An Optimized Defence Plan for a Power System

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Abstract- **This paper presents a novel optimization technique for determining the setting of various emergency power system controls. This will allow for the production of a comprehensive defence plan, against events such as cascading blackouts. The goal of this technique is to retrieve a new equilibrium operation point following a severe contingency. In the proposed optimization technique described in this paper the generator tripping, load shedding and islanding are considered as the main emergency control actions. Genetic Algorithm approaches are very successful at solving nonlinear combinatorial optimization problems; these have been applied in this work to produce an optimized defence plan. A Genetic Algorithm approach is used to find the optimal combination of generators and loads to be tripped as the best solution for the network to regain a new state of equilibrium that is operationally stable, whilst maintaining supply to as many consumers as possible. System islanding may also be applied if a satisfactory state of equilibrium can not otherwise be obtained. The optimization technique uses transient stability evaluation algorithms, based on time-domain simulation, to assess the fitness of the potential solutions. The test case, presented in this paper, for the optimization technique was the Libyan power system network. In order to show the validity of the optimized defence plan, a comparison between the existing Libyan power system defence plan and the optimized defence plan is presented for the case of a major blackout in the western part of the Libyan power system that took place on 8th November 2003. The results presented in this paper show that a robust defence plan with a satisfactory amount of load shedding and system islands can be obtained by the new technique. The paper also demonstrates that the new defence plan outperforms the existing Libyan power system defence plan.**

I. INTRODUCTION

The main goal of power system security measures taken during planning and operation is to minimize the number of interrupted customers following likely incidents. This goal can be reached by implementing planning and operation rules to ensure that power systems remain viable following any credible contingency. However, abiding by these security rules does not guarantee that the network will be fully protected against all types of severe faults. This is due to the fact that major disturbances are the consequence of complex situations associated with control or protection failures. This kind of situation is rare but does occur. Instances include France in 1978 and 1987 and the Western United States in July 1996 [1]. Practically, special defensive measures called a "defence plan" are used. By limiting the geographical extent, duration and effects of the disturbances, defence plans can play an important role in minimizing the number of interrupted customers [2]. Owing to the complexity of modern power systems, the design of defence plans can be very difficult. Human experience and observation are used as the main keys in designing the necessary measures. Although using the experience of power systems engineers can be of assistance in the design of a good defence plan, the optimality of the defence plan, in terms of loss of loads, can not be guaranteed [3]. This heightens the necessity of using optimization methods to obtain more optimal defence plans. Mathematical optimization methods have been used over the years for power system control problems. However, the solution for large-scale power systems is not easy to obtain by way of ordinary mathematical optimization methods. This is due to the fact that there are many uncertainties in power system problems due to their complexity, size and geographical distribution. It is also much preferred that the solution for the power system be close to the global optimum solution. However, this can not easily be reached by mathematical methods due to the multi-objective, discontinuous nature of the problem space [4]. All of these factors therefore make it necessary to use a robust global search technique such as a Genetic Algorithm [5]. In this paper, a Genetic Algorithm is applied to find the minimum amount of load shedding, following severe faults, at various frequency thresholds that are able to secure the network, or even enhance the dynamic performance. Also, another Genetic Algorithm is applied to obtain an optimal islanding scheme to geographically restrict the extent of the fault. Practically, defence plans are designed to act against incidents which are not covered at the system planning stage. There are many methods that can be used to prevent system collapse immediately following an incident. These include generator tripping, fast valving, load shedding excitation controls and system islanding. Of these, load shedding, generator tripping and system islanding are considered to be the most effective control actions [6]. However, generator tripping is often associated with conservative networks. These defence schemes are based on the fact that, in extreme situations, it is better to shed some loads, or parts of the network, rather than to lose the whole network.

II. HOW TO DESIGN A DEFENCE PLAN

Numerous specific dynamic simulations are taken into consideration in the process of defence plan design [2, 3]. Unlike conventional operational security studies, the contingencies that are investigated for defence plan design are much more complicated than N-1 contingencies. The goal of these dynamic simulations is to assess system security and to determine the behaviour and the limits of the adopted defence measures, and to examine the impact of a new strategy [7].

A. Necessity to represent an accurate model for the network

As in any other study, the relevance of the study and the usefulness of the results depend on the accuracy of the system modelling. With regard to the dynamic simulation, a good representation of the dynamic components such as generators, AVR, governors, and the fast-valving system, SVC and FACTS, should be ensured. It is necessary to model the behaviour of the protection system, including unit protection such as generation unit protection, lines protection, and protection schemes that include the defence plan itself [8].

B. Incident Scenarios

Building incident Scenarios that represent different types of transient phenomena which lead to full system collapse, is one of the important steps in defence plan designing. Under secure operation conditions, power systems can withstand most likely incidents. Therefore, chosen incidents scenarios should be sufficiently complex and severe to break the system. Most of the time, the network is built to be of sufficient strength to withstand major disturbances. For this reason, the network must be weakened in order to simulate the situation that is very different from the normal operation conditions. Taking into account different weakening operation conditions such as unhealthy voltage profile, an unbalanced generation plan, an exceptional load demand, special import/export conditions and losing an important high voltage line, can be of assistance in representing severe transient phenomena that might lead to full system breakdown. Hence, this leads to a feasible defence plan. Incident scenario can be also built by using a probabilistic technique [9].

C. Simulation Tools

System collapses involve complex transients, which are a combination of slow transient and fast transient phenomena. Therefore, it is necessary to have simulation tools to study the ability of the power system to remain in synchronization for just a few seconds following the occurrence of the incident and to represent voltage, frequency and power flow variations[10].

III. Libya's Power System

The power system in Libya consists of four geographically well-dispersed, totally interconnected major island systems. The transmission system is supplied via 55 generating plants. These are mainly simple-cycle gas-turbine plants and steam units with some diesel generators located in rural areas of the Libyan Desert. The prime fuels are natural gas, residual fuel oil and distillate. The ultra high voltage level is 400 kV with a total circuit length 442 km, a high voltage transmission level of 220 kV, and a total circuit length 13,472 km. The sub-transmission voltage level is 66 kV, with a total circuit length of 13,582 km. The distribution network's voltage level is 30 kV; with a total circuit length of 6,237 km. geographically, the Libyan Network is characterized by heavy loads with most of the generation located in the north. Light loads are located far away from the generation, in the south. For purpose of study the Libyan Power System is geographically divided into seven electrical areas [11].

IV. Current Defence Plan

A. Overview

Since the current situation of the Libyan power system is characterized by weak connections in extended areas, the main goal of Libyan power system engineers was to produce a defence plan which is able to avoid propagation of severe phenomena, like loss of synchronism and voltage collapse.

B. Current Defence plan design

The Libyan defence plan design is based on the following steps [12]:

STEP 1 *Operation conditions definitions.*

In order to be able to represent severe transient phenomena that could lead to full system collapse, the 2003 Libyan network with interconnection with Egypt and the peak load situation has been considered along with some severe conditions. The conditions are attached with this paper in appendix 1.

STEP 2 *selections of assessment contingencies.*

As mentioned in Section 2.2, building comprehensive incident scenarios assists in the design of an efficient defence plan. In the Libyan defence plan, the assessing contingencies are attached in appendix 1.

STEP 3 *Contingency simulations*

The current Libyan defence plan including load shedding schemes, lines trip under frequency criterion and islanding scheme has been performed on a SICRE simulator environment [13].

STEP 4 *Local protection design and setting*

In order to achieve an accurate system, the following protection relays were implemented: out of step relays, under-voltage protection, power flow protections and power swing blocking.

STEP 5 *Load shedding scheme design*

Based on the Libyan power system topology, the Libyan network was considered as six areas. Each area has its own load shedding scheme as can be seen in Table 1. For coordination reasons, General Electricity Company of Libya recommended 49.4, 49.2, 49.0, 48.8, 48.6 Hz as frequency thresholds for load shedding. However, the choice of the first and last threshold is based on the following points. The first threshold should be fixed so as to avoid load shedding for electromechanical oscillations, even of large amplitude, in case of interconnected systems still integrated. With the amount of spinning reserve being fixed, it is a good rule to choose the first threshold that is low enough to allow the regulating energy to recover frequency drops with no load shedding. Therefore, in order to get the reasonable threshold values, the following values should be determined: maximum frequency deviation recovered by spinning reserve, maximum frequency deviation due to electromechanical oscillations and minimum frequency value. The minimum frequency threshold has to be fixed with reference to the under-frequency protection of units. In addition to the load shedding scheme, further load is shed by line trips for under-frequency protections intervention. Table 1 represents the amount of load shed and figure 1 shows the areas that were shed by line trips protection.

STEP 6 *Under-frequency islanding design*

The adopted technique of splitting the system into islands for a frequency below the last load shedding stage has both pros as well as cons. One advantage is the increase in probability of survival of some islanded power plants, with the possibility of accelerating the restoration procedure. One drawback is the diminution of the probabilities of survival of the small areas, along with instability of the units in small areas and a greater difficulty in balancing load and generation. Based on the experience of electrical Engineers from GECOL and the criteria of the designed islanding scheme, the Libyan Power system was islanded into six islands as shown in figure 1.

Table I The current load shedding scheme

AREA	LOAD SHEDDING FOR EACH THRESHOLD					
	49.4 Hz	49.2 Hz	49.0 Hz	48.8 Hz	48.6 Hz	Total
Area 1	3.30%	3.3%	0.00%	0.4%	0.0%	6.9%
Area 2	2.4%	1.8%	4.7%	3.9%	1.3%	14.1%
Area 3	1.60%	1.20%	1.2%	2.30%	1.9%	8.2%
Area 4	0.4%	0.0%	2.8%	1.7%	6.60%	11.6%
Area 5	2.9%	1.5%	2.4%	0.5%	2.1%	9.4%
Area 6	0.00%	0.9%	0.00%	1.6%	1.30%	3.8%
Area 7	0.00%	0.00%	0.00%	0.20%	0%	0.20%
Total	10.6%	5.6%	11.1%	10.7%	13.2%	54.3%

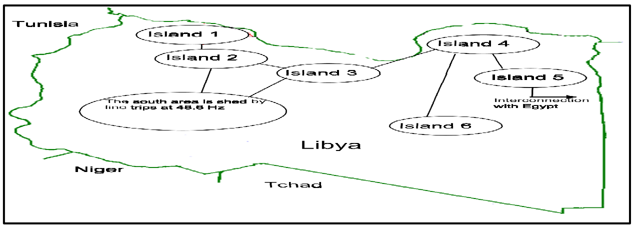

Figure 1 The Current islanding Scheme

V. OPTIMIZED DEFENCE PLAN

A. Overview

Generally, in this study, the same defence plan designing procedures are followed. Unlike the current defence plan, optimization techniques are applied in some critical stages. The first optimization technique is used to obtain a load shedding scheme. At this stage, the optimization technique is used to find the minimum amount of loads that should be tripped in every frequency level. At the second stage, the optimization is applied while obtaining the islanding scheme. Therefore, the optimization technique would be of assistance in finding the optimal islanding scheme.

B. Optimization tools (Genetic Algorithm)

A Genetic Algorithm (GA) is a global search technique used in optimization problems. It imitates the mechanisms of natural selection and genetics. [14]

C. Optimized defence plan design

The optimized defence plan design follows the same logic as the current defence plan. Therefore the optimized defence plane is based on the following:

STEP 1 *Operation conditions definitions.*

Unlike the current defence plan, the optimized defence plan is based on one operation situation. This is due to the fact that it is believed that if the defence plan design is based upon the worst operation conditions, it can act properly in better conditions. In this case, the weakest operation conditions for the Libyan power system is the 2003 Libyan network with interconnection with Egypt and the peak load situation with 120 MW exchange from Egypt and 64 MW from the West to the East.

STEP 2 *Assessing contingencies selections.*

The assessing contingencies reported in appendix 1 are recommended by the General Electricity Company of Libya. This is due to the fact that these contingencies are carefully chosen to represents different types of severe transient phenomena on the Libyan System.

STEP 3 *Contingency simulations.*

For the simulation and stability evaluation, a stability-assessment–optimized simulator, (PSSENG) [15, 16, 17] is used to decide whether the system is stable or not, due to its ability to give clear assessments of the system stability. The stability evaluation algorithm on PSSENG is based on a time domain simulation output.

STEP 4 *Local protection design and setting.*

PSSENG is not implemented with any type of protection system. Undoubtedly, the protection systems play a vital role in defence plan design. However, using GA helps to simplify the application of the protection system. By using GA, the solutions violating the protection elements are avoided. In other words, the power system protection is added to the assessment of the GA. So, if a certain solution causes some protection relays to be actuated, this solution will be lowly ranked.

STEP 5 *Under-frequency load shedding design.*

Unlike the current defence plan, an optimization technique is used to find the minimum amount of load shedding that is able to stabilize the network in every frequency stage. GA is used as an optimization tool.

STEP 6 *Islanding scheme design.*

As mentioned before the GA is applied to obtain an optimal islanding scheme. The idea is to produce an optimal islanding scheme that can preserve as many stable areas as possible

D. Genetic algorithm Implementation for load shedding

- **Encoding**

Before applying GA to an optimization problem, an encoding scheme must be decided upon. The encoding scheme should map all possible solutions to the problem into symbol strings (chromosomes).Since the aim of the optimization technique in this stage is to minimize the amount of load shedding in different frequency stages (frequency threshold) , the amount of power in every load is considered in the structure of every chromosome. Also, every chromosome is divided into five parts (5 frequency thresholds). Every part corresponds to a certain frequency stage, and is hence applied in that frequency stage. The following is an example of the chromosome structure:

F1			F2			F3			F4			F5		
4	7	6	0	0	3	88	0	12	0	0	13	0	0	14

Figure 2 chromosome structure

- **Selection**

The Roulette Wheel technique is used as the probabilistic technique to select the chromosomes [5].

- **Crossover**

In this Algorithm the Midpoint for exchanging information was applied [5].

- **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 each chromosome with respect to the following aspects:

- Stability class: The stability evaluation algorithm will rank the chromosome according to its stability class.
- Amount of generated and load power: The chromosomes are evaluated in terms of the amount of tripped power they possess. 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 can be written as

$$FF = \begin{cases} SC + \dfrac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \dfrac{1}{SI} + PS & \text{Stable case} \\ SC + \dfrac{10}{1 + \sum_{i=1}^{N_L} MVI_{Li}} + \dfrac{1}{TDR} + PS & \text{Unstable case} \end{cases} \quad (1)$$

Where: SC represents the stability class and is equal to

30 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, SI is the severity index and PS is the protection system evaluation.

E. Results of the GA for Load shedding

The GA operators were selected as follows: number of generations is 500, size of chromosomes is 60 and mutation Rate is 5%. The GA obtains the best solution after generation 260. Due to the complexity of the Libyan network, the GA has taken long time to evolve toward this solution. The ultimate solution is reported in Table 2. It is interesting to note that the load shedding scheme obtained by GA is similar to the current one in some senses. However, some extra load shedding is required in the new scheme in areas 1, 2 and 4. This makes the total load shedding in the network 63.32%, which is higher than that of the current scheme. It is worthy of note that the optimized solution shares with the current scheme the necessity of tripping the majority of area 4 by line trips load shedding at 48.6Hz . Also, it can be noted from Table 2 that an additional amount of load shedding is introduced in the last stage of load shedding.

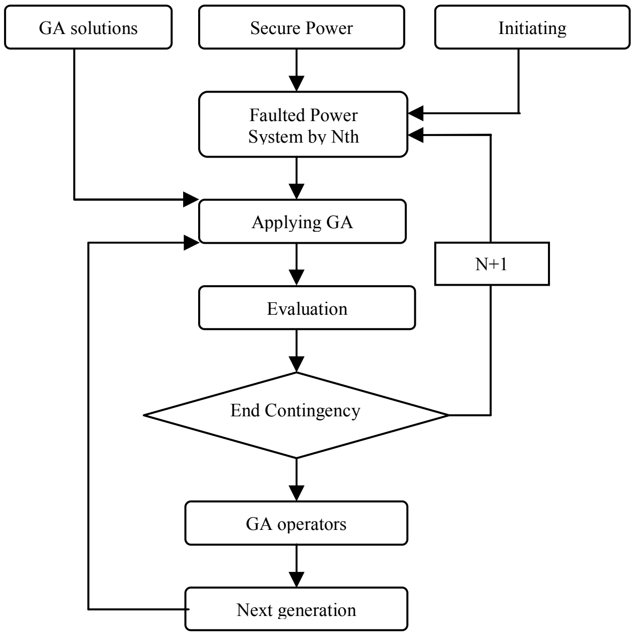

Figure 3 Load shedding algorithm flowchart

This additional amount of load shedding will play important role in saving the system in some critical situations, since it is vital in preparing the network for islanding.

Table II The optimized load shedding scheme

AREA	LOAD SHEDDING FOR EACH THRESHOLD					
	49.4 Hz	49.2 Hz	49.0 Hz	48.8 Hz	48.6 Hz	Total
Area 1	4.20%	4.10%	0.00%	2.00%	1.0%	11.30%
Area 2	2.00%	2.60%	4.10%	5.00%	3.10%	16.80%
Area 3	1.30%	1.00%	0.90%	2.50%	3.10%	8.80%
Area 4	0.32%	0.8	2.40%	2.10%	6.60%	11.6%
Area 5	2.00%	1.00%	2.10%	0.00%	3.10%	8.20%
Area 6	0.00%	1.00%	0.00%	1.00%	2.30%	4.30%
Area 7	0.00%	0.00%	0.00%	0.20%	0%	0.20%
Total	9.82%	10.60%	9.50%	12.80%	20.20%	63.32%

F. GA Implementation for islanding

The implementation of the islanding algorithm is fully explained in the accompanying paper [18] and [19].

G. Results of the GA for islanding scheme

The GA operators were selected as follows: number of Generations is 500, size of chromosomes is 60 and mutation Rate is 5%. The GA obtains the best solution after generation 394. Due to the complexity of the Libyan network, the GA has taken long time to evolve toward this solution. Referring to figure 2, in spite of the fact that the GA had completely free hand to choose the cutting point to form the islands, the GA obtained the same island formation of the current defence plan. The only change is in combining island 2 and island 3.

VI. OPTIMIZED DEFENCE PLAN VS CURRENT DEFENSE PLAN

A. Overview

In order to show the validity of the optimized defence plan, it is compared with the current defence plan for the case of the major blackout in the western part of the Libyan Power System took place on 8th November 2003.

B. November 2003 Blackout

Four years ago, one of the most severe blackouts was experienced in Libya. The blackout, which affected 74.0% of the served loads, was triggered by a short circuit on the 220/30 kV transformer on a power production plant on the West side of the Libyan Power System, Tripoli West Plant (on island 1). This occurred while the Libyan power system was connected to the Egyptian power system with Zero power exchange and the power transfer from the West to the East was 30 MW. Before the occurrence of the fault, the power system was 69.6% loaded. The fault was cleared on the second zone.

Dynamic evolution vs. the current defence plan

Figure 4 presents the evolution of the frequencies in the Libyan power system with the current defence plan. The dynamic evolution following the occurrence of the fault can be divided based on time into three periods. The first period, which is from 0-10s, starts with the fault occurrence which caused an immediate loss of four units in the west of Tripoli, which caused a loss of generation equal to 120 MW. At 0.8 s following the fault, three units were lost in the south of Tripoli, which caused a loss of generation equal to 237 MW. Two-generation units were lost in the Zawia Plant at 5.5s. One second later another unit in the same plant lost. This period can be distinguished by a loss of generation amount equal to 848 MW. The second Period 2 (7-12s) is characterized by a slow dynamic instability between the East and the West side of the Libya. The third Period (12s- end) started with a fast drop in voltage in the interconnected line between East the West. This is due to a loss of synchronism between the East and the West. Therefore, the interconnection lines between the East and the West were tripped due to under voltage protection at 16.33s at the same time, the Libyan Network was disconnected from the Egyptian Network. It is noticeable from Figure 5 that the East part of Libya survived while the West part of Libya fell in a cascading manner by losing four units in Homs plant until it reached the islanding stage at 48 Hz. Here, the islanding scheme played a decisive role at 19.34s where the network was splitted into three unstable islands. This led to a complete shutdown of the west.

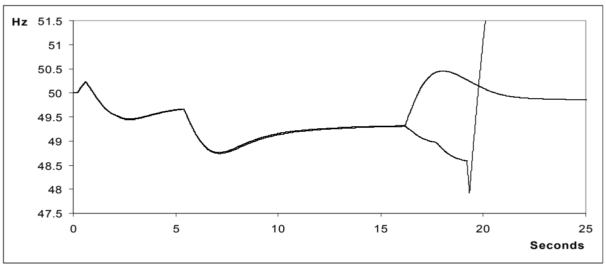

Figure 4 The dynamic evolution of the current defence plan

Dynamic evolution vs. the optimized defence plan

Figure 5 presents the evolution of the frequencies in the Libyan power system with the optimized defence plan. Similarly, the dynamic evolution in this case went in the same sequence as in the previous one. However, the extra load shedding introduced in the beginning of the optimized load shedding scheme was able to survive two generation units in the Zawaia Plant which helped to reduce the fast drop in the voltage in the interconnection lines between the East and the West of the country. Hence, the disconnection was postponed to 19.1 s. In general, the period of 10-18s is also characterized by long and slow instability due to loss of synchronism between the East and the West, leading to disconnection. Following the disconnection between the East and the West part of the country, the additional amount of load shedding introduced in the last frequency dependent on the load shedding step has properly prepared the west part of the network for islanding phase. At 23.5 s the network reaches the islanding stage where island 2 (island 2 and 3 in the current defence plan) was able to survive while island number 1 (island of Tripoli) lost its stability just following the islanding action. Comparing the optimized defence plan and the current defence plan in terms of survival load, the current defence plan was able to survive the eastern part of Libyan power system which is equal to 26.0 % of the total load and the optimized defence plan was able to preserve the east part of the Libyan power system and considerable part of the western part of the network. The whole preserved amount of loads is equal to 41.4% of the total loads. Besides this substantial increase in the amount of served load, this difference plays a vital role in reducing the restoration time.

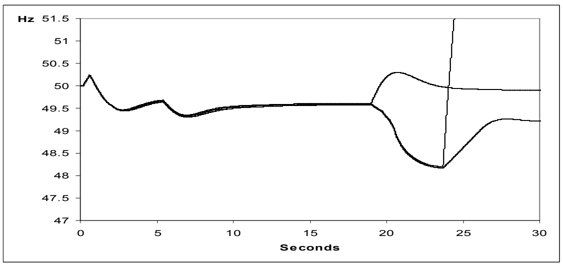

Figure 5 The dynamic evolution of the optimized defence plan

VII. CONCLUSION

The new defence plan algorithm that has been described in this paper can play an important role in obtaining the optimal islanding boundaries and the minimum amount of load shedding required stabilizing the power system after severe faults. The paper has shown that the algorithm is robust and has produced a superior defence plan when compared to the present Libyan defence plan. In particular, it recommends the amalgamation of two islands and in doing so it is able to preserve the supply to more loads. This was tested using the data from the Libyan blackout of 2003. The use of the optimization method has shown the necessity of having an additional amount of load shedding in the last frequency dependent load shedding step, not only to stabilize the network but also to prepare the system for the islanding phase**.**

REFERENCE

[1]. G. Anderson, P. Donalek, R. Farmer " Causes of the 2003 Major Grid Blackouts in north America and Europe, and Recommended Means to Improve system Dynamic Performance" , IEEE Transaction on Power System. VOL. 20, NO. 4, November 2005, PP.1922-1928.

[2]. G. Trudel, S. Bernard and G. Scott, " Hydro-Quebec' defence plan against extreme contingencies", IEEE Transaction on power Systems, Vol.14, No.3, August 1999, PP.958-967.

[3]. Grewal, G.S.; Konowalec, J.W.; Hakim, M., "Optimization of a load shedding scheme", IEEE industry application Magazine, July/August 1998, PP. 25-30

[4]. R. C. Bansal Dr. "Optimization Methods for Electric Power Systems: An Overview," *International Journal of Emerging Electric Power Systems*: Vol. 2 : Iss. 1, Article 1021 March 12, 2005.

[5]. M.Mitchell "An Introduction to Genetics Algorithms" A Bradford Book, the MIT, 1996, ISBN 0262631857.

[6]. Machowski, "Power System Dynamics and Stability". New York : Wiley, 1997

[7]. Tamronglak et al, "Anatomy of Power system blackouts: Preventive relaying strategies. IEEE Transaction on power delivery, VOL 11, NO. 2, April 1996, PP 780-715.

[8]. M.P.Houry, O. Faucon, "Defence Plans Economic solutions for improving the security of power systems", Control engineering Practice 7, 1999, PP. 635-640.

[9]. L. Wehenkel, "A probabilistic approach to the design of power systems protections scheme against blackouts", IFAC/ CIGRE Symp. On Control of Power systems and Power Plants, 1997.

[10]. B. Carreras, V.E. Lynch, I. Dobson, " complex dynamic of blackout in power transmission systems" ,Choas , an interdisciplinary journal of Nonlinear science, September 2004, VOl. 14, Issue 3, PP. 643-652.

[11]. www.gecol.ly, the official website of General Electricity Company of Libya, "Operational study Department".

[12]. "Libyan Power System Defence Plan", Operational study Department, General Electricity Company of Libya, 2000.

[13]. P.Baratella, PScarpellhi, R.Marconato, B.Cova, E.Gaglioti, R.Zacheo: "A power system simulator covering different time scale phenomena: models, algorithms, MMI and test results". Proc. Stockholm power tech, Stockholm, June 1995,pp.376-381.

[14]. D.E.Goldberg , Genetic Algorithm in search ,Optimization and Machine Learning Addison-Wesly Puplishing Company inc., Jan1989

[15]. K. Chan, R. Dunn, A. Danieks, A. Padget, A. Ekwue, P Buxton and J Rawlins, "on-line dynamic security contingency screening and ranking" IEE Proc on Generation, Transmission and distribution,144,2,March 1997,PP. 132-138

[16]. K.Chan,R.Dunn and A. Daniels, " on-line stability constrained assessment for large complex power system" Journal on electric power Systems Research, Elsevier, issue 46,1998,PP.169-176.

[17]. M.E. Bradley, A.O. Ekwue, F. Li, K.W. Chan, R.W. Dunn, and A.R. Daniels. "On-line stability analysis for an operational tripping scheme monitor". Proceedings of IEE Power System Control and Management, IEE-421:71-75, April 1996

[18]. M.El-werfelli, R. Dunn "Controlled Islanding scheme for Power Systems" to be presented in UPEC2008, Padova Italy.

[19]. M. El-werfelli,H. Haddud, R. Dunn " Design of an Optimized Defense Plan for the Libyan Power system" CIGRE, Paris 2008 (C2-209).

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