



Optimal Voltage Control Technique Using Optimized PI Controller for the Stability of Islanded Microgrid System

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ABSTRACT

The voltage deviation challenge associated with Islanded microgrid system terminal voltage usually impacts negatively on the stability of the Islanded microgrid. This occurs as a result of load variation conditions and the intermittency nature of distributed generation (DG) in the Islanded MG. To curtail this effect and ensure the stability of the system for power quality improvement, an optimal voltage control technique can be employed to minimize this drawback on Islanded microgrid operations. This study utilized the Sine Cosine algorithm (SCA) to optimize the control gains of the PI controller for voltage deviation minimization in an Islanded microgrid. The SCA technique was implemented on modelled Islanded microgrid with two parallel-connected inverters. Stability analysis was carried out on the Islanded microgrid and voltage deviation, overshoot, settling time, and rise time was used as performance metrics. The simulation results that emerged from the MATLAB/Simulink are compared to the PSO technique established in the literature. The results reveal that the SCA optimized PI controller has achieved a voltage overshoot improvement of 21.6%. The results indicate that SCA optimized PI controller outperformed the PSO reported in the literature.

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INTRODUCTION

The ever increasing demand for electricity occasioned by population growth and advancement in technological-industrial utilization of electricity to meet load demands world all over has greatly impacted on the existing conventional grids. More concerned in this power poverty are the developing nations. To improve the availability of electricity for larger percentage of the population then the idea of distributed generations (DGs) integration into the ever stressful distribution networks is considered. DG is an electric power source that can be supplied directly to the distribution network or on customer site of the meter (Paul & Timothy, 2015). DGs are different types of renewable resources that generates electricity independence of the main grid for isolated community. The determination to pursuit for an improved and stable power supply that is lacking in the existing bulk power grid, and exploit technology advancement in power electronic converter, the concept of MG has emerged at the inception of this century (Lasseter, 2002). The microgrid concept is considered as a promising technique to

coordinate different types of distributed energy sources effectively and brings electricity more closely to the consumers. The MG do enables the DGs to work in an Islanded system, and therefore improves the provision of electricity to remote communities.

Thus, when the Islanded MG is subject to load variation condition, the voltage output tends to become unstable and affect the power quality of the system. This study considered minimization of voltage deviation in the Islanded MG in order to improve voltage stability in the MG. Voltage deviation can be defined as the difference between the nominal voltage and the actual voltage, the smaller the deviation of bus voltage from the nominal voltage, the better the voltage condition of the system (Le *et al.*, 2007). In MG, additional power electronic equipment are connected with the DG units, this equally makes the Islanded MG and its control different to the traditional power electronics (Maniza *et al.*, 2018) When a MG is operating in the Islanded mode each DG unit should be able to supply its share of the total load in proportion to its rating. To realize this, different control techniques that



mimic the behavior of synchronous machines in main utility power systems are widely adopted in the literature. This study considered two units of DGs, and two parallel-connected inverters as components in Islanded MG system.

Many researchers have conducted studies on voltage control because of its significant role in MG power stability. Many research works have been reported on different voltage control techniques for the purpose of minimizing voltage deviation in islanded MG and improve stability (Elkhatib *et al.*, 2011; Elkhatib *et al.*, 2012; Nasirian *et al.*, 2014; Olivier *et al.*, 2015). Different control schemes have been employed by researchers to ensure proper control of the MG. A distributed control technique was evoked which focuses on the MG control (Yazdani & Mehrizi, 2014). Distributed and decentralized methods offered a robust and flexible control of the islanded MG with limited communication and have advantage of not been affected by fault in the communication line (Olfati *et al.*, 2007). Communication-oriented power control are effective in power sharing and voltage regulation no case of single point of failure, but required high capital for the communication's infrastructure. Many similar research works on voltage control have been reported (Ghosh *et al.*, 2016; Kim *et al.*, 2012; Kulmala *et al.*, 2014). Particle Swarm Optimization is used to obtain optimal parameters of a controller by minimization of the error in the current and voltage controller. however, the drawback in this algorithm is that it have problem of uncertainty in its parameters selection, trapping into local minimum in high-dimensional space and suffer low convergence which affect the performance and stability of the islanded MG (Dharmawardena *et al.*, 2018). The major setback in this algorithm, includes the time consumed toward performing the control action, as such it may result in a delay while entering an unstable region of the operation (Šulc *et al.*, 2014). Droop control was employed for regulating frequency, ensure active and reactive powers flow control and obtain good power sharing without use of communication (Han *et al.*, 2015). The droop control scheme employed in hierarchical control result in poor transient response because of real and reactive power coupling (Han *et al.*, 2016). A

PI controller is use to compensate for the voltage and frequency deviation caused by droop control. Also, a steep droop curve ensure better power sharing although it causes voltage and frequency deviations (He & Li, 2012).

The voltage control challenge in the Islanded microgrid system constitutes severe drawback in assuring power quality, reliability and stability of the islanded microgrid. The load variation condition usually experienced during the operation of Islanded microgrid caused voltage deviation in the Islanded microgrid. This subsequently affects microgrid stability and reduced power quality of the system. However, the conventional method of voltage regulation is not prompt enough to addressing the problem of voltage deviation, because the operation of devices are mechanically oriented and also constitute a financial burden as regard to installation and maintenance of the equipment. This study focused on minimization of this voltage deviation in Islanded microgrid, it utilized SCA optimization technique and optimized the control gains (K_{PV} and K_{IV}) of the PI controller. Overshoot, settling time, and rise time were used as performance metrics. Mean square error used for minimizing error signal as objective function in this research achieved a minimum voltage deviation compared to one presented in (Kamarposhti, 2018)

METHODOLOGY

The methodology employed for modelling of Islanded microgrid and the voltage control technique for optimal voltage control are outlined as follows.

1. Modeled an Islanded MG system with two parallel-connected inverters on MATLAB/Simulink environment.
 - i. Development of two parallel-connected inverters on the MATLAB/Simulink environment.
 - ii. Controlling the Islanded MG system with PI controller
2. Implementation of SCA-based technique in (1) and optimized the gains (K_{PV} and K_{IV}) of the PI controller through simulation in MATLAB/Simulink environment, the following steps were followed:
 - i. Initializing the set of search agents (control gains X).

- ii. Evaluating the value of each of the search agents by the objective function subject to its constraints.
 - iii. Save the best solution obtained at moment, assigns it as final tip ($p=X^*$) then update the other solutions with respect to it.
 - iv. Also update the sine and cosine function ranges r_1 , r_2 , r_3 and r_4 to emphasize search space development while iteration progresses.
 - iv. Observe the termination criteria: in this work SCA stops the optimization process when the iteration counter is higher than upper limit number of iterations, best solutions are obtained if condition satisfied.
 - v. Otherwise update the status of search agents using equation (2.27) and return to step (ii).
3. Compared the results obtained in (2) with the PSO based technique applied in

(Kamarposhti, 2018) using voltage deviation as performance metric.

Modeling of Isolated Microgrid

Modeling of Isolated MG system comprising some distributed generation, and other components that made up the MG, such as voltage source inverters, output filter and loads as outlined in Figure 2, was developed in MATLAB/Simulink environment. The isolated MG constitute two DGs which are considered in this study to be DC source, given the fact that most renewable energy sources such as wind, solar, hydro, energy storage system are considered as DC source after they undergone rectifications. Individual DG unit is connected to the load via an inverter, LC filter and coupling inductor. The Figure 2, is flowchart used in modeling of Isolated microgrid with two parallel connected inverters. The parameters used was adopted in ((Kamarposhti, 2018).

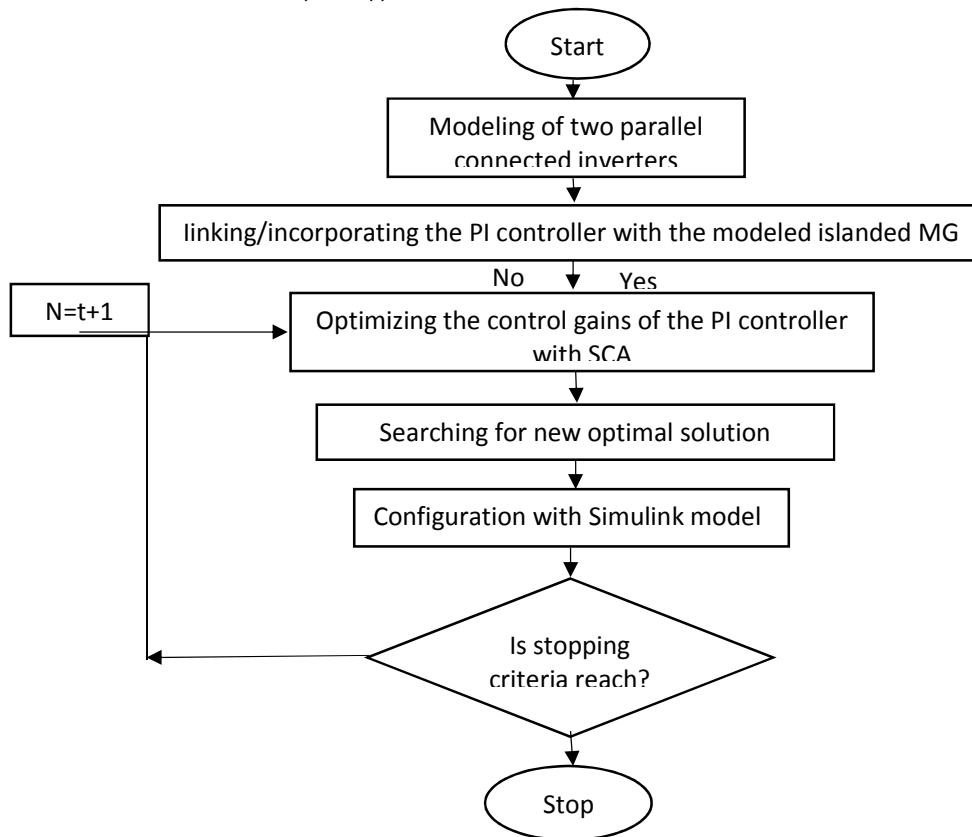


Figure 2. Flowchart for modeling Isolated microgrid

Table 1: Parameters of Islanded MG (Kamarposhti, 2018)

Parameters	Value
DC-link Voltage	580V
Inverter filter inductance	1mH
capacitance	50 μ F
Inverter switching frequency	8KHz
S _{rate}	10KVA
M	6.25e-5
N	1.83e-3
W _n	50Hz
V _n	220V
Z ₁ and Z ₂	j0.4 Ω
Load	6KW
RMS line voltage	220 $\sqrt{3}$

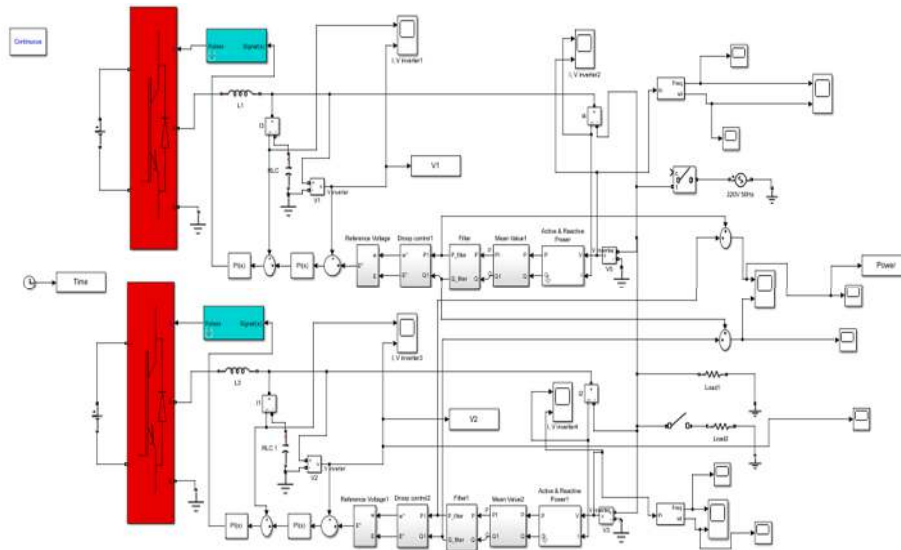


Figure 3. Modeled Islanded Micro-grid on the MATLAB/Simulink environment.

Objective Function

The voltage control is considered as an optimization problem with the objective of minimizing the mean squared error (MSE). In this paper, MSE was used as voltage deviation index, the objective function is given as;

$$\min J = V_d = \sum_{i=1}^{NL} (V_i - V_i^{ref})^2 \quad (8)$$

Where, V_d is the total voltage deviation in the MG system

NL is total number of load buses in the MG system.

V_i is the voltage magnitude at each load bus i .

V_i^{ref} is the pre-specified reference voltage magnitude. V_i^{ref} is usually set as 1.0 per unit is to maintain the load bus voltages within $\pm 5\%$ of nominal voltage (Younis *et al.*, 2018).

SIMULATION RESULTS AND DISCUSSION

The SCA optimization technique was applied to optimize the control gains of the PI controller. The optimized PI controllers performs the role of restoring the nominal voltage value of the microgrid whenever there is disturbances in the system, this was achieved by sending the current value of the objective function from Simulink model to the

MATLAB workspace continuously at specified time interval while SCA optimizes the objective function in line with new values. The stability analysis were carried out on the modeled Islanded microgrid in the MATLAB/Simulink environment using voltage deviation, overshoot, settling time, rise time as performance metrics. In the simulation results,

SCA technique presented in this paper was compared the PSO technique in the literature. Simulation results obtained are presented and discussed. Figure 4. shows output power of the two distributed generations that made up the Islanded microgrid.

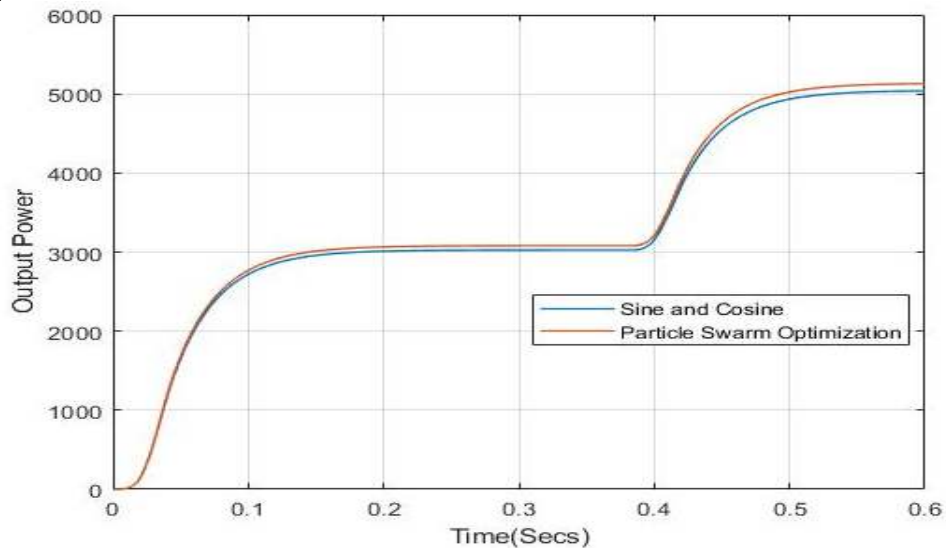


Figure 4. Output power by the two DGs

It is clear from the Figure 4 that the load is shared equally between the two DGs, since the optimal output power values of the PI controller obtained are of the same, the output power generated by each DGs before the load variation condition occurred at 0.4 seconds is 3kW and after the load variation from 6kW to 10kW each DG supplies 5kW to the load.

Thus, it is obvious from Figure 5, that SCA technique shared power more precisely compared to the PSO applied technique. This implies that the SCA employed to optimize the control gains of the PI controller proved more capable compared to PSO method. Figure 6, shows step response of voltage controller.

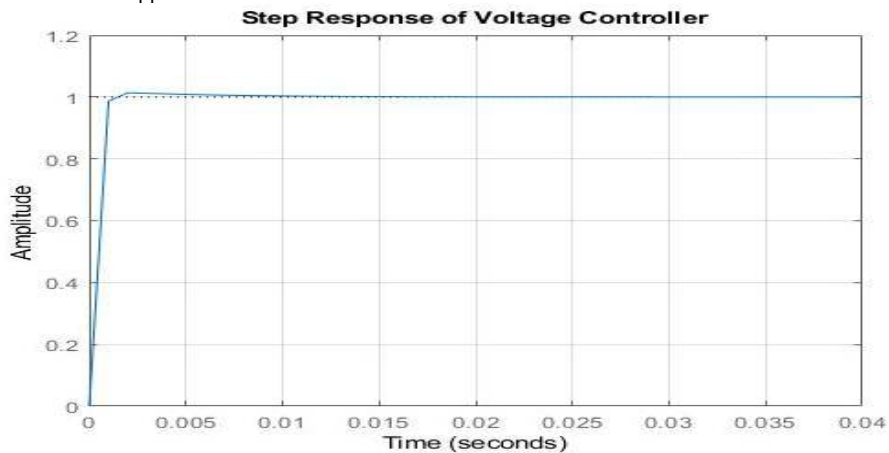


Figure 5.: Step response of voltage controller

From Figure 5, the maximum output voltage realised to the load from the developed Islanded microgrid at start immediately overshoots to 1.02 p.u. It further revealed that with SCA technique the stability analysis performance metrics indicates that out voltage overshoot is 0.02 p.u., rise time is 0.0015 seconds and steady state error is zero. Simulation results have verified the capability

of the SCA method in minimizing the voltage deviation compared to PSO technique. The results reveals that the SCA optimized PI controller has achieved voltage overshoot improvement of 21.6%. The results indicate that SCA optimized PI controller outperformed the PSO reported in the literature. Figure 6. Shows step response of current controller

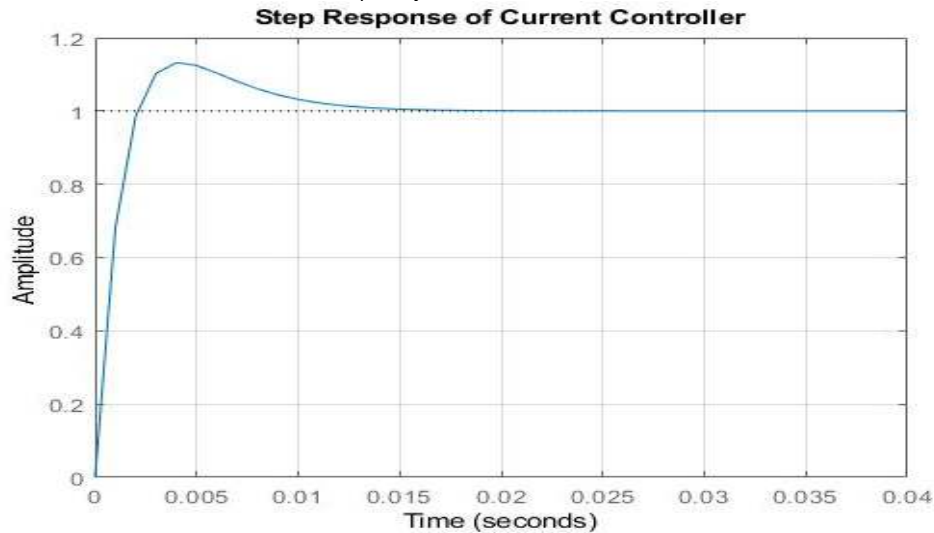


Figure 6. Step Response of Current Controller

Figure 6 illustrates the step response of current controller after the PI controller was optimized by SCA technique. It is evident from Figure 6, that the current overshoot is 0.12, rise time is 0.0015sec and settling time is at 0.015 seconds. The obtained results from

simulation also verified the viability of the SCA control technique compared to the established PSO method in the previous reported study. Figure 7, output power of DGs using SCA and PSO techniques.

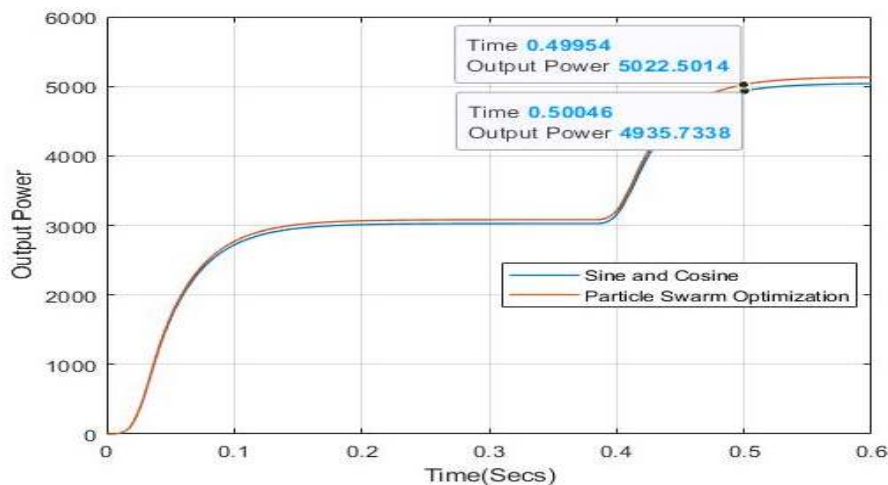


Figure 7: Output power of DGs using SCA and PSO techniques

It is obvious from the Figure 8 that the SCA technique gives a better output power of DGs to the loads. The plot derived from the SCA method achieved precisely 3KW power output immediately the Isolated microgrid was start compared to PSO technique as sbverved from the plot. As soon as the microgrid undergone load variation condition from 6kW

to 12Kw, there were some fluctuation in the output power of the loads. However, it indicates that the plot obtained when SCA optimized the control gains of the PI controller achieved a more precise 5kW output power compared to PSO technique. Figure 8 shows frequency response of the Isolated microgrid.

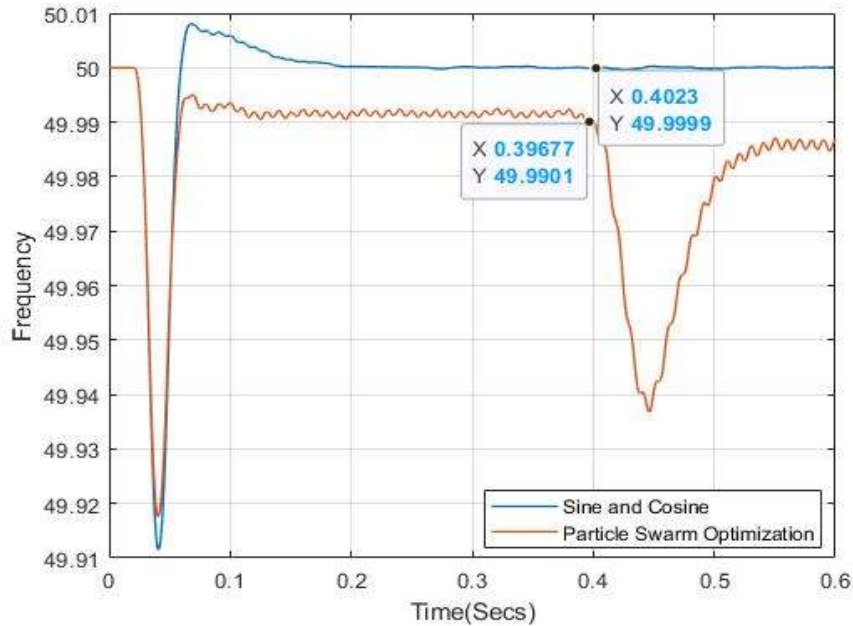


Figure 8, Frequency response of the Isolated microgrid.

It can be observed from the Figure 8, that when the Isolated microgrid was switched on, the frequency deviates to 0.0801Hz, from the nominal value when the SCA technique was used to optimized the PI controller compared to frequency deviation of 0.0701Hz when PSO technique was employed. Thus, when the microgrid was subjected to load variation condition from 6kW to 12kW, the SCA optimized PI Controller indicates frequency deviates to 0.0001Hz at 0.4023 seconds compared to PSO optimized IP controller that deviates to 0.0099Hz.

From the Figure, it is evident that the SCA technique outperformed the PSO based technique, when the Isolated MG system was subjected to change in load condition, since the frequency deviation of each DGs was 0.0001Hz under SCA technique compared to deviation of 0.0099Hz under PSO technique.

The deviation in frequency under SCA technique is more acceptable and therefore results in reduced voltage deviation since there is balance between the active power output of DGs and that of the loads and no power mismatched.

CONCLUSION

The development of an optimal voltage control for the stability of the Isolated microgrid system using optimized PI controller has been presented. The SCA technique was implemented on the modeled Isolated microgrid system with two parallel connected inverters and DGs on the MATLAB/Simulink environment. The simulation results from the MATLAB using SCA technique reveals that power shared between the two DGs more equally with SCA technique compared to PSO technique, The obtained results also reveals



that as soon as the Islanded microgrid was exposed to load variation condition at 0.4023 esconds, frequency deviates to 0.0001Hz this proved that SCA technique withstand the load variation condition with minima deviation of 0.0001Hz from nominal value.compared to PSO technique. ster with minima overshoot compared with PSO technique. In future work multiple distributed generations for an Islanded microgrid.

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