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An Adaptive V-I Droop Scheme for Improvement of Stability and Load Sharing In Inverter-Based Islanded Micro grids

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Abstract: *Micro grids performance and stability mostly depend on power-flow control strategy. In order to allow for coordinated control while maintaining reliable operation, decentralized control methods based on and droop characteristics have been utilized. Inherently, the power droop control methods have slow dynamics. In this paper, a novel control method based on V-I characteristics is introduced to exploit the flexibility and fast dynamics of the inverter-based distributed energy resources.*
In the proposed method, the direct and quadrature axis voltage components are drooped with the corresponding currents according to a piecewise linear droop function. Eigen value analysis of a sample microgrid shows that the proposed method features faster dynamics and improved damping compared to the conventional droop scheme. Simulation results are presented to verify the efficacy of the proposed method.
Keywords: *Load sharing, distributed energy resource (DER), droop, inverter, microgrids, power sharing.*

I. Introduction

As a consequence of political and environmental goals together with technological advances, the worldwide use of renewable energies has increased significantly in recent years [2]. This development not only changes the mix of the generation structure, but also strongly affects the power system structure and its operation as a whole. In particular, most renewable power plants are relatively small-sized in terms of their generation power. Therefore, they are often connected to the power system at the medium (MV) and low voltage (LV) levels. Such units are commonly denoted as distributed generation (DG) units and are mostly interfaced to the network via AC inverters [9].

The latter are power electronic devices, which possess significantly different physical characteristics from synchronous generators (SGs). This implies that new control and operation strategies are needed in networks with a large share of DG units. Microgrids [3] are foreseen to be a promising solution to address these changes by enabling an efficient and reliable integration of large shares of renewable DG units in the electrical power system. A microgrid is a locally controllable subset of a larger electrical network. It is composed of several DG units, storage devices and loads. One main feature of a microgrid is that it can be operated either in grid-connected or in islanded mode, i.e., in a completely isolated manner from the main transmission system to increase the reliability of power supply. As in any power system, stability is a key performance criterion in microgrids[8].

In conventional power systems, mostly SG-based units, operated as so-called grid-forming units, are used for this task. However, in inverter-dominated microgrids, grid-forming capabilities have to be provided by inverter-interfaced sources. Inverters operated in grid forming mode are commonly represented as ideal controllable AC voltage sources. The power droop control methods are intrinsically low bandwidth controllers with slow dynamics. Moreover, increasing droop coefficients results in a degraded dynamic response and ultimately instability [6]. The stability of the – droop method can be improved by adding a supplementary controller, which controls the voltage amplitude based on the variations of has replaced the linear supplementary controller by a nonlinear controller to maintain system stability even in case of large signal disturbances.

In an adaptive derivative term has been added and droop controllers to decrease current overshoot and improve stability. In an adaptive feedforward [4] control scheme is proposed to eliminate the dependency of microgrid performance and stability on droop coefficient and load dynamics. The scheme re-shapes the conventional droop characteristics by injecting two supplementary control signals in the voltage control loop. However, the performance of the method is dependent on an identification mechanism, which is used to calculate feedforward gain. It has improved the method by using a gain scheduled scheme.

The existing communication-less microgrid control methods utilize and - or - and droop characteristics. This paper proposes an alternative approach, where the problem of power sharing is simplified to current sharing. In this method, DERs are coordinated by adjusting the inverter voltage as a function of current. This change simplifies the nonlinear control problem of P/Q sharing to the linear problem of current sharing.

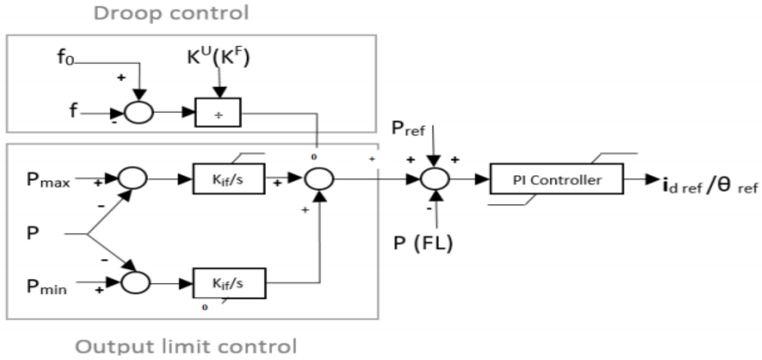

Fig.1. the Droop control blocks diagram.

In addition, with the inherent delay of P/Q measurement eliminated, the controller reacts quickly subsequent to load changes. Since the inverter voltage variations are small, the objectives of and sharing are satisfied. By applying the method to a microgrid, it is shown that the system dynamic response depends on the droop function. A piecewise linear droop function is adopted to increase damping as well as power sharing accuracy at high loading conditions, when the DERs are vulnerable to overload[5].

The droop control theory is explained with the block diagram as shown in Figure 1. This droop control block is composed of two function blocks: (1) Frequency droop control (2) Output limit control. The central controller delivers the inputs such as the system frequency (f) and the output of power generation (P), or feeder flow (FL) and set points. In power grid attached mode, the microgrid frequency is same as the rated value, so that the power output (P) and the feeder flow (FL) are sustained to the fixed value. When the microgrid is detached from the power grid, the power mismatch is balanced by the droop control automatically. With this the systems attain its steady state and finally the system frequency is restored to its rated value.

II. Proposed Algorithm

Droop-based control methods utilize some electrical parameters, such as frequency and voltage, as a signal for coordination of local controllers (LCs) in a microgrid. In order to allow for constant frequency operation, a global positioning system (GPS) signal, which is a pulse train with a period of 1 s, is used to synchronize LCs [7]. With the LCs synchronized, all electrical parameters of the microgrid can be referred to a common synchronous reference frame. Fig. 2 illustrates a simple microgrid consisting of two DERs and one load. The DERs are assumed to be dispatchable, that is, capable of producing active power on demand. Each DER consists of an energy source, a voltage-source converter (VSC) followed by an LC filter, and an isolation transformer. The DERs are connected to the PCC via low-voltage cables.

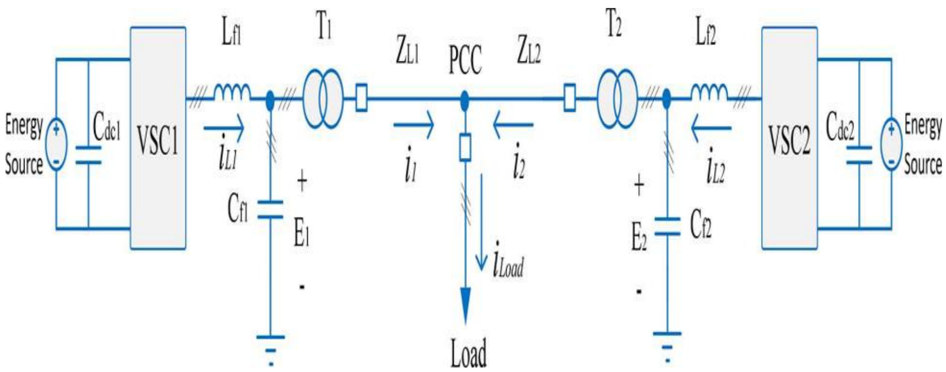

Fig.2. Microgrid model.

A cascaded voltage-current regulator is used to keep track of the reference voltage. The time constant of the cascaded controller is in the order of milliseconds, thanks to the fast dynamics of the inverter and the large resonance frequency of the LC filter. In order to simplify analysis, the dynamics of the voltage regulator are not considered in this section.

It can be inferred that steady-state current sharing error is dependent on the mismatch of the line voltage drops and increases with the load rise. On the other hand, the system is more vulnerable under heavy loading conditions, as the DER output currents are strictly limited by the current rating of the inverters switches[6]. In order to decrease the current sharing error and improve the damping under heavy loading conditions, a piecewise linear droop function is adopted. The droop controller calculates the inverter reference voltage. The reference voltage is then fed to a cascaded PI controller consisting of voltage and current feedback loops and a current feedforward loop.

A current limiter along with an anti-windup feedback is used in the voltage controller to protect the inverter from over current during transient or fault conditions. The DER operating mode is selected by an automatic switch. The current controller output is fed to the PWM module to control the switching duty cycle. Therefore, the droop control law is defined as follows:

$$\begin{bmatrix} E_{xq}^{*} \\ E_{xd}^{*} \end{bmatrix} = \begin{bmatrix} E_0 \\ 0 \end{bmatrix} + \begin{bmatrix} R_{Tx} & X_{Tx} \\ -X_{Tx} & R_{Tx} \end{bmatrix} i_{xqd} - \begin{bmatrix} m_x f(i_{xq}) \\ n_x f(i_{xd}) \end{bmatrix}$$

Small-signal behavior of the proposed control considering the dynamics of the cascaded voltage regulator as well as the LC filter is investigated. The proposed controller is applied to the microgrid of Fig. 2 and the system is modeled in the synchronous rotating reference frame. The model is formulated in state-space form with 20 independent states, including filter capacitors voltages, filter inductors currents, voltage and current regulator integrators, DER output currents, and load voltage.[1]-[4] The system is linearized around the operating point which is calculated by time-domain simulation. The dynamic response and stability are then investigated by eigen value analysis by using the MATLAB Control Design Toolbox.

III. Simulation Results

In order to verify the efficacy of the proposed control method, it is applied to the CIGRE benchmark microgrid proposed. The benchmark schematic diagram is depicted in Fig. 4. It simulates common low-voltage distribution feeders with a variety of load types. Five DER units are integrated into the feeder to provide an uninterruptable energy supply. The overhead lines and loads parameters are shown on the diagram [8]. The load power factor is set to 0.7 to replicate worst case conditions in a residential area. The benchmark microgrid is modeled in MATLAB/Simulink, and time-domain simulations are conducted to study the system dynamic response to step-load change and fault-triggered islanding scenarios.

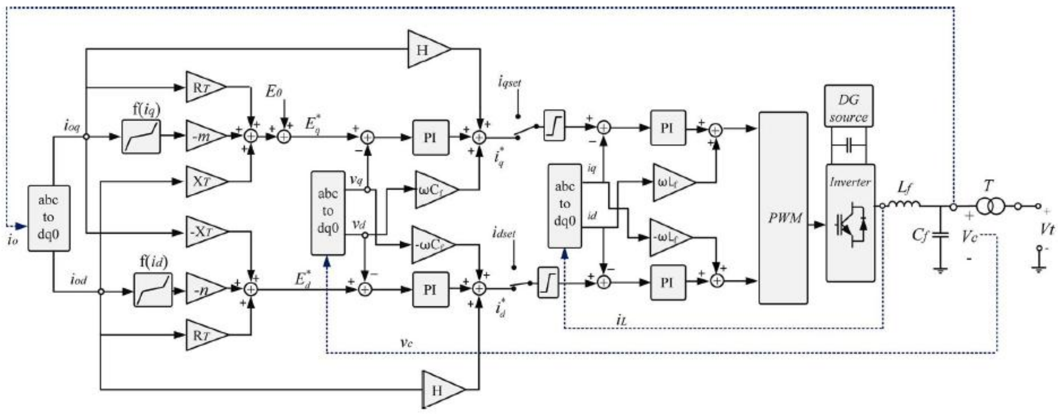

Fig. 3. Proposed controller schematic

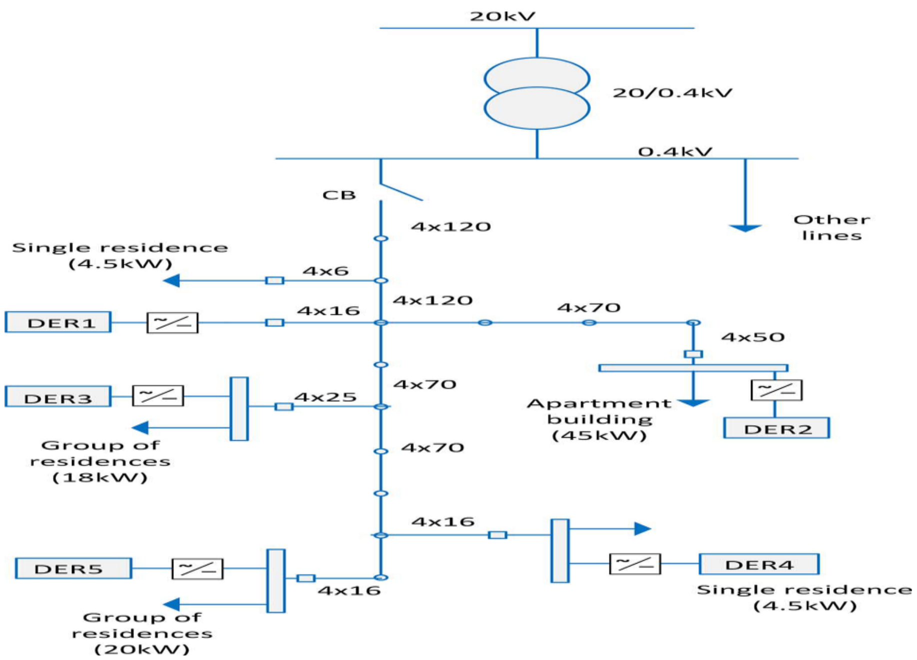

Fig. 4. Benchmark microgrid.

Simulation results show the effectiveness of the proposed method in improving the system dynamic response hence alleviating the current overshoots and stress on the inverter switches. The steady-state error of active power sharing can be justified by the fact that perfect even sharing of is usually neither economical nor necessary. Nonzero error might only result in some DERs reaching the maximum limit, after which their active power is kept constant.

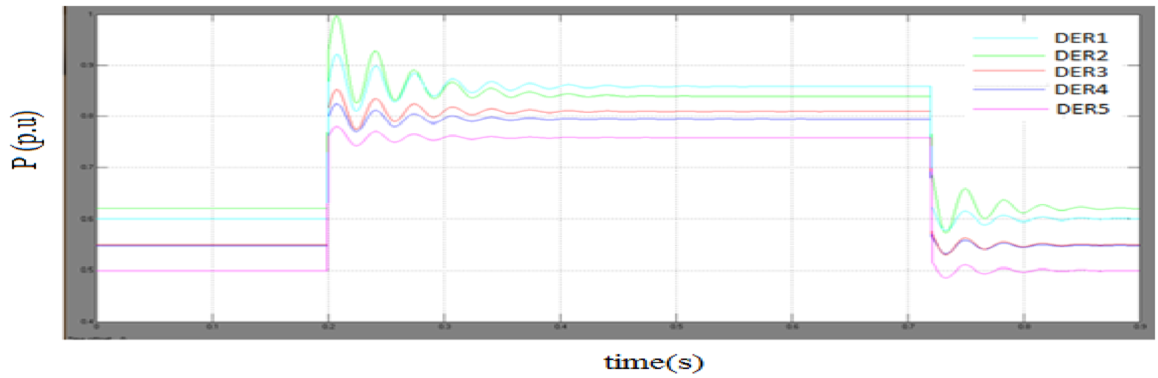

Fig.5 (a)

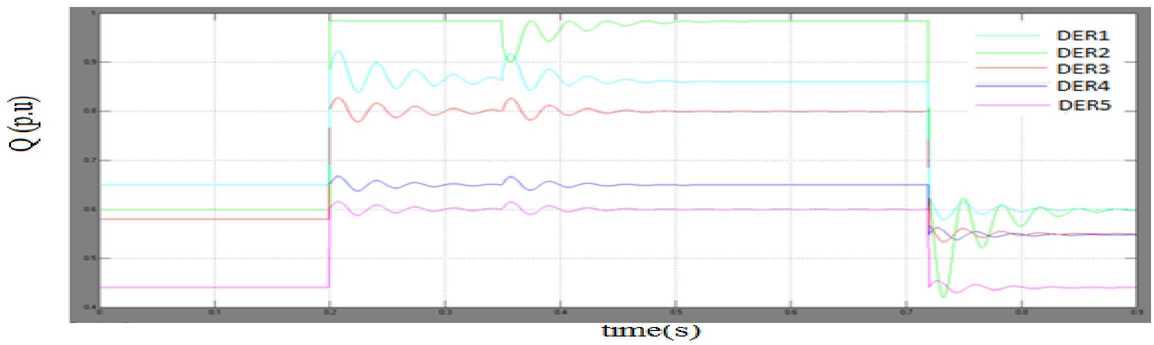

Fig.5 (b)

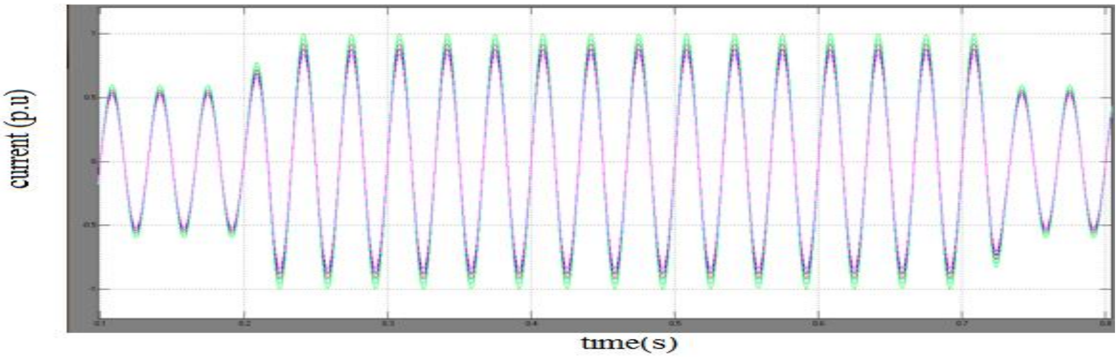

Fig.5(c)

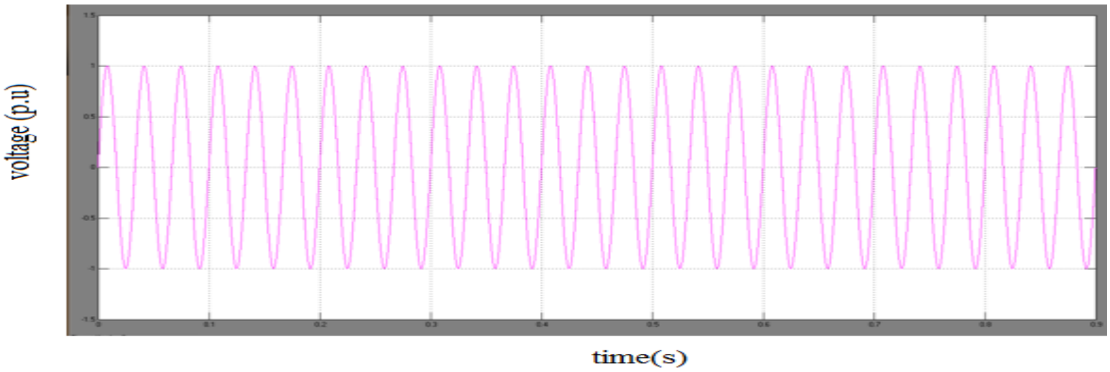

Fig.5 (d)

Fig.5. System response due to a step-load change in the apartment building with the conventional droop control method: (a) active power, (b) reactive power, (c) current, and (d) voltage of different DER units.

It is observed from the above figures 5(a) to 5(d) that the system response undergoes several oscillations until settling to the steady-state conditions. Moreover, the reactive power sharing is quite poor due to the small - droop coefficient and unequal per-unit impedance of DERs' transformers. The current sharing is hence poor, and the output current of DER2, which is located close to the apartment building, rises up to 1.03 in the first cycle after the disturbance. This overshoot might stress the inverter switches and threaten system security.

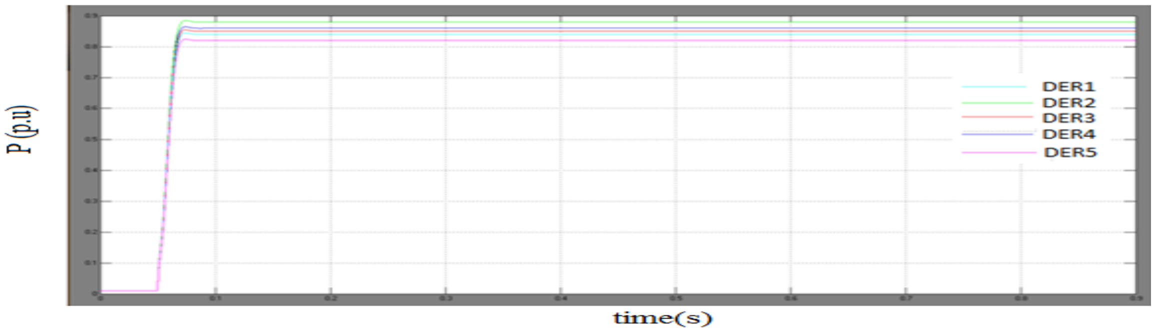

Fig.6 (a)

The system response with the proposed method is depicted in Fig. 6. With a time constant of less than 1 cycle, all LCs react to the load increase in the first cycle after the disturbance. Therefore, the DERs currents rise smoothly and without overshoot. The maximum current of is 0.88 p.u., which is 0.15 p.u. lower than the conventional method case. The active and reactive powers also rise smoothly. Steady-state errors of active and reactive power sharing are initially within 6% and 3%, respectively.

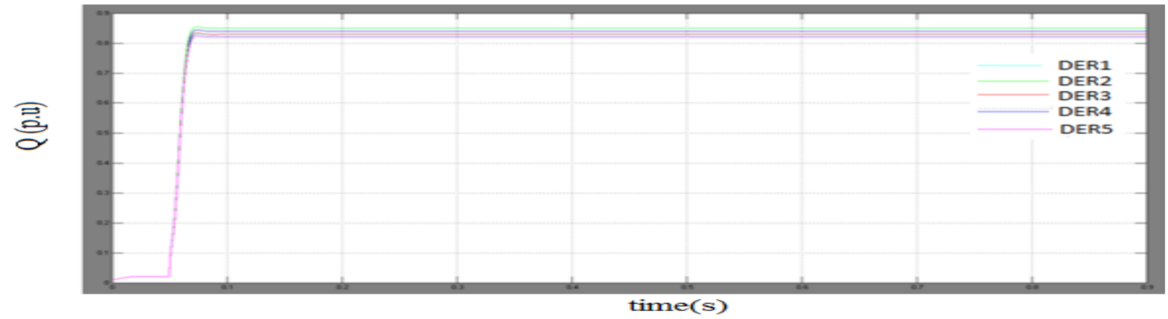

Fig.6 (b)

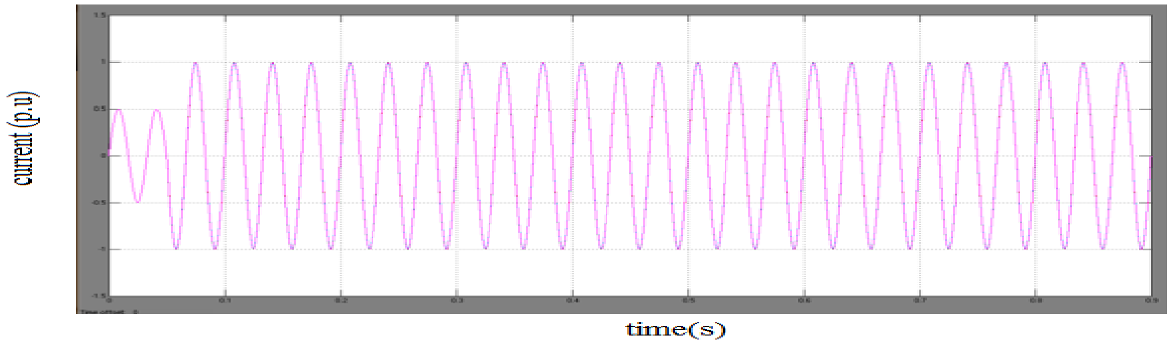

Fig.6(c)

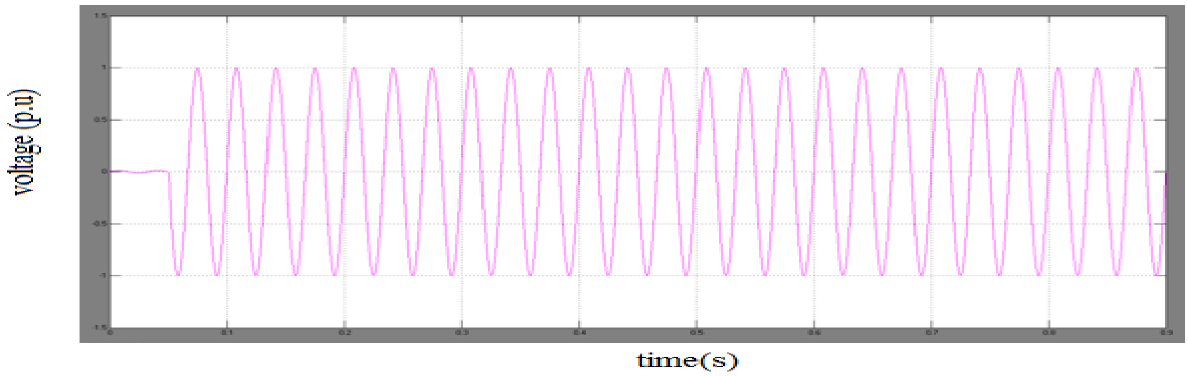

Fig.6 (d)

Fig.6. System response due to a step-load change in the apartment building with the proposed control method: (a) active power, (b) reactive power, (c) current, and (d) voltage of different DER units.

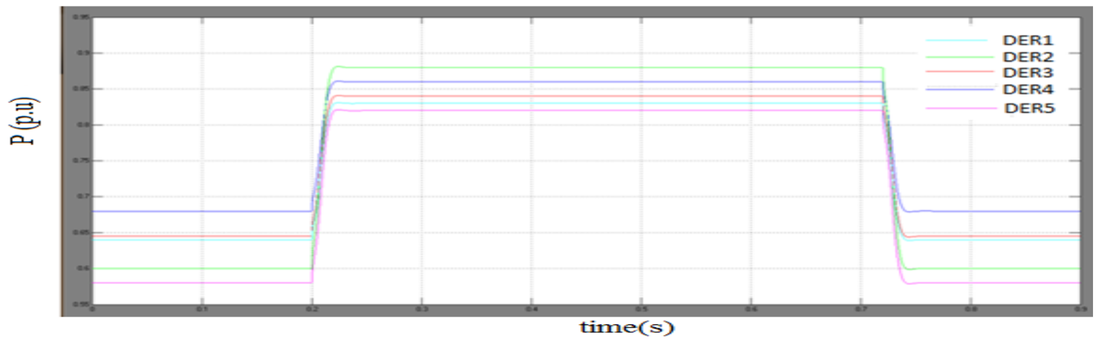

Fig.7 (a)

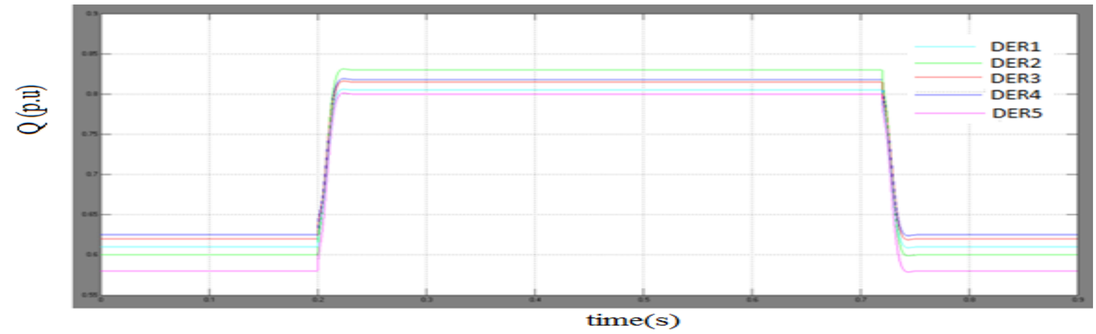

Fig.7 (b)

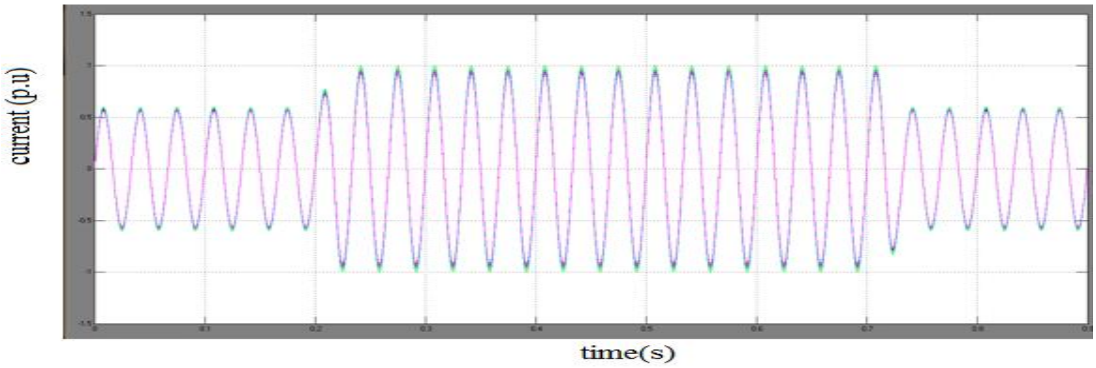

Fig.7(c)

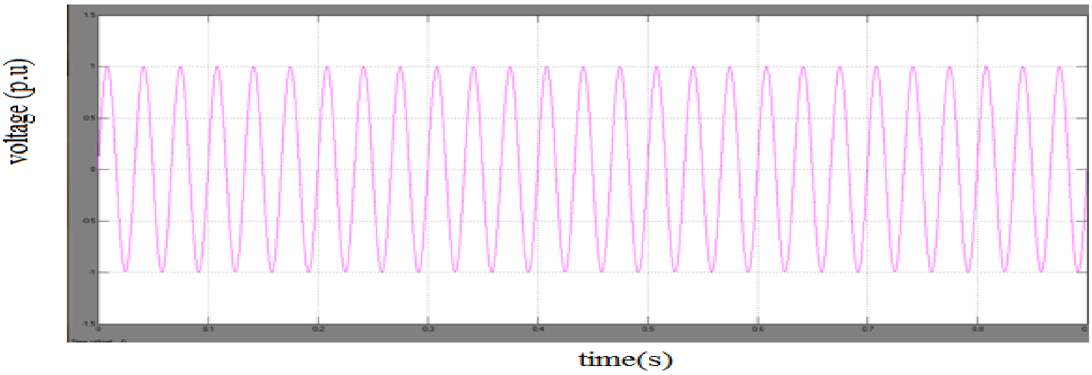

Fig.7 (d)

Fig.7. System response due to fault-triggered islanding with the proposed control method: (a) active power, (b) reactive power, (c) current, and (d) voltage of different DER units.

The main circuit breaker then opens and the microgrid is switched to the islanding mode. The simulation results are illustrated in Fig. 7.During the fault conditions, the voltage is nearly zero and so are the active and reactive powers. At 0.05, the microgrid is islanded and the LCs is switched to the droop control mode. Subsequently, the voltage is raised by the coordinated action of the LCs. It is observed that the controller responds equally well to islanding, which is a large signal disturbance.

IV. Conclusion

Microgrids provide a context for facilitating the integration of renewable energy resources in low-voltage networks while delivering high quality and reliable energy to consumers. However, low inertia, strict current limits, and small size of inverter-based DERs, on one hand, and large step-load changes on the other hand make microgrids vulnerable to PQ and stability issues. The authors suggest that the dynamic and stability of microgrids can be improved significantly by designing a droop control scheme in accordance with the characteristics of inverter-based DERs, that is, low inertia and strict current limits. In this paper, a new coordinated control method based on the droop characteristic is proposed to fulfill the aforementioned aims.

In order to improve power sharing accuracy at high loading conditions, when the DERs are vulnerable to overload, a piecewise linear droop characteristic is adopted. The performance of the droop controller considering the voltage regulator and the filter dynamics is investigated by eigenvalue analysis. The analysis verifies the fast dynamic response and small-signal stability of the method. The method is then applied to the CIGRE benchmark microgrid and step-load change and islanding scenarios are studied.

The simulation results demonstrate smooth dynamic response, which settles within two cycles after the disturbance. Moreover, the voltage is maintained within 96% to 104% of nominal value. The narrow range of voltage variations on one hand and the fixed frequency operation on the other hand, imply a high quality of energy delivered to the consumers. The proposed control method is analogous to the voltage droop method in dc microgrids, where the converters output voltages are drooped in accordance to the output current.

However, the method is discriminated from the virtual output inductance and virtual resistance methods in ac microgrids, which utilize droop characteristics for power sharing. It is worth comparing the proposed method with the adaptive feedforward compensation scheme and gain-scheduled decoupling control strategy. Similar to those methods, the proposed method adds two voltage signals into the reference voltages. The voltage signals in all three methods are obtained by multiplying and axis currents by a gain matrix. However, the injected voltages are transient signals, introduced to improve the transient performance and stability of the droop controllers.

On the other hand, the injected voltages in this paper are droop signals, which include steady-state and transient components. There is more to explore about the proposed control method. One of the next steps is to investigate the effect of harmonic and unbalanced load currents on controller performance. Another is applying necessary modifications so that the method can be used for nondispatchable DERs. Nevertheless, this paper has laid out a novel droop control strategy, which aims at improving the dynamic response and stability of microgrids by exploiting the intrinsic features of voltage-source inverters.

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