Quantum Inspired Artificial Immune System (QIAIS) For Optimum Load Shedding Technique For Loss Minimization

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Abstract—**In power system restructuring, losses occur in generation and transmission may caused high cost to consumers. So that the optimum load shedding techniques are developed in order to reduce the losses thus minimize the consumer's costs. In order to solve this problem, a several techniques had been developed to optimum the load shedding. Besides that, Quantum-Inspired Artificial Immune System optimization technique is an approach for optimal load shedding in distribution system. QIAIS is a combination of Artificial Immune System and the Quantum Inspired techniques. The concept of AIS is taken from the study of human body immune system which contains several mechanisms for defense against pathogenic organisms. This research represented that QIAIS optimization technique had a better performance compared to single AIS optimization technique. QIAIS optimization had a minima total losses and a better computation time. An IEEE 30-bus system is used in this study.**

Keywords- **Loss minimization, Load Shedding (LS), Artificial Immune System (AIS), Quantum Inspired Artificial Immune System (QIAIS)**

I. INTRODUCTION

Power system consists of three parts which are power generation, transmission and power distribution. Failure may occur in the generation and transmission system. This may lead to an increase in total losses in the transmission and distribution system. The two aspects which are the basic function of an electricity power system are to provide electric power to customers at the lowest possible cost also with an acceptable level of reliability. Since losses occurred in generation and transmission caused high cost to consumers, the optimum load shedding techniques are developed in order to reduce the total system losses thus minimized the costs. A load-shedding decision is made based on system security concerns, such as voltage and current. Load current in the system would increase during heavily load network. The objective in this case is to minimize load curtailment subject to system security constraints, and many techniques have been developed [1]. The use of load shedding as a mitigation tool has been constantly evolving, and different approaches have been formulated [2].

The previous work on load shedding for minimization of system interruption costs is presented by P.Wang and R.Billinton [1]. Customer concerns regarding interruption costs are incorporated in the load-shedding decision process when a faulty system occurs. Based on capacity and cost match, the cost weight factors for different feeder types are used to determine the load-shedding decision among feeders. Then, the work on load shedding scheme is improved by D.K.Subramanian [3] which is using the programming techniques such as sensitivity models, linear programming methods, and an exact model. Yun Chi in his study [4] proposed a load shedding scheme for classifying multiple data stream. A Markov model is used to predict the distribution of feature values which exact feature values of the data are not available because of load shedding.

Quantum computing is a technique consists of concepts similar to quantum mechanical computers and quantum algorithm. It is characterized by the use of quantum mechanics inspired such as standing waves, interference and coherence as well as the classical algorithm which checking that the solutions generated are in fact correct [5]. Many efforts on quantum computers have actively progressed since the early 1990s because these computers were shown to be better than classical computers on various specialized problems. Research on merging evolutionary computing and quantum computing has been started since the late 1990s. They can be classified into two respects which are focus on designing new quantum algorithms using automatic programming techniques such as genetic programming. The other one is focus on quantum-inspired evolutionary computing for a classical computer [7].

In [8], Jiaquan Gao et. al. introduced an algorithm which is combination of a quantum-inspired artificial immune algorithm (QAIS) and an artificial immune system based on binary encoding (BAIS) for solving the multiobjective 0-1 knapsack problem (MKP). Besides that, Quantum-inspired Artificial Immune System had been approached in previous research for optimal network reconfiguration in distribution system. Network reconfiguration is performed by altering the topological structure of the distribution feeder. It provides an efficient way to control the tie-line and sectionalizing switches

[6] as well as improved the voltage stability and system total losses can also be minimized for the loads in a distribution system.

In this study, Quantum-inspired Artificial Immune System (QIAIS) optimization technique is approached for a solution for optimum load shedding scheme at 30-bus IEEE distribution system that will minimize the losses thus reduce the total interruption cost. QIAIS technique is a combination of Artificial Immune System and the Quantum Inspired techniques.

II. METHODOLOGY

A. Artificial Immune System

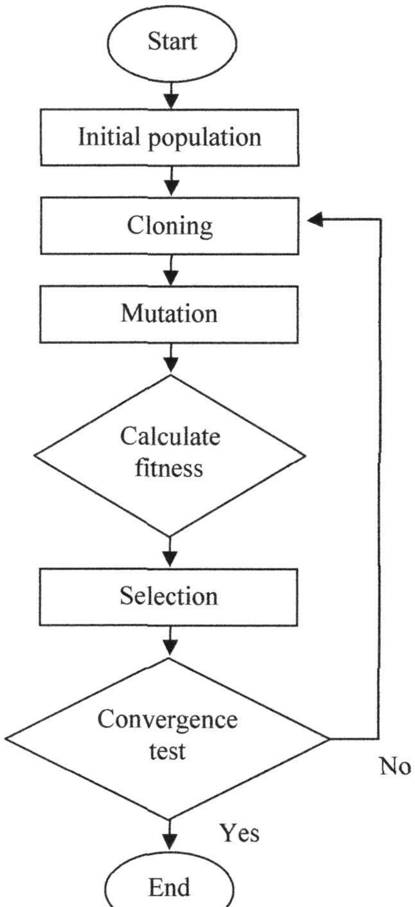

Figure 1: Single AIS flowchart

Artificial Immune System (AIS) is a computational method inspired by biological immune system which protects creatures (human beings and animals) from intrusions [10, 11, 12]. There are a few types of AIS such as Negative Selection, Clonal Selection and Immune Network. The disadvantage of AIS is it has slow convergence to a good optimum for a high dimensional optimization problem.

The proposed techniques are tested on IEEE 30-bus system. Before implementation of any programs, the 30-bus system is tested to evaluate the base case of system total losses. During the implementation of AIS and QIAIS process, it is important to ensure that the total losses are lower than the base case value. Several steps are involved in artificial immune system for load shedding by referring the Fig. 1 above.

i. Generate Initial Population

Table 1 below showed the types of buses in the system. The load buses which had power 0 MW are excluded to be shed. So that bus 3, 4, 7, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 26, 29 and 30 will be selected to be shed.

TABLE I. TYPE OF BUSES

Bus Code	Bus Type	Buses
0	Load bus	3, 4, 6, 7, 9, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 25, 26, 27, 28, 29, 30
1	Slack bus	1
2	Generator bus	2, 5, 8, 11, 13

There are 3 load buses are shed at one time for a system. The 3 buses are selected at randomly. The program is evaluated and give a result which is the result will be compared with following constraints:

a) Voltage magnitude in the system should be laid between 0.95 p.u to 1.10 p.u..

b) Total losses should be less than base case losses which is 17.5998 p.u.

c) Active power for load bus i must greater than 0, $P_i > 0$

d) $P_i > P_{imin}$, which are P_i = remaining load after shedding and P_{imin} = amount of load cannot be shed.

If the results satisfying the constraints, the program will continue to create 20 first populations.

ii. Cloning

After 20 populations are generated, they are replicated according to the cloning factor. If the cloning factor used is 10, hence, the cloned population will turn out to be 200 populations. In this project, the cloning factor used is 10.

$$\text{Cloned pop.} = \text{First pop.} \times \text{Cloning factor} \quad (1)$$

So that the new populations are 200 populations.

iii. Mutation

Mutation process is a process which generates the offspring or children by mutated the existing individual or called as parents. There are several types of mutation technique such as Gaussian Mutation Technique, Cauchy Mutation Technique and others [9]. Cauchy Mutation Technique is an enhance version of mutation technique compared to Gaussian Mutation Technique. So that Gaussian Mutation Technique is implemented in QIAIS as follow:

$$x_{i+m,j} = x_{i,j} + N\left(O, \beta\left(x_{j\,max} - x_{j\,min}\right)\left(\frac{f_i}{fmax}\right)\right) \quad (2)$$

Where ;

i = offspring, j_{max} = max parent

j = parents, j_{min} = min parent

β = search step, f_i = fitness 'ith'

f_{max} = max fitness

Maximum and minimum parent is referred to maximum and minimum of initial populations. β is search step size and also known as mutation scale. Fitness of the equation is equal to total losses in initialization step. It can be manually adjusted to achieve better convergence. Convergence of AIS is expected to occur more quickly if β had the lower value. For the easier way to understand the Gaussian Mutation Technique, the equation is simplified as:

$$xi'(j) = xi(j)\,exp(\Upsilon' N(0,1) + \Upsilon Nj(0,1)) \quad \textbf{(3)}$$

$$x'(i) = x(i) + xi'(j)Nj(0,1) \quad \textbf{(4)}$$

where;

$x'(i)$ = offspring

$x(i)$ = parent

$xi'(j)$ = mutated value

$xi(j)$ = strategic parameter

There are seven gaussians equation that are used in this programming which are Gauss 0, Gauss 1, Gauss 2, Gauss 3, Gauss 4, Gauss 5 and Gauss 6. Random numbers created from Gaussian equation are used to get the mutated values. After that, the parent which is generated from initialization is combined with mutated value to get the offspring.

iv. Selection

Selection process is a process to select the survival of the fittest. When the 200 mutated populations are generated, the populations are sorted in ascending order based on the total losses since the objective of this project is to find the minimum optimal total system losses. Then up to 20 best populations are selected.

v. Convergence Test

Convergence test is used to determine the stopping criterion of the program. The process of cloning, mutation and selection are repeated and only stop if the fitness meet the constraint which is:

$$Fitness_{max} - Fitness_{min} \leq 0.0001.$$

Where, $Fitness_{max}$ = maximum of total losses

$Fitness_{min}$ = minimum of total losses

For the difference of maximum and minimum losses which is the constraint, it can be 0.01, 0.001 or 0.0001. In this project, value 0.0001 had been used.

B. Quantum-Inspired Artificial Immune system

Quantum-Inspired Artificial Immune System optimization technique is a combination of Artificial Immune System and the Quantum Inspired techniques. It is developed in this program. Fig. 2 below is the flowchart:

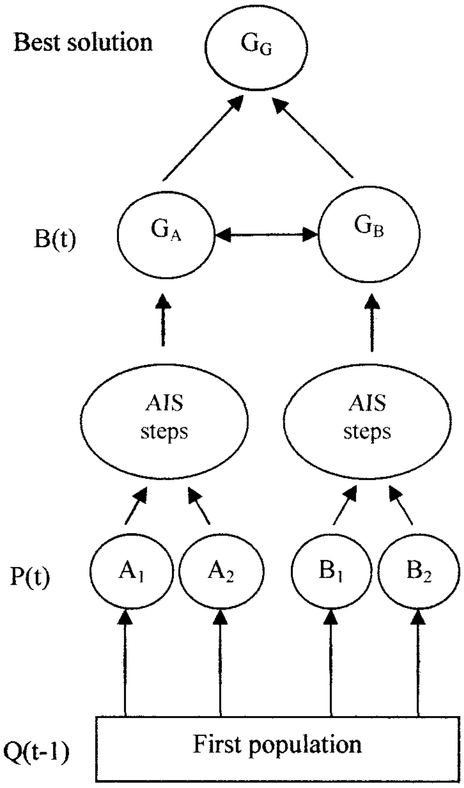

Figure 2: QIAIS flowchart

i. Q (t-1)

Considering the best 20 populations obtained from single AIS, the best 20 populations are used as the initial values for QI. Those 20 populations are considered as the Q-bit individual. Hence, there are 4 sets of Q-bit individual involved.

ii. P (t)

Each Q-bit individual will go through the process of the conventional single AIS for once again which are cloning, mutation and selection. At the end of this stage, there are 20 populations for each set. The 4 sets of Q-bits individual are being pairing with one another and a selection will be made in order to find the best populations.

iii. B (t)

The best solution obtained at the previous stage will be stored. There are 2 sets of B(t) obtained from P(t). These groups will then be combined.

iv. Best solution

The combination of populations in B(t) are sorted in order to have the best population, Q_{global}. The populations are ranked in ascending order during this stage. The best 20 solutions are determined.

III. RESULTS AND DISCUSSION

The proposed method is developed at IEEE 30-bus data system. It consists of 1 slack bus, 5 generator buses, and 24 load buses. The base power is 100MVA. The load buses which should be shed are selected randomly. In this case, there are three load buses should be selected to be shed since this is a stable system. The active power and reactive power is reduced by percentage and the value of percentage is identified by randomly. The main objective function is the total system losses, in addition looking for the computation time. Table 2 below, showed the total system losses for the base case system.

TABLE II. BASE CASE VALUE

Total System Losses *(MW)(p.u)*
17.5999

Table 3 showed the comparison between Single AIS and QIAIS in terms of computation time. It can be seen that QIAIS optimization technique had less computation time compared to Single AIS technique. It is proven that QIAIS optimization technique is better than Single AIS.

TABLE III. COMPARISON BETWEEN SINGLE AIS AND QIAIS BASED ON COMPUTATION TIME

Optimization Technique	**Computation Time (s)**
Single AIS	4038.580255
QIAIS	190.005288

From Table 4 below, it can be seen that the total system losses is reduced after the optimization technique is applied to the bus system. The three load buses are selected randomly. The values for active power and reactive power shown were the amount of power to be shed in terms of perunit.

Single AIS optimization technique is applied and the result showed in Table 5. Then, the proposed method which is QIAIS is implemented. Table 6 proved that the reduction of total system losses on QIAIS method is better than Single AIS method. Even the load had been shed, the system still in stable condition due to the limitation of voltage. Based on Table 4, Table 5 and Table 6, it was shown that the voltage was lying on the limit which is $0.95 \leq$ voltage ≤ 1.1.

The results obtained from the evaluation of this system were plotted and shown in Fig. 3 below. The red line represented the values of Single AIS as well as the green line represented the values of QIAIS optimization technique. From the graph, it can be observed that the fitness values obtained from QIAIS are lower compared to Single AIS method. Besides that, it can be seen that QIAIS optimization technique gave more consistent value as compared to Single AIS method.

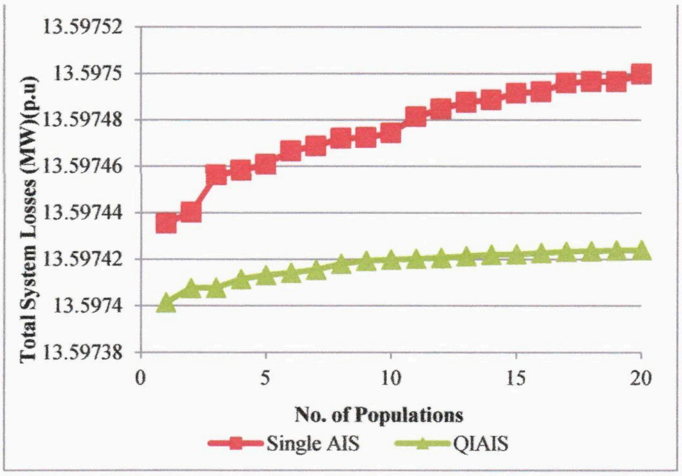

Figure 3: Comparison between the Single AIS and QIAIS for the 20 best populations after the convergence test is achieved

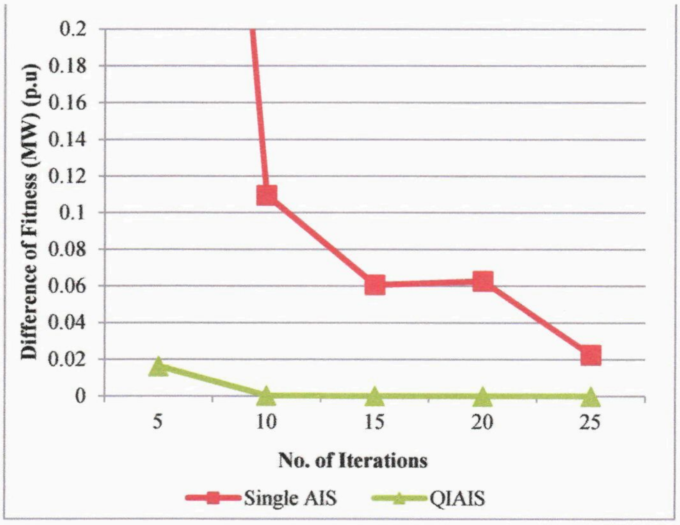

Figure 4: Comparison between Single AIS and QIAIS in terms of difference of fitness

From Fig. 4 above, it can be seen that QIAIS optimization *technique had achieved its solution at 15th iteration of* evaluation. At the same time, Single AIS technique has not converged yet. It is strongly proved that QIAIS method had a better computation time as compared to Single AIS technique.

The evaluation of this system is repeated 10 times to observe the consistency of both techniques. From the results, QIAIS technique is seems more consistent than Single AIS due to the difference between maximum and minimum fitness for QIAIS technique is lower as compared to Single AIS.

TABLE IV. COMPARISON BETWEEN FIVE POPULATIONS FOR INITIALIZATION

Optimization Technique	Load Bus			Active Power (p.u)			Reactive Power (p.u)			*Minimum Voltage (p.u)*	*Maximum Voltage (p.u)*	*Total System Losses (MW)*
	L1	*L2*	*L3*	*P1*	*P2*	*P3*	*Q1*	*Q2*	*Q3*			
Initialization	20	24	7	0.161925	0.640338	1.678127	0.051521	0.493134	0.802262	0.995348	1.082	17.22069
	12	18	10	1.708702	0.488201	0.884864	1.14422	0.137306	0.305125	0.99491	1.082	17.22087
	7	29	14	3.099159	0.326227	0.842754	1.481616	0.122335	0.217485	0.996096	1.082	16.97694
	7	16	21	4.679303	0.718314	3.591571	2.237035	0.369419	2.298605	0.996408	1.082	16.32035
	16	29	24	0.274913	0.188512	0.683355	0.141384	0.070692	0.526262	0.995951	1.082	17.41904

TABLE V. COMPARISON BETWEEN FIVE POPULATIONS FOR SINGLE AIS

Optimization Technique	Load Bus			Active Power (p.u)			Reactive Power (p.u)			*Minimum Voltage (p.u)*	*Maximum Voltage (p.u)*	*Total System Losses (MW)*
	L1	*L2*	*L3*	*P1*	*P2*	*P3*	*Q1*	*Q2*	*Q3*			
Single AIS	19	7	21	5.699869	13.67988	10.49974	1.264249	4.053092	4.164581	0.998833	1.082	13.59744
	19	7	21	5.69994	13.67991	10.49959	1.264265	4.053102	4.164519	0.998833	1.082	13.59744
	19	7	21	5.699936	13.67966	10.49973	1.264264	4.053027	4.164574	0.998833	1.082	13.59746
	19	7	21	5.699794	13.67957	10.49996	1.264233	4.053	4.164667	0.998833	1.082	13.59746
	19	7	21	5.699479	13.67991	10.49991	1.264163	4.0531	4.164647	0.998833	1.082	13.59746

TABLE VI. COMPARISON BETWEEN FIVE POPULATIONS FOR QIAIS

Optimization Technique	Load Bus			Active Power (p.u)			Reactive Power (p.u)			*Minimum Voltage (p.u)*	*Maximum Voltage (p.u)*	*Total System Losses (MW)*
	L1	*L2*	*L3*	*P1*	*P2*	*P3*	*Q1*	*Q2*	*Q3*			
QIAIS	19	7	21	5.699992	13.67993	10.49986	1.264277	4.053106	4.164626	0.998833	1.082	13.5974
	19	7	21	5.699904	13.67996	10.49986	1.264257	4.053116	4.164628	0.998833	1.082	13.59741
	19	7	21	5.699932	13.67998	10.49981	1.264263	4.053122	4.164607	0.998833	1.082	13.59741
	19	7	21	5.699905	13.67991	10.49988	1.264257	4.053101	4.164636	0.998833	1.082	13.59741
	19	7	21	5.699899	13.67997	10.49981	1.264256	4.053118	4.164608	0.998833	1.082	13.59741

IV. CONCLUSION

The effect of distribution system load-shedding decisions on total system losses is investigated in this project. The decisions are made by using QIAIS as the optimization technique which it is the combination of QI and AIS techniques. With the purpose of optimizing the load shedding, the objectives of this project are the loss minimization thus consumer's costs reduction. The combination of QI and AIS optimization technique has given the better performance and it is the best solution compared to the conventional Single AIS method.

The results of this project are promising. The test results on IEEE 30-bus showed that the total distribution system losses can be reduced using an optimum load-shedding policy. The most significant advantage of using QIAIS optimization technique is it provided better loss minimization in the system and less computation time. It is recommended to apply QIAIS optimization technique in operating the load shedding operation scheme. In this project, QIAIS was tested on static distribution system data. In implementation of QIAIS optimization technique in real situation, QIAIS should be test on lively-loaded distribution system data to see how good the program is.

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REFERENCES

[1] Wang, P. and Billinton, R, "Optimum Load-shedding Technique To Reduce The Total Customer Interruption Cost In a Distribution System," IEE Proc.-Gener. Transm. Distrib., Vol. 147, No. I , January 2000.

[2] Erick E. Aponte, Nelson J. K., "Time Optimal Load Shedding for Distributed Power Systems," IEEE Transactions on Power Systems, Vol. 21, No. 1, February 2006.

[3] Subramanian, D.K., "Optimum Load Shedding Through Programming Techniques," IEEE Transactionc on Power Apparatus and Systems, Vol. Pas-90, No. 1, January/February 1971.

[4] Yun Chi, Philip S. Yu, Haixun Wang, Richard R. Muntz, "A Load Shedding Scheme for Classifying Data Streams," Department of Computer Science, University of California, Los Angeles, CA 90095, proceeding of Fifth SIAM International Conference on Data Mining.

[5] Moore. M, Narayanan. A, "Quantum-Inspired Computing," Department of Computer Science, Old Library, University of Exeter, Exeter EX4 4PT, UK, November 20, 1995.

[6] N.H. Ahmad, T.K.A. Rahman, N.Aminuddin, "Multi-objective Quantum-inspired Artificial Immune System Approach for Optimal Network Reconfiguration in Distribution System," IEEE International Power Engineering and Optimization Conference (PEOCO2012), Melaka, Malaysia: 6-7 June 2012.

[7] J. Licheng, Yangyang Li, G. Maoguo, and Xiangrong Zhang, "Quantum-Inspired Immune Clonal Algorithm for Global Optimization," IEEE Transactions on Systems, Man, And Cybernetics—Part B: Cybernetics, Vol. 38, No. 5, October 2008.

[8] Jiaquan Gao, Lei Fang, and Guixia He, Zhijiang College, " A Quantum-Inspired Artificial Immune System for Multiobjective 0-1 Knapsack Problems," Zhejiang University of Technology, Hangzhou 310024, China.

[9] Ridzuan Idris, "Quantum—Inspired Evolutionary Programming For Network Reconfiguration At Distribution System For Minimum Losses," Faculty of Electrical Engineering, University Teknologi MARA, Malaysia, unpublished.

[10] Timmis, J., "Artificial immune systems: today and tomorrow," Natural Computing 6(1), 1–18 (2007).

[11] Bernardino H.S and Helio J.C. Barbosa, "Artificial Immune Systems for Optimization,"

[12] Sabine Bachmayer, Gustaf Haellstroemin, "Artificial Immune Systems," Manuscript received in March 2007.