Using Clonal Selection Algorithm to Optimize the Control Parameter for Microgrid System

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***Abstract*—** This paper presents a controller which used for operation of Microgrid. Microgrid has two operation modes. First mode is grid connected and second mode is Islanding. During grid connected mode, DGs operates in PQ control mode. It means that DGs inject constant active and reactive power. In this mode the voltage and frequency of Microgrid are controlled with main grid. During Islanded mode, the Microgrid must be able to supply the loads and controlled the voltage and frequency of Microgrid in permissible range. The proposed controller has power and current control for regulating voltage and frequency and droop controller for power sharing between the parallel DG systems. In this research the control parameters are optimized by Clonal Selection Algorithm (CSA).

***Keywords*—** Microgrid, Distributed Generation (DG), Islanding, Droop, Power Sharing, Clonal Selection Algorithm.

INTRODUCTION

A microgrid is defined as an independent low or medium-voltage distribution network comprising various DGs, energy storages, and controllable loads that can be operated in two distinct modes: 1) grid-connected, 2) islanded (autonomous). In grid-connected mode, the DG usually operates in PQ (active-reactive power) control. This means the DG injects the active power available at its input into the grid and the reactive power injected corresponds to a prespecified value. In Islanding mode, the DG control will transit from PQ control to VF (voltage-frequency) control to regulate the voltage and frequency of autonomous microgrid.

The interconnection of distributed generators (DG) to the utility grid has raised concern about proper load sharing between different DG and the grid as well as the overall system stability. Concerning the interfacing of a microgrid to the utility system, it is important to achieve a proper load sharing by each of DG. A load sharing with minimal communication is the best in the distribution level as the network is complex. Active load sharing techniques such as centralized [1], master-slave [2], average load sharing [3] and circular chain control [4] are effective ways to achieve these objectives. But, due to their dependency on critical intercommunication lines among modules, these techniques could reduce system reliability and expendability [5].

The most attractive alternative is droop method. The droop method uses only local measurement and does not have a critical high bandwidth communication link among the DG units. Thus it achieves a higher reliability level and is flexible in terms of the physical location of the modules.

Several control techniques based on the droop method have been proposed in order to avoid using communication between DG units [6]–[8].

In this paper base on dynamic equation of system a control strategy for controlling the voltage and frequency of microgrid is proposed. A droop controller is added to share the active and reactive power of the loads in islanded mode.

MICROGRID AND CONTROLLER CONGIGURATION

In Figure1 a single-line diagram of a microgrid simulation model that includes inverter-interfaced DGs and loads is shown. The microgrid is connected to a 13.8kV feeder through an inter-tie breaker. The power system parameters are similar to [9] and [10], which were originally extracted from IEEE standard 399-1997 [11]. Various line connections and parameters are slightly modified The three inverter- interfaced DGs considered here have the same voltage and power ratings of 4.14kV and 2MW, respectively. Each DG has three-level VSI interface, which consists of IGBT bridges with 4 kHz PWM switching. DGs are connected to 13.8kV system through three-phase transformers. Three lumped load models represent sensitive loads. One of the loads is changed during the autonomous operation in order to test operating condition changes.

During grid connected mode, the voltage and frequency of microgrid is controlled by main grid and DGs inject the predefine power. When the microgrid is disconnected from main grid, DGs supply loads and regulate the frequency and voltage of microgrid. According to previous studies [12-15],

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droop controller is an effective method to coordinate the power generation between DG units, because they can immediately adjust the DG's output power and also do not for load power sharing between DGs. The droop equations are need instant communication between DGs. Two droop controllers, P-F and Q-V-droop controllers have been applied given as [18]:

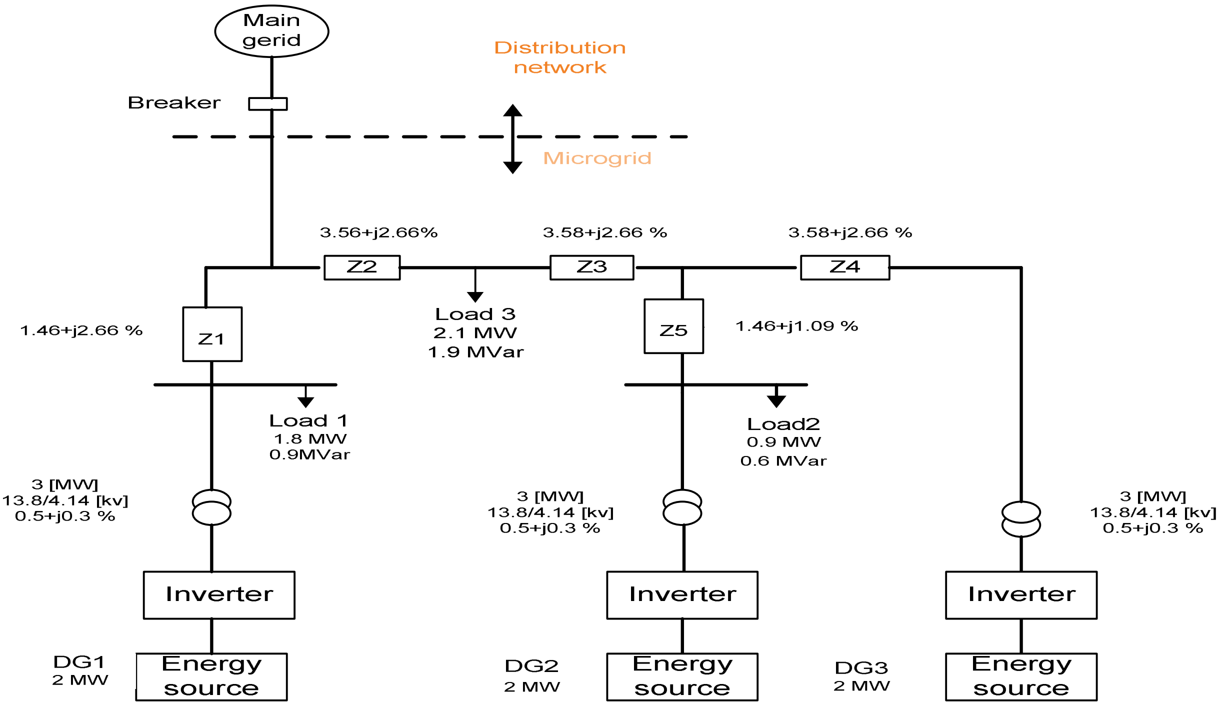

Fig. 1. Single Line Diagram of Microgrid

$$\begin{cases} P_i^* = P_{0i} + (f_0 + f_{loadref} - f)/M_i \\ Q_i^* = Q_{0i} + (V_{0i} + V_{loadref} - V_i)/N_i \end{cases} \qquad (1)$$

Where M_i and N_i are droop constants. P_i, Q_i, V_i and f are locally measured real and reactive power, bus rms voltages, and the system frequency. $f_{loadref}, V_{loadref}$ are the load reference signals of frequency and voltage, respectively. The subscript 0 represents the preset values of normal operating points. In most cases, fo and Vo should be the nominal values. Different settings of the droop constants can assign different power sharing between DG units.

Figure 2 shows the droop characteristic and Figure 3 shows the control block diagram of inverters. The droop controllers generate the references P*and Q* using droop characteristics. Since P and Q can be decoupled into d- and q-axis components in the rotating reference frame [16],[17], the reference inverter output currents (i_d^* and i_q^*) can be obtained using PI controllers whose gains are K_{pp} and T_{ip} Finally, the current controllers generate the inverter voltage references (V_d^* and V_q^*) considering the inverter output circuits.

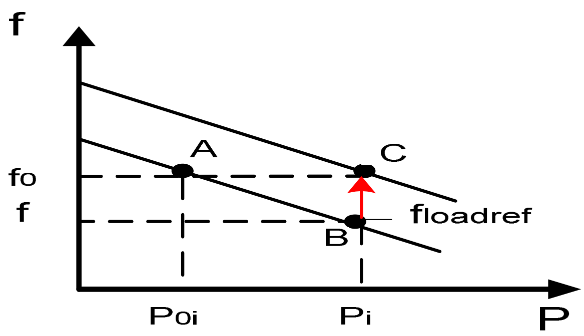

Fig. 1. Droop Characteristics[18]

The inverter output circuit including an inductor and a step-up transformer can be modeled as equivalent inductance (L_s) and impedance (R_s).Then, the circuit equations in the abc-reference frame are given by[18]:

$$\frac{d}{dt}\begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} = \frac{R_S}{L_S}\begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \frac{1}{L_s}\left(\begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix} - \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}\right) \qquad (2)$$

Where the subscript s and a-b-c represent the inverter output values and the values in the abc-reference frame, respectively. Applying the dq-transformation yields[18]:

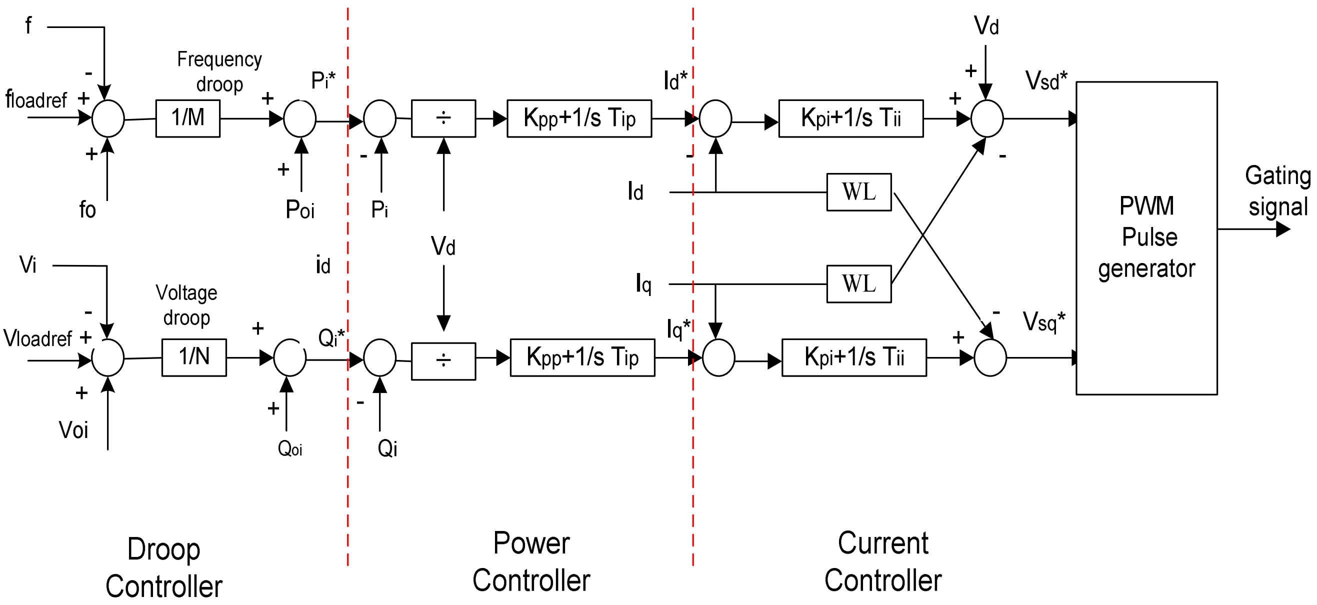

Fig. 2. Control Block Diagram for Interface Inverter[18]

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & W \\ -W & -\frac{R_s}{L_s} \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L_s}\left(\begin{bmatrix} V_{Sd} \\ V_{Sq} \end{bmatrix} - \begin{bmatrix} V_d \\ V_q \end{bmatrix}\right) \quad (3)$$

Where the abc-to-dq transformation is defined as [18]:

$$T = \frac{2}{3}\begin{pmatrix} Cos(\theta) & Cos(\theta - \frac{2\pi}{3}) & Cos(\theta + \frac{2\pi}{3}) \\ Sin(\theta) & Sin(\theta - \frac{2\pi}{3}) & Sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \quad (4)$$

and the synchronous rotating angle $\theta = W_S t + \theta_0$. Then, the current controller using PI controllers can be applied as [18]:

$$\begin{bmatrix} V_{0d}^* \\ V_{0q}^* \end{bmatrix} = \begin{bmatrix} -K_{pi} & -WL_S \\ -WL_S & -K_{pi} \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} -K_{pi} & 0 \\ 0 & -K_{pi} \end{bmatrix}\begin{bmatrix} i_d^* \\ i_q^* \end{bmatrix} + \begin{bmatrix} \frac{1}{T_{ii}} & 0 \\ 0 & \frac{1}{T_{ii}} \end{bmatrix}\begin{bmatrix} \chi_d \\ \chi_q \end{bmatrix} + \begin{bmatrix} V_d \\ 0 \end{bmatrix} \quad (5)$$

Where $\frac{d}{dt}\chi_d = i_d^* - i_d$ and $\frac{d}{dt}\chi_q = i_q^* - i_q$.

After applying the inverse dq-to-abc transformation, the voltage reference signals are converted to the PWM gating signals.

III. Control Parameter and Optimization

A) Control objectives and optimization methods

This research considers three objectives of microgrid control.

Control performance: DGs in the microgrid should efficiently control their output power in order to immediately match the load demand power in the Islanding mode.

Power quality: voltages and frequency of the microgrid should be maintained around their nominal values and variations in voltages and frequency must be kept within 0.1p.u and 0.016 p.u from the nominal values.

Stability and steady-state performance: transient responses must be acceptable and the steady-state error should be minimized. Each of DGs has six control parameters – two droop control gains and four PI gains such that

$$X = \left[M_{base}, N_{base}, K_{pi}, T_{ii}, K_{pp}, T_{ip}\right] \quad (6)$$

The actual frequency droop (M) gains are obtained by multiplying M_{base} by 0.05, 0.06, and 0.07. The voltage droop gains (N) are calculated by multiplying N_{base} by 0.02 for each DG. The multiplying numbers are chosen arbitrarily in order to implement variations in the real power sharing of DGs.

In this paper optimization of the control parameter of microgrid by using Clonal Selection Algorithm (CSA) is presented. These days, one of the most important issues that to be considered in all investigations, reviews of the control parameter of microgrid and usually trying to optimize it. It keeps all qualitative characteristics of search algorithms.

B) Clonal Selection Algorithm

The Clonal Selection theory proposed by Burnet is used to describe the basic features of an immune response to an antigenic stimulus [19]. According to this idea, only these cells proliferate that can recognize the antigen, thus are selected against those that do not [20]. Attracted by the biologic characters such as learning, memory and antibody diversity which are represented in the immune Clonal process, based on Clonal Selection theory some algorithms are proposed. This idea has been widely applied in some fields like intrusion detection [21], system control [22], optimization [23, 24], and etc.

Nevertheless, these algorithms founded on Clonal Selection mechanisms are few and simple.

The calculation consequences are ungratified after solving complicated problem. Clonal Selection is shown in figure4.

In this paper, the power loss and the voltage security founded on the analysis of immunology and theory of Clonal Selection and finally compare to the Genetic Algorithm will be discussed.

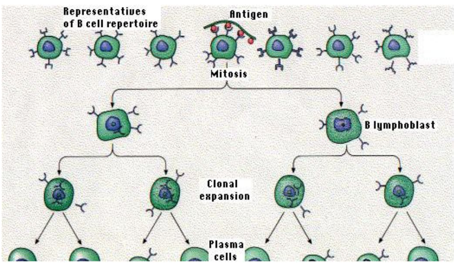

Fig. 4. Clonal Selection

The main idea of Clonal Selection theory lies in that antibodies can selectively react to the antigens, which are the native peptides on the cell surface. When exposed to antigens, the immune cells that recognize and eliminate the antigen presenting cells will be selected and arouse an effective response against them. This reaction leads clonally cell proliferation and the cells in colony have the same antibodies. Consequently, the process of Clonal Selection actually consists of three main steps: clone: descend a group of identical cells from a single common ancestor through asexual propagation. Mutation: gain higher affinity mainly through hyper mutation. [25]

Assuming the objective function and restraining conditions of optimization are the antigens invading the body and candidate solutions are antibodies recognizing antigens, then the process of optimization can be considered as the reaction between antigens and antibodies, and the affinity between the antigens and the antibodies are the matching degree between objective function and solutions. The optimization process includes two steps: first, the antibodies are gained, second, according to the Clonal Selection theory, the most capable antibodies are produced. The framework of clone selection optimization algorithms is shown in figure5 [26].

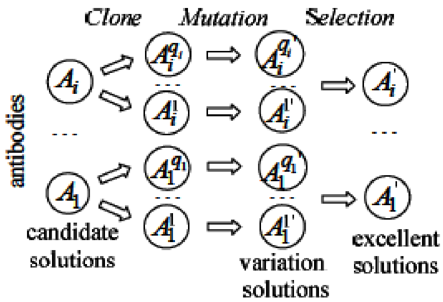

Fig. 5. Frame Work of CSA

The principle of Clonal Selection is a form of natural selection [27]. This describes the essential features which contain adequate diversity, discrimination of self and non-self and long-lasting immunologic memory.

The main idea of Clonal Selection theory lies in that the antibodies can selectively react to the antigens, which are the native production and spread on the cell surface in the form of peptides. When exposed to antigens, the immune cells that recognize and eliminate the antigens will be selected and arouse an effective response against them. The reaction leads to cell proliferating clonally and the colony has the same antibodies. Consequently, the process of Clonal Selection actually consists of three main steps: Clone: descend a group of identical cells from a single common ancestor through asexual propagation. Mutation: gain higher affinity mainly through hyper mutation [28]. Selection: select some excellent individuals from the sub-population generated by Clonal proliferation. Assuming the objective function and restraining conditions of optimization are the antigens invading the body and candidate solutions are the antibodies recognizing antigens, then the process of optimization can be considered as the reaction between antigens and antibodies, and the affinity between the antigens and the antibodies are the matching degree between objective function and solutions.

In this section, the proposed Clonal Selection Algorithm is presented and analyzed. Figure6 shows the flowchart of the proposed algorithm. Generally, the proposed model can be described as follows:

Step1. Initialize the population of antibodies that is, creating an initial pool of m antibodies randomly (candidate solutions $(Ab_1, Ab_2, ..., Ab_m)$).

Step2. Compute the affinity of all antibodies $(A(Ab_1), A(Ab_2), ..., A(Ab_m))$, where A(.) is the function to compute the affinity.

Step3. Select the n (n < m) best (fittest) individuals based on their affinities from the m original antibodies. These antibodies will be referred to as the elites.

Step4. Place each of the n selected elites in n separate and distinct pools in a descending order of the affinity $(Ab_1, Ab_2, ..., Ab_n))$. They will be referred to as the elite pools.

Step5. Clone the elites in each elite pool with a rate proportional to its fitness, i.e., the fitter the antibody, the more clones it will have. The amount of clone generated for these antibodies is given by:

$$P_i = \text{round}\left(\left(\frac{n-i}{n}\right)\times Q\right) \qquad (7)$$

Q determines the scope of the clone and round (.) is the operator that rounds its argument towards the closest integer. After this step, we can obtain $\sum P_i$ antibodies just as:

$(Ab_{1,1}, Ab_{1,2}, ..., Ab_{1,P_1}; ...; Ab_{n,1}, Ab_{n,2}, ..., Ab_{n,p_n})$.

Step6. Subject the clones in each pool through either hyper mutation or receiver editing processes. Some of the clones in each elite pool undergo the hyper mutation process and the remainders of the clones pass the receiver editing process. The mutation number (P_{hm} and P_{re} for hyper mutation and receptor editing, respectively) are defined as follows:

$$P_{hm} = \mu . p_i \qquad (8)$$

$$P_{re} = (1-\mu).P_i \qquad (9)$$

In our prior work [29], we had demonstrated that an equivalent level of P_{hm} : P_{re}, that is, μ = 0.5 will lead the CSA algorithm to a better performance. After this step, we obtain $\sum P_i$ mutated antibodies just as:

$(Ab'_{1,1}, Ab'_{1,2}, ..., Ab'_{1,P_1}; ...; Ab'_{n,1}, Ab'_{n,2}, ..., Ab'_{n,p_n})$.

step7. All of the mutated antibodies enter into a reselect process where the mutated ones $Ab'_{i,j}$ are judged to compare with their parent antibody $Ab_{i,j}$ according to the following updating rule:

$$\begin{cases} Ab''_{i,j} = Ab_{i,j} & \text{if } A(Ab_{i,j}) > (Ab'_{i,j}) \\ Ab''_{i,j} = Ab'_{i,j} & \text{if } A(Ab_{i,j}) \le (Ab'_{i,j}) \end{cases} \qquad (10)$$

Then we can obtain $\sum P_i$ updated antibodies just as

$(Ab''_{1,1}, Ab''_{1,2}, ..., Ab''_{1,P_1}; ...; Ab''_{n,1}, Ab''_{n,2}, ..., Ab''_{n,p_n})$.

Step8. Determine the fittest individual B_i $(A(B_i) = \max\{(Ab''_{i,1}, Ab''_{i,2}, ..., Ab''_{i,P1})\}, i=1,2,...,n$ in each elite pool from amongst its updated clones.

Step9. The n antibodies $(B_1, B_2, ..., B_n)$ are subjected to the apoptosis process in a descending order. The best m antibodies can survive and enter into the elite pools; the rest n-m antibodies are eliminated.

Step10. Replace the worst c (η = c/m) elite pools with new random antibodies earned once every k generations. It is interesting to point out that this step was expected to preserve the diversity and preserve the search from being trapped in local optima in CSA.

Step11. Determine if the maximum number of generation G_{max} to evolve is reached. If it is terminate and return the best antibody, if it is not, go to step 4.

Hyper mutation and receptor correcting play complementary roles in the act of affinity maturation. Hyper mutations allow the immune system to investigate the local area by making small variations and receiver accurately offers the ability to run away from local minima.

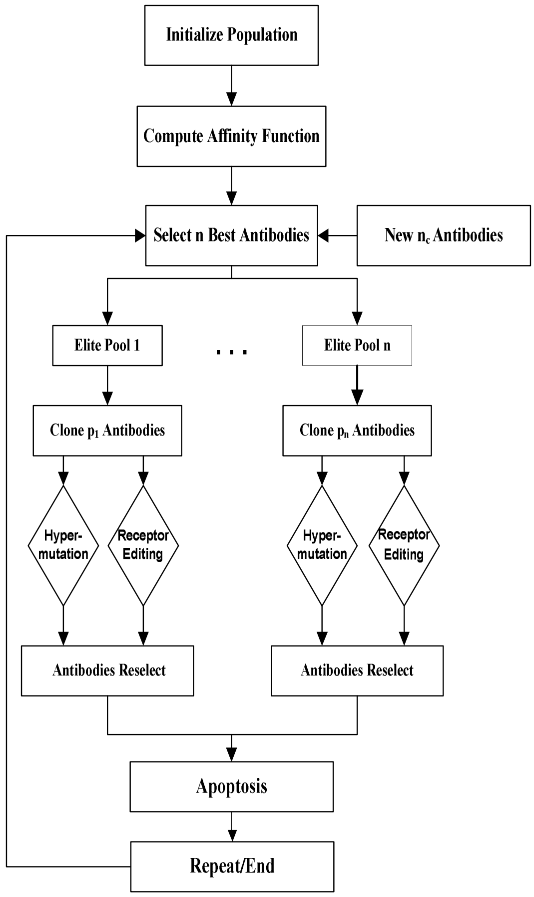

Fig. 6. Flowchart of Clonal Selection Algorithm

c) Application to control parameter tuning

The fitness of the particles is evaluated by a cost function, which returns a scalar value evaluating the position of a particle. The cost function should exhibit the relevant alterations in cost according to the position in the solution space because it is the only means of evaluating the physical system and it parameter solution space in the optimization process.

For evaluating control performance of the microgrid according to the previously mentioned objectives, the cost function (J) in the form of the integral of time-weighted absolute error (ITAE) can be defined as [18]:

$$J = \sum_{k=k_0}^{T_0} (k-k_0).\ W.\ E_{abs}(k) + \sum_{i=1,2} c_i.\gamma_i \qquad (11)$$

The first term of (11) is to evaluate control performance where k is the current sample time; ko and Tc are the starting time of load change in the autonomous operation and the end time of calculation. The second term is the penalty function to penalize voltage and frequency limit violations where i is the constraint index (1 for voltage violation and 2 for frequency violation); c_i is a penalty constant set to 1,000; γ_i is the constraint violation index, which equals to 1 if the constraint i is violated and 0 otherwise. The constraints are the voltage and frequency boundaries of 0.1 p.u. and 0.016 p.u., respectively. The absolute error vector is defined as [18]:

$$E_{abs}(k) = \left[\left| P_i^{new} - P_i(k) \right|, \left| 1 - V_a(k) \right|, \left| 1 - f(k) \right| \right]^T \qquad (12)$$

where P_i^{new} and $P_i(k)$ are the amount of power demand after load change and the measured power, respectively; $V_a(k)$ is the average of rms voltages; $f(k)$ is the measured frequency. W is the 1-by-3 weighting matrix, whose elements are all set to 1.0. The final optimal solution should provide optimal load following performance, maintain the voltages and frequency in the microgrid near the nominal values, and strictly keep them within the limits. In addition, since the cost function is weighted by time, the solution can have good steady-state performance.

IV. Simulation Studies

The system shown in Figure1 was implemented using MATLAB/SIMULINK. The simulation model and the Clonal Selection Algorithm (CSA) were developed based on the following thoughts. First, six control parameters are defined for optimization as $\left[M_{base}, N_{base}, K_{pi}, T_{ii}, K_{pp}, T_{ip}\right]$ based on the assumption that three DGs have identical configuration, ratings, and PI controllers and the DGs can operate with the same PI gains Kpi, Tii, Kpp, and Tip for simplification. The cost has been minimized to 19.94 in 585 iterations. The final optimal parameters are shown in table I:

TABLE I
PARAMETERS OPTIMAL VALUE

Parameter	**Optimal value**
Rbase	0.19867
Mbase	1.84357
Kpi	0.14498
Tii	2.10034
Kpp	9.45612
Tip	0.014123

0.0 sec: main grid supplies the loads so that the system is initially stabilized and all the voltages and frequency can be maintained near the nominal values.

0.25 sec: the DGs are connected to the grid and start generating power in the grid-connected mode. The output power references for DGs are set to PDG1 = 1.6 MW, PDG2 = 1.4 MW, PDG3= 1.2 MW, QDG1 = 1 MVar, QDG2 = 0.8 MVar, and QDG3 = 0.6MVar.

3.0 sec: the load reference signals for restoration of voltage and frequency are sent to DGs.

4.0 sec: load 3 changes to 1.6MW and 0.5MVar.

V. Simulation Results

Real and reactive power values extracted from simulation are presented in table II. Initially main grid supply all of loads in microgrid. At t=0.25s, DGs are connected and they inject preset active and reactive power (P/Q control mode). At t=2s, islanding occurred and microgrid is disconnected from main grid. Hence, DGs must supply all of microgrid loads. The power sharing between DGs is based on the droop control. Since all of the DGs have same droop constants, load change equally share between DGs. At t=4s, load3 is changes and output power of DGs is changes base droop control.

System frequencies are presented in table III. Frequency of islanded microgrid can be maintained within ±0.016 p.u (1.0Hz) from the nominal value.

VI. CONCLUSION

In this paper base on dynamic equation of system a control strategy for controlling the voltage and frequency of microgrid is proposed. A droop controller is added to share the active and reactive power of the loads in islanded mode. Clonal Selection Algorithm (CSA) is used for optimization of controller parameters. Simulation results verify the control performance of the DGs optimized by the CSA.

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TABLE II
ACTIVE AND REACTIVE POWER GENERATED BY DGS AND SUPPLIED BY MAIN GRID

Output powers	Time	T=0	T=0.25	T=2	T=4
Main grid	P(MW)	0	1.6	1.8	1.6
	Q(MVar)	0	0.5	0.7	0.6
DG1	P(MW)	0	1.4	1.6	1.4
	Q(MVar)	0	0.4	0.6	0.5
DG2	P(MW)	0	1.2	1.4	1.2
	Q(MVar)	0	0.3	0.5	0.4
DG3	P(MW)	4.8	0.6	0	0
	Q(MVar)	1.9	0.7	0	0

TABLE III
SYSTEM FREQUENCY

t	0<t<2	2<t<3	3<t<4	4<t<5
frequency	60 HZ	60.13	59.96	60.08

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