International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 / https://doi.org/10.14445/22315381/IJETT-V70I4P202

Volume 70 Issue 4, 15-20, April 2022

Original Article

Voltage Regulation in an Islanded Microgrid using a GA-based Optimization Technique

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Received: 18 February 2022 Revised: 24 March 2022 Accepted: 26 March 2022 Published: 26 April 2022

Abstract - *The power industry is undergoing significant changes due to apprehensions about traditional energy prices and greenhouse emissions due to the use of fossil fuels. As a solution, numbers of Distributed Energy Resources (DERs) are connected to the grid. Accumulation loads and DERs constitute a microgrid as a small-scale grid compared to a conventional grid. In a conventional grid, regulation of voltage and frequency are controlled by the speed variation of alternators interconnected to the grid. As the usage of DERs in power networks grows, additional challenges emerge, like the frequency and voltage regulation problems. However, the voltage and frequency must be regulated independently of the main grid if the microgrid is detached from the main utility grid. In this paper, the deviation in voltage is regulated by utilizing a Genetic algorithm (GA) to optimize the droop coefficients. The work is carried out for various loads to regulate voltage variation and reactive power-sharing, and the responses are presented. The results for voltage deviations with and without GA optimizations are also presented.*

Keywords - *Distributed energy sources, Autonomous microgrid, Genetic algorithm, Voltage control, Reactive power-sharing.*

1. Introduction

With distributed energy sources (DERs) and advancements in power electronics (PE) devices, the microgrid concept is becoming a viable option. Microgrids are made up of loads, distributed generation (DER) sources, and energy storage devices to deliver dependable power. Most DER sources are connected to the distribution via a Voltage Source Inverter (VSI) that uses modulation techniques like the Sinusoidal Pulse Width Modulation (SPWM) technique.

The microgrid should operate in two modes:

- Grid integrated operation mode
- Islanding operation mode

The microgrid is connected to a power system network at a connection point known as the "Point of Common Coupling (PCC)" in the grid integrated mode. It facilitates the microgrid to operate at a constant frequency and voltage and allows electricity to be exchanged between the microgrid and the host power supply. In grid-connected mode, the microgrid controls the supplied active and reactive power generated by the DERs to meet the load need. In an islanded microgrid, where electricity is generated locally, independent control is necessary for voltage and frequency, which is difficult to achieve because power balancing necessitates the deployment of precise load sharing mechanisms [1]. Local controllers or central controllers can use a variety of control mechanisms to balance the power. Under any operating scenario, microgrid controllers are primarily responsible for

- Voltage and frequency regulation
- To ensure proper power distribution in both modes.
- A smooth transition between the two modes

Control systems at DER units take directions from the microgrid's central controller in the centralized approach, requiring considerable communication. For isolated microgrids, the centralized solution has technical and cost limitations. Concentrated control, master/slave control, and dispersed control are some of the centralized control systems. The self-contained operation of the microgrid, which includes a significant number of PEs, gives rise to technological problems in microgrid performance. For example, there may be issues arising in load sharing, harmonics, and voltage and frequency regulation in an islanded microgrid operation and control. To improve steady operation, new control has to be developed. With no advantages, droop control seems to be the most commonly adopted control approach in parallel DERs. The DER units are managed by local information in a decentralized fashion. The droop principle underpins the decentralized approaches.

Droop controllers aid in determining the microgrid's frequency and voltage based on local power readings [2-5]. This is a desirable technique for controlling many inverters in parallel [6].

As observed in a typical power system, the concept of power balance in alternators inspired this control approach. The alternators compensate for the rapid increase in load by lowering the frequency following the droop characteristics. Furthermore, the reactive power is shared amongst the DERs based on the voltage droop characteristic. The droop control is implemented in the primary control of the inverters in the islanded mode of operation. The output voltage and frequency of VSI-based DER devices will fluctuate according to the droop characteristics; however, when the load changes [7-10], the droop coefficients must be properly determined to keep the voltage and frequency within the acceptable range. To determine the same, optimization approaches based on natural selection, such as Swarm intelligence techniques, which provide quick and effective answers, can be applied. Swarm intelligence is a form of artificial intelligence technology that mimics the coordinated behaviour of swarms in nature [11, 12]. In [13-15], some of the swarm intelligence algorithms like “Genetic Algorithm (GA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), Differential Evolution (DE), Artificial Bee Colony (ABC), Grey Wolf, Grasshopper, Cuckoo Search Algorithm (CSA)” are listed. This article adopts the GA-based droop control technique, and the working procedure is explained in the subsequent section.

The GA is a search and optimization algorithm that mimics natural selection, evolution, and genetics. It generates optimal and almost optimal solutions from which the best one can be chosen. Droop coefficients for voltage regulation using GA are evaluated in this paper. The paper is structured into the subsequent sections: Section II dictates the proposed control approach. In Section III, the Genetic Algorithm (GA) is described. In Section IV, the responses of the SIMULINK are reported. The conclusion is given in Section V.

2. System Model for Proposed Control Technique

This section describes the suggested technique for an islanded microgrid, consisting of two inverters interconnected DER sources connected in parallel. The schematic diagram is shown in Fig. 1. Two three-phase inverters are included, a power controller, a voltage controller, and a current controller. The inverters' switching signals are generated using the SPWM technique. The power controller is built on the droop characteristics to determine active and reactive power. The optimal droop coefficient values are found using the Genetic algorithm. Traditional PI controllers are used to implement current and voltage controllers. The voltage controller provides the reference current for the filter inductor, and the current controller generates the command voltage for PWM signal generation.

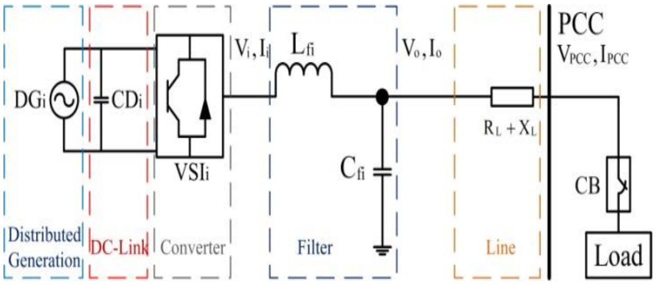

Fig. 1 Block diagram of two inverter-interfaced DER sources in islanded mode

The envisioned control approach for an islanded/autonomous microgrid is shown in Fig. 2. Equations (1) and (2) give the instantaneous active and reactive powers.

$$\tilde{p} = v_{od} i_{od} + v_{oq} i_{oq} \tag{1}$$

$$\tilde{q} = v_{od} i_{oq} - v_{oq} i_{od} \tag{2}$$

where,

v_{od}= Inverter voltage in d axis frame

i_{od}= Inverter current in d axis frame

The equations for evaluation of active and reactive powers corresponding to basic component are given in (3) and (4) as follows [16-18]:

$$P = \frac{\omega_c}{(s+\omega_c)} * \tilde{p} \tag{3}$$

$$Q = \frac{\omega_c}{(s+\omega_c)} * \tilde{q} \tag{4}$$

ω_c = Cut-off frequency of low pass filter used in the power controller block.

The voltage is set according to droop gain n_q given by equation (5)

$$V^* = V_{dn} - n_q Q \tag{5}$$

Where V_{dn} = Nominal frequency, $n_q = \Delta V / \Delta Q$. ΔV is the change in voltage, and ΔQ is the change in reactive power. Additionally, an optimal droop controller can be constructed to share active power among DERs, although this is beyond the scope of this paper.

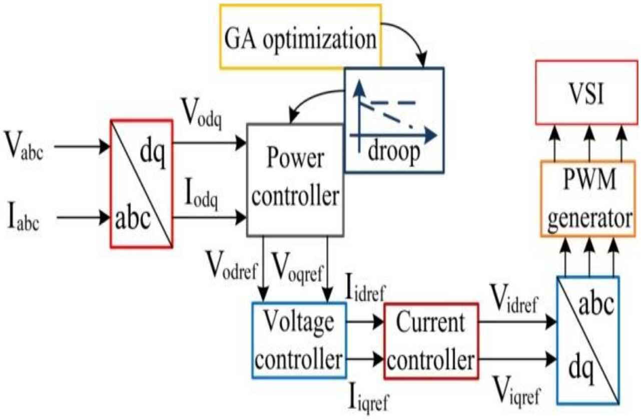

Fig. 2 Proposed control strategy for the autonomous microgrid

3. Optimization Algorithm

By maximizing or minimizing the objective functions, optimization is finding the best optimal solutions among all potential solutions. A genetic algorithm is one such optimization strategy that provides the best possible optimum values. This search-based algorithm is motivated by natural selection, Evolution and Genetics. Here the population of individual solutions is repeatedly modified. The genetic algorithm selects parents randomly from the present population for the next generation's offspring at each step. Over generations, the population "evolves" toward the optimal solution. To summarise, the genetic algorithm uses three steps to create the next generation from the existing population.

First, the selection rules determine which individuals, known as parents, will contribute to the next generation's population. Second, crossover rules combine the offspring of both parents to create the next generation, whereas mutation rules make random changes to individual parents to create offspring [19]. The basic structure of GA is depicted in Fig. 3 below.

The population is first initialized, and then the fittest individuals (parents) are chosen. Crossover and mutation on the parents are used to create new generations of offspring. Those who survive among the best progress to the termination point, where they are subsequently optimized. When the best survivor offspring are not chosen, the loop process repeats itself, and control shifts to the fitness function calculation phase. Much iteration is used to process the termination and best return values, and the best values are returned. Whenever there is a change in the load voltage, deviation may occur. This deviation in voltage should be within the nominal range. GA is employed to optimize the reactive droop coefficients to regulate the voltage.

The objective function (OF) that has to be minimized is the voltage deviation given in equation (6).

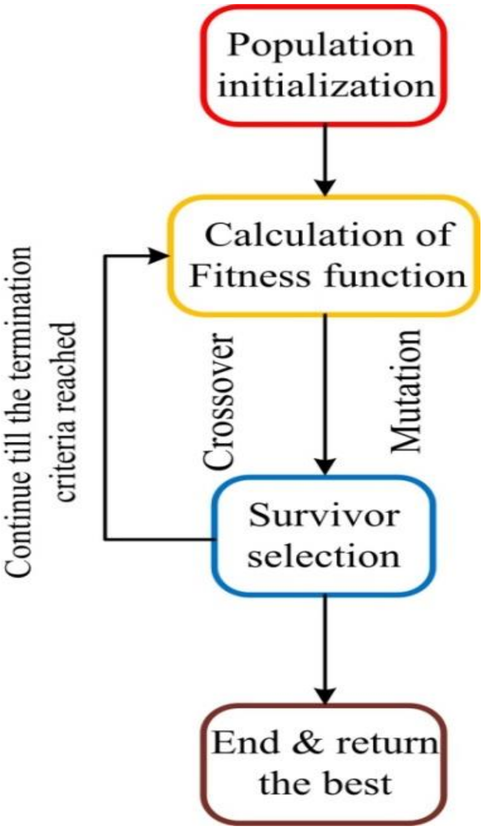

Fig. 3 Basic Structure for GA optimization algorithm

$$OF=min(\Delta V) \tag{6}$$

The voltage of microgrid and reactive power share between two DERs connected in parallel for load change in an autonomous mode of operation should satisfy equation (7)

$$\frac{\Delta V}{n_{q1}}+\frac{\Delta V}{n_{q2}}=\Delta Q_{load} \tag{7}$$

Where ΔV is the voltage deviation of the microgrid during load change, nq1 is the reactive droop coefficient of DER1 and nq2 is the reactive droop coefficient of DER2 [20-24].

From equation (7), the relationship between voltage deviation and reactive droop coefficients is given in equation (8).

$$\Delta V=\frac{n_{q1}*n_{q2}}{n_{q1}+n_{q2}}*\Delta Q_{load} \tag{8}$$

.

4. Result and Discussion

Table 1 lists the system model parameters considered for this study. The MATLAB/SIMULINK model for simulation is depicted in Fig. 4. It consists of two DERs that are connected in parallel. The two DERs are considered to be of identical ratings. Each DER consists of a DC, voltage source inverter and a filter. AS EXPLAINED IN SECTION II, the PWM signals for the inverter switches are generated.

Table 1. Model specification

Element	Specification	Value
DER1 &DER2	DC-link voltage	800V
	Inverter Filter inductance	20mH
	Inverter Filter Capacitance	500µH
Voltage controller	Proportional voltage gain (K_{pv})	0.05
	Integral voltage gain (K_{iv})	390
Current controller	Proportional current gain (K_{pi})	10.5
	Integral current gain (K_{ii})	16000

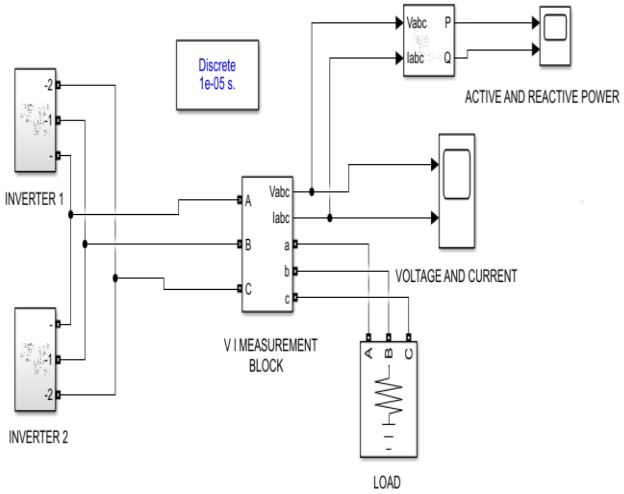

Fig. 4 Simulation model of the system

At time t=0.3 seconds, the load is changed. The optimized value of the reactive droop coefficients obtained using GA when there is load change is used in the power controller block. Simulation is carried out for various loads (linear and non-linear). The DERs' reactive power and voltage for various loads are presented.

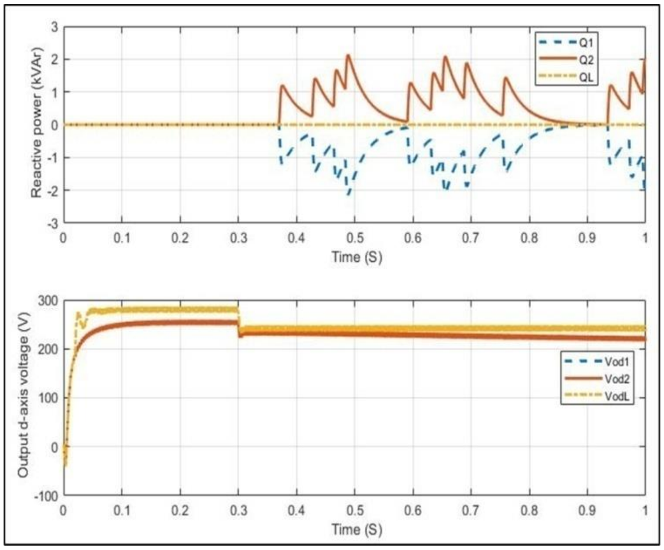

Fig. 5 DER$_1$, DER$_2$ reactive power in kVAr and output d-axis voltage in volts for R load with step in load at 0.3 s

Fig. 5 shows the Reactive power and d-axis voltage of the two DERs for a Resistive load. It is very evident from the graph that reactive power is 0, and the voltage is well within the nominal range.

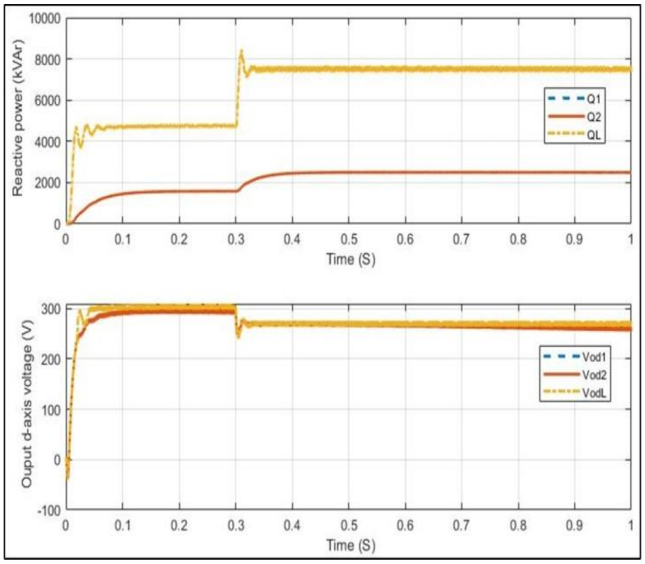

Fig. 6 DER$_1$, DER$_2$ reactive power in kVAr and output d-axis voltage in volts for RL load with step in load at 0.3 s.

DER1 and DER2 reactive power for resistive-inductive (RL load) are shown in Fig.6. It is obvious from the Figure that the voltage deviation is not very significant and does not cross the boundaries even after the change in the load at 0.3s

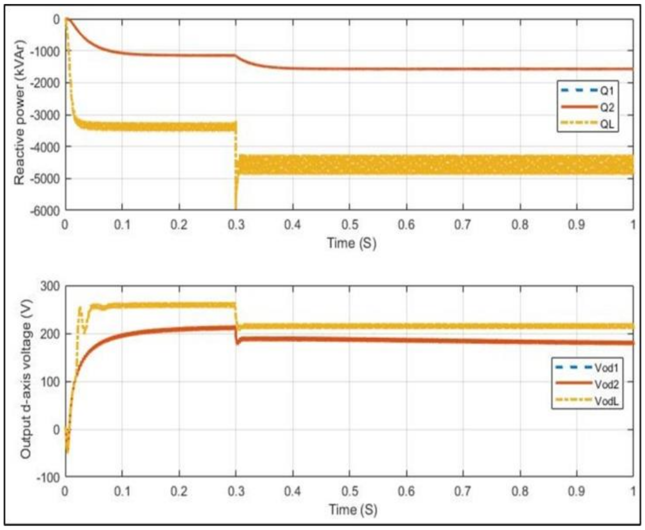

Fig. 7 DER$_1$, DER$_2$ reactive power in kVAr and output d-axis voltage in volts for RC load with step in load at 0.3 s

For resistive –capacitive (RC load), the DER1 and DER2 reactive power and voltage are presented in Fig.7. Variation in voltage for a change in the load is within the permissible limits.

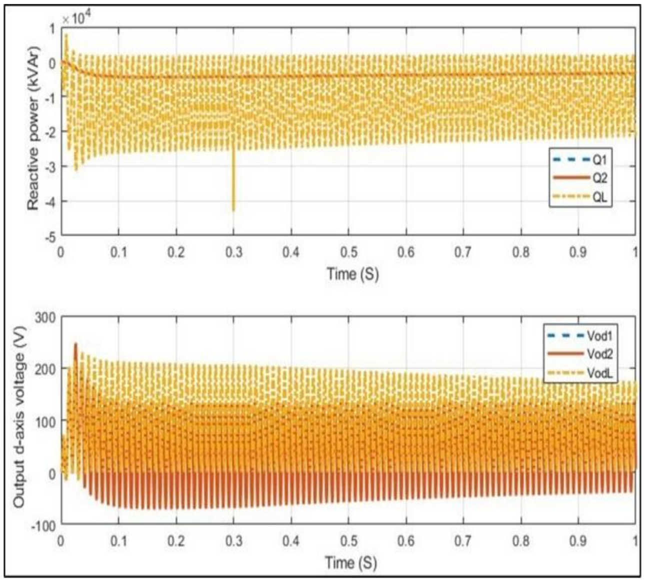

Fig. 8 DER$_1$, DER$_2$ reactive power in kVAr and output d-axis voltage in volts for a rectifier load with step in load at 0.3 s

Simulation results are shown in Fig. 8 for a non-linear load (rectifier). The voltage deviation is observed to be well within the nominal range when the load changes.

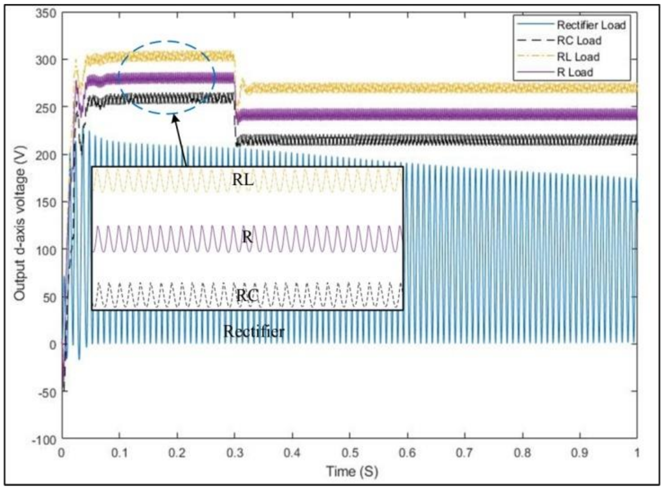

Fig. 9 Output d-axis voltage for R, RL, RC and Rectifier load in volts with step in load at 0.3 s

Fig. 9 shows the exaggerated view of the d axis voltage for the different types of loads. The deviation in voltage is negligible with the implementation of GA.

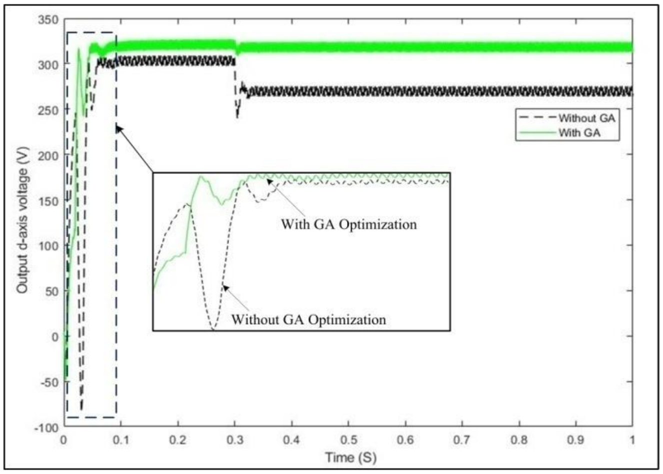

Fig. 10 DER$_1$, DER$_2$, and Load reactive power in kVAr and output d-axis voltage in volts with step in load at 0.3 s

With the implementation of GA, the change in voltage for a change in the load happens very quickly, whereas, with GA, the change happens drastically. From this, it is clear that the controller's response is better with GA.

5. Conclusion

Voltage and frequency are key factors influencing the microgrid's power supply dependability and quality. A genetic algorithm-based optimization approach for a droop-controlled islanded microgrid has been implemented. For every sudden change in load, the droop coefficients are optimized so that the voltage variation is within the permitted range. Simulation results support the validity of this optimization. The voltage variation is well within the nominal range for various linear (resistive) and non-linear loads (inductive, capacitive and rectifier) under test. The control method proposed in this paper for an autonomous microgrid proves reliable power delivery in remote places.

Nomenclature

OF : Objective function
n_q : Voltage droop coefficient
ΔV : Voltage deviation in Volts
C_D : DC-link capacitor in Farad
V_{od} : Output d-axis voltage in Volts
I_{od} : Output d-axis current in Amperes
f : Frequency in Hertz
ω : Angular frequency in radians
ω_c : Filter cut-off frequency in radians
R_L : Line resistance in Ω
X_L : Line reactance in Ω
Q : Reactive power in kVAr
P : Active power in kW
Q_{Load} : Load reactive power in kVAr
P_{Load} : Load active power in kW
$\tilde{p}$: Instantaneous-active power in kW
$\tilde{q}$: Instantaneous-reactive power in kVAr

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