unstable, or 0 for transiently unstable. NL is the number of predetermined shedding loads, MVI is the summation of the amount of load reductions, TDR is the time decay ratio and SI is the severity index.

The overall fitness function for each chromosome is

$$FF=F_1+F_2+\ldots\ldots\ldots\ldots\ldots +F_N \quad (3)$$

Where N is the number of islands in one chromosome.

V. 118 IEEE BUS SYSTEM

A. *Overview*

In order to show the validity of the algorithm, the algorithm is applied to IEEE 118 bus system [15]. The network is fully loaded and every generator is equipped with AVR and governor. The dynamic data can be requested from the main author.

B. Assessing contingencies

Due to the large size of 118 networks, there are many type of contingencies which are able to cause generators slow coherency. Out of these, three contingencies are carefully chosen to help find the optimal islands formation. These four contingencies are assumed to be most probable and severe contingencies.

Contingency 1: At 1.00 second permanent three phase fault on the transformer between bus SproneE and SproneW with failure of bus bar protection. The fault was cleared on the second zone.

Contingency 2: At 1.0 S permanent three phase fault on the transformer between MuskngumN and MuskngumS with failure of bus bar protection. The fault was cleared on the second zone.

Contingency 3: At 1.0 S permanent three phase fault on ClinchRV bus with protection failure. The fault was cleared on the second zone.

Contingency 4: At 1.0 S permanent three phase fault on the transformer between TannrsCKN and TannrsCKS with failure of bus bar protection. The fault was cleared on the second zone.

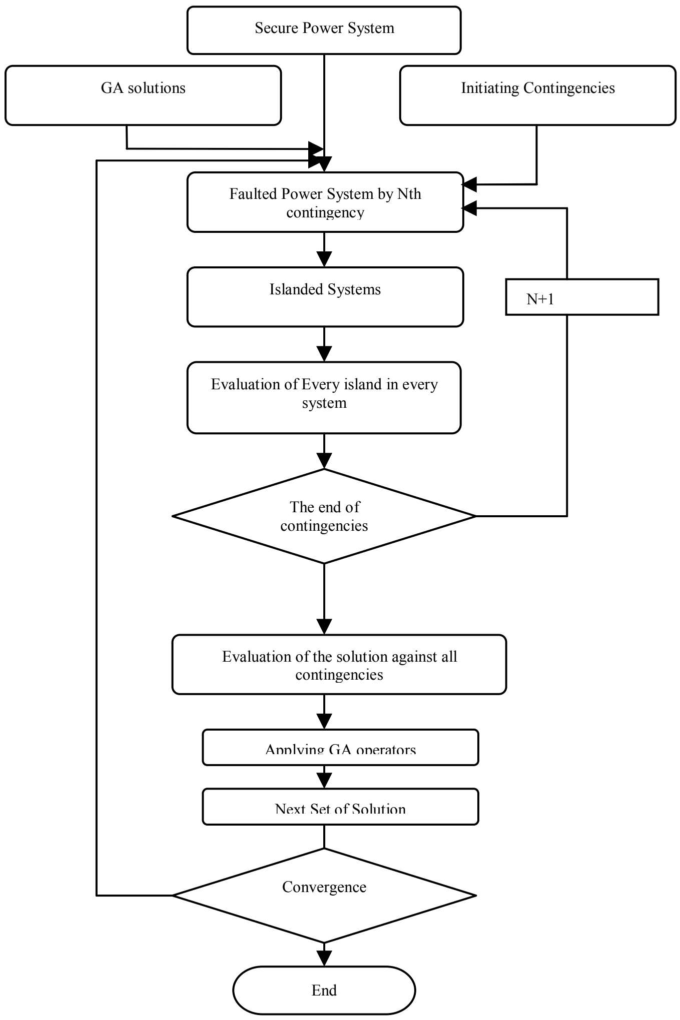

Figure 1 Algorithm Flowchart

VI. RESULT AND ANALYSIS

A. *Traditional scheme*

Based on the geographical distribution of the synchronous generators, the obvious boundaries of the islands and load

/generation balance requirement, the system can be islanded into six viable islands which can be seen in figure 3. Table 1 shows the amount of load shedding, required to maintain load / generation balance, in every island. At the stage of choosing the island boundaries, the issue of uncertainty appears. This is due to the fact that many combinations of the six mentioned islands can fulfill the requirement of the load /generation balance [16]. Practically, the islanding scheme designers analyze every island combination against some critical contingencies. However, this makes the best combination very difficult to reach in large power systems.

B. Optimized Islanding Scheme

GA criteria

Following the experience of many previous experiments, the GA operators were selected as follows: Number of generations = 150, Size of chromosomes = 35, Number of chromosomes =150 and Mutation rate =5%. It can be noticed from GA convergence on figure 2 that the best solution was found just before generation number 80 and after that all solution converged to the best one.

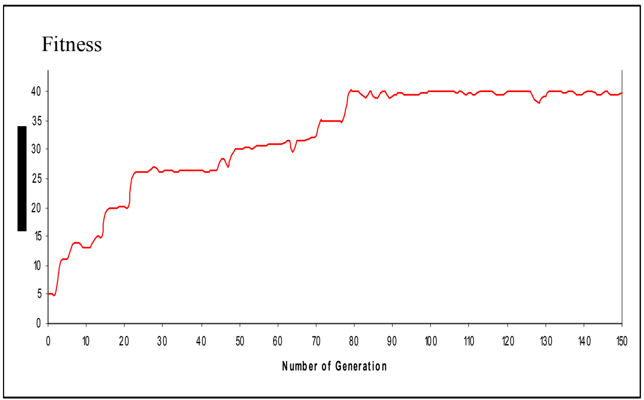

Figure 2 Genetic Algorithm Convergence

Table 1 The performance of the islands using Traditional method

	CO	Island	SC	TDR	LC
Traditional Islanding Scheme	1	1	Stable	8.5	%42.7
		2	Unstable	-	
		3	Stable	6.6	
		4	Stable	4.6	
		5	Stable	3.9	
		6	Stable	7.2	
	2	1	Stable	7.15	%34.8
		2	Stable	4.9	
		3	Stable	8.5	
		4	Unstable	-	
		5	Stable	4.7	
		6	Stable	8.4	
	3	1	Stable	8.91	%42.7
		2	Unstable	-	
		3	Stable	6.4	
		4	Stable	4.1	
		5	Stable	3.6	
		6	Stable	7.34	
	4	1	Stable	6.2	%22.4
		2	Stable	4.65	
		3	Stable	6.2	
		4	Stable	4.9	
		5	Unstable	-	
		6	Unstable	-	

GA outcome

Based on the islanding Algorithm result the optimized islanding formation can be shown in Figure 4. The algorithm was able to find five islands without any need of load shedding to maintain the generation/load balance equilibrium. Also the islands formation found by the algorithm can preserve more stable areas than that of the traditional one. It is interesting to notice that the solution obtained by the GA algorithm combined island 3 to island 4 and island 6 to 5. This is due to the fact that island 6 and island 3 can not survive following contingency 4 and contingency 2 respectively, as it can be seen on Table 2. Also, another reason for island number 3 to disappear is the large amount of load shedding required to maintain load/generation balance. Island number 2 has been divided into two islands. This happened in order to minimize the amount of the load collapse following contingency number one and number three. The boundaries of island number two have been adjusted to drop some loads to strengthen the island from the stability point of view. Based on the traditional scheme and the optimized scheme, Table 2 and Table 3 present the stability class (SC) and the time decay rate of every stable case (TDR) of every island against the assessing contingencies (CO). Also percentage of total load collapse (LC) after each contingency is presented on the tables. It can be noticed that, following the application of assessing the contingencies, the optimized scheme can maintain more serviced loads than that of traditional one. For instance, the optimized islanding scheme decreased the percentage of total load collapsed from 42.7 of the total load to 11.8 of the total load. This reduction in the collapsed area can be noticed as well following contingency number 3. It is worth noting that the optimized islanding scheme performs as good as the traditional scheme following the application of contingency 2 and 4. However it was perfectly able to preserve more areas following the application of contingency number 1 and 3. Also by observing the Time decay Rates and the amount of collapsed loads in both schemes in Table 2 and Table 3, it can be noticed that the algorithm made a decent compromise between stability and the amount of collapsed loads. In other words, the algorithm forms big island in order to avoid small islands that can not survive after some contingencies or require big amount of load shedding to survive, such as island number 6 and 3 in the traditional scheme. On the other hand, it goes towards the choice of small islands in order to preserve more stable area.

Table 2 The performance of the islands using Optimized method

	CO	Island	SC	TDR	LC
Optimized Islanding Scheme	1	1	Stable	8.5	%11.8
		2	Stable	6.3	
		3	Unstable	-	
		4	Stable	3.9	
		5	Stable	4.9	
	2	1	Stable	7.15	%34.8
		2	Stable	6.1	
		3	Stable	5.4	
		4	Unstable	-	
		5	Stable	3.1	
	3	1	Stable	8.91	%22.8
		2	Unstable	-	
		3	Stable	9.89	
		4	Stable	4.0	
		5	Stable	3.4	
	4	1	Stable	6.2	%22.4
		2	Stable	4.9	
		3	Stable	5.2	
		4	Stable	4.0	
		5	Unstable	-	

VII. CONCLUSION

By minimizing the amount of disrupted loads, the algorithm can play an important role to obtain the optimal islanding boundaries. Also, the Algorithm shows its robustness by obtaining islanding formation, which preserves more stable areas, with optimal amount of load shedding required to maintain load/generation balance. The comparison between the traditional and the optimized scheme shows that the optimized scheme performs as good as the traditional one in some contingencies and performs better in other contingencies. By using a list of assessing contingencies, the optimal islanding scheme becomes skewed towards these contingences. This makes the islanding scheme perform much better than the one designed for an open list of contingencies. Of course, the list of contingencies can be easily extended and is not in any way restricted to any particular limits. The algorithm makes good compromise between stability and the amount of collapsed loads. Finally, this algorithm will be more helpful in the case of complicated power systems where the natural boundaries of the islands are not obvious. This method will be applied to find an optimal islanding scheme for the Libyan Power System.

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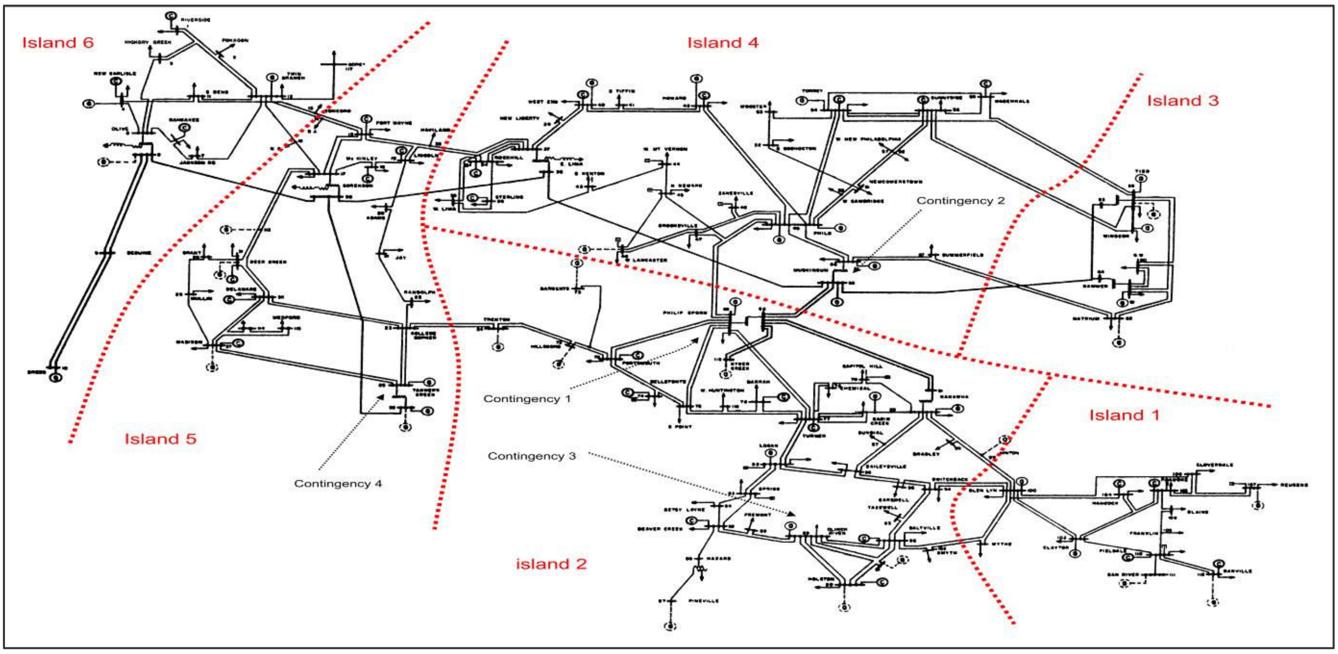

Figure 3 the performance of the islands using Traditional method

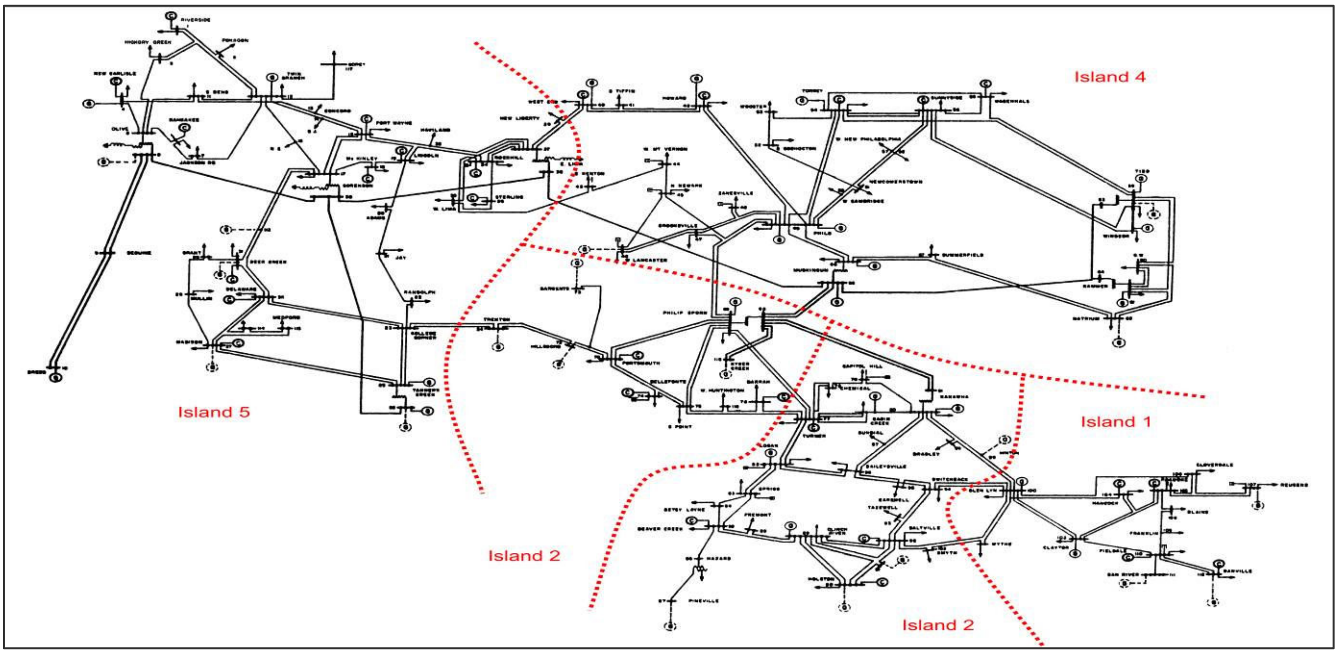

Figure 4 the performance of the islands using Optimized method