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An Adaptive Droop Control for Power Sharing Between Three Phase Parallel Inverter in Autonomous Microgrid

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***Abstract*—The development of an adaptive droop controller is for power sharing between three-phase parallel inverters. Traditionally, droop controllers have been employed in conventional power systems to allocate the load among generators with varying capacities. Our approach involves the utilization of an adaptive control technique. This method is designed for a setup involving three-phase parallel inverters linked to an AC microgrid, to enhance the proportional distribution of active power despite changes in feeder network characteristics and loads. The proposed control mechanism automatically tunes the frequency droop parameter to address mismatch frequencies. The system includes two sets of three-phase inverters regulated by a combination of P-F droop control, an enhanced droop control loop, and PI controllers. The adaptive droop coefficient control is capable of addressing problems where power distribution inaccuracies arise due to different line loads as well as different inverter capacities.**

Keywords—Droop Control, Adaptive Control system, Microgrid, PI controller, Inverter

Introduction

Nowadays, more and more distributed generation and renewable energy sources, e.g. wind, solar and tidal power, are connected to the public microgrid via power inverters. To achieve higher reliability, better system redundancy, and larger power scale at lower cost, inverters are connected in parallel. A microgrid comprises a set of DG and local loads as a part ofan electric distribution network. DGs are usually connected to the utility by a VSC and are often known as inverter-interfaced DGs. Microgrids can be planned to operate in islanding mode which is known as autonomous connected mode.

In the islanding mode of operation, demand power should be shared among DGs considering their capacity. The primary challenge for the autonomous microgrid is maintaining voltage and frequency of operation for the proper operation of the loads. Once the primary challenges are dealt with, the secondary challenge surfaces which is meeting the load demand in a microgrid and the final challenge is, to maintain the power-sharing between different sources proportionately to ensurethe sources do not hit their current limits for their operational longevity.

Among the parallel strategies without any interconnections between the parallel-connected modules, the simplest strategy is based on the droop method. With this strategy, the control loop makes the tight adjustment over output voltage and frequency and amplitude of the inverter to obtain good power sharing and to compensate for the active and reactive power unbalances. The droop control method is a way to achieve proportional power sharing for the parallel inverters. It mimicsthe operation of the governor and exciter of a synchronous generator to adjust the frequency and voltage of each sourceas the active and reactive power of the system is increased.

Droop Control Method

Droop control is the key solution for sharing the demand power between generators in autonomous Microgrids where there is no support from the electricity distribution grid. The purpose of a droop controller is to maintain stability and balance in the system by effectively sharing the load among multiple interconnected sources. The most common application of a droop controller is in power generation and distribution systems, such as Microgrids or parallel-connected generators. In these systems, multiple generators or power sources are connected to supply electricity to a common load. Droop characteristics can be artificially created for electronically interfaced inverter DG units. The inverter is controlledby simulating the droop characteristics of the synchronous generator.

To simplify the analysis, the configuration of two inverters sharing a common load is taken as an example, and the equivalent circuit is shown in Fig.1

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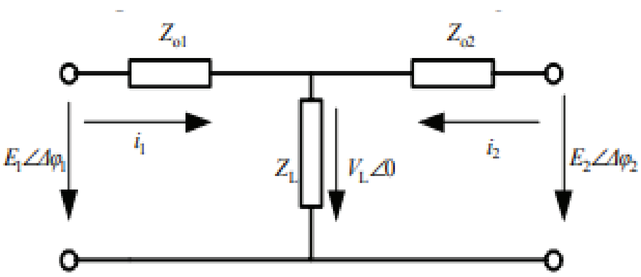

Fig 1: Equivalent circuit of two inverters sharing a load

Assuming the output impendence Zo1, and Zo2 are pure reactive by ignoring their resistive parts, namely Xo1, and Xo2, the active and flowing out of every module can be expressed as

$$P = EV/X \sin\Delta\emptyset \quad (1)$$

Equation (1) indicates that if the phase angle (Δφ) between the voltage vector E and VL is very small, the active power flow P is largely dependent on this phase angle. The conventional droop control equations can be expressed as

$$P - f \rightarrow \omega = \omega * - mP \quad (2)$$

$$Q - V \rightarrow V = V * - nQ \quad (3)$$

Where ω* and V* represent the rate values of angular frequency and output voltage magnitude .m and n represent droop slops of real and reactive power, respectively. Due to m and n being fixed coefficients, the Q-V and P-f characteristic equations are linear equations. Fig. 2 shows the droop curve of conventional droop control according to equations (2) and (3).

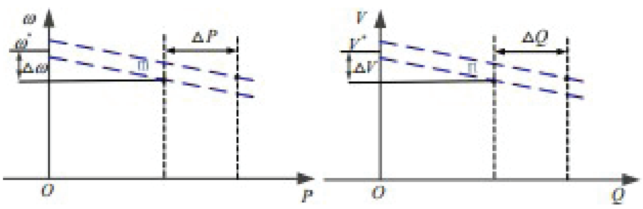

Fig. 2. Droop characteristics of conventional inverter

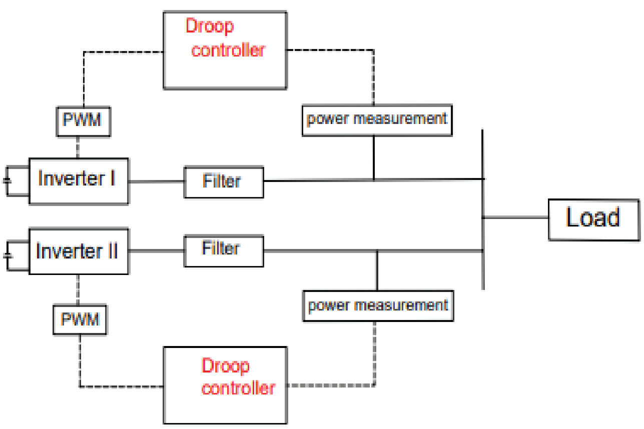

Fig. 3. Block Diagram of Conventional Droop Control Method

Adaptive Droop Control

An adaptive droop control method is proposed for a three-phase parallel inverters system connected to an AC microgrid for the improvement in active power sharing and frequencyin the midst of changing loads. The control law is adaptive because the controller gains are self-adjusting to the operating conditions imposed by the loads and the legal restrictions for fluctuations in voltage and frequency in the microgrid. In this case, the coefficient value of each droop control is no longer fixed but is a function corresponding to the power of each inverter To explain the working principle of in droop, the relationships between real power and frequency are as follows.

$$w = wref - m * p; \quad (4)$$

Where,
m= droop coefficient
wref = Reference Frequency

Here, the frequency of an inverter is compared with the reference frequency (i.e., 50Hz) and an error is obtained and passed through the PI controller. The droop value which has a constant droop coefficient is multiplied with the outcome from the PI-controller. Thus, the obtained data will be the new droop coefficient. It is then multiplied with the real power and stored as a proportion gain in the P controller. The obtained value is then compared with the standard frequency and a new frequency is obtained. And also used this signal for a reference generator.

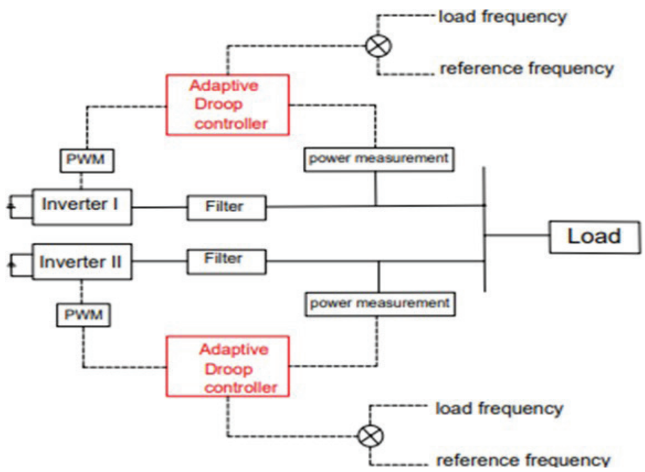

Fig. 4. Block diagram of Adaptive droop control

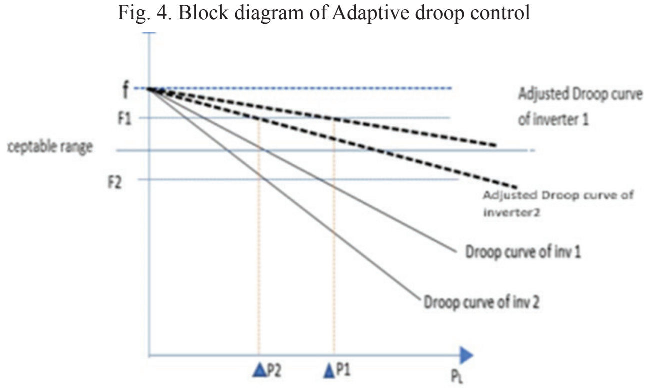

Fig. 5. Droop characteristics of Adaptive Droop control

Modelling of Conventional System

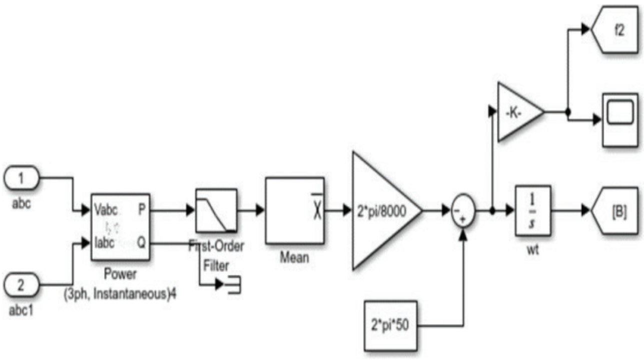

Fig 6: Simulation of microgrid with VSM

Here, the P-F droop control is shown in the figure above. Each subsystem comprises such a droop controller. In this controller, the power is calculated with its three-phrase parameter of voltage and current and passes through a first-order filter and mean such that it gives a smooth signal or output. Thus, the obtained output is multiplied by the droop coefficient and gives a frequency of an inverter (ΔF) which can be expressed as:

$$R * \Delta P = \Delta F \qquad (5)$$

Thus obtained ΔF and standard frequency are passed at the summing and it gives the frequency (wt) of a system in thetime domain and stored in block A.

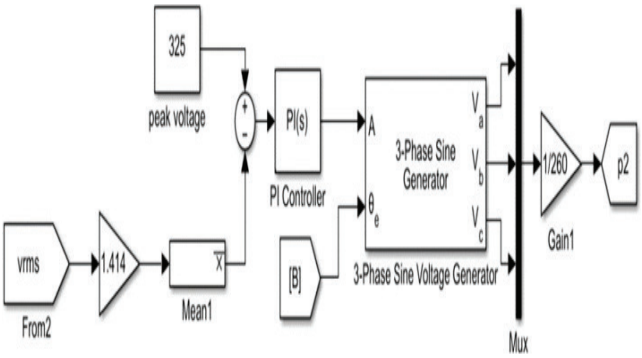

Fig. 7. Voltage regulator

The above figure shows the voltage controller for conventional droop. Each subsystem consists of a controller. When the load increases, the voltage across the system decreases. Due to P-F and Q-V droop controller results losses in the line cause a voltage drop. So, to compensate for an output voltage drop in the system, a voltage controller is used. Here, When Rms voltage is multiplied by 1.414 gives the max value andis made smooth through the mean. Thus, the obtained output and max reference voltage are passed to a summing, and the error is passed through the PI controller and gives output as a control signal. Control signal and frequency (from Figure 7) are passed through the reference generator and then gain which ultimately gives the reference signal of a PWM and controls the inverter of each subsystem.

Modelling of Adaptive Control System

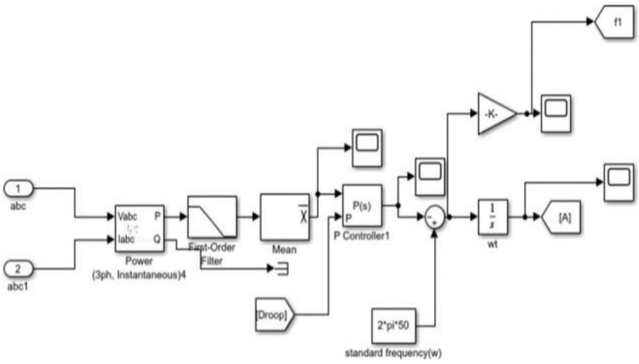

Fig. 8. Adaptive droop control system

The above figure illustrates the P-F droop control system for the subsystem. Each subsystem consists of each droop control. In the above figure, power is calculated and made smooth through the first-order filter and mean. Its output along with the droop factor (from Figure 8) is passed to the P-controller and the output is compared with the standard frequency giving the new frequency for the subsystem which is needed to maintain the stability of the system.

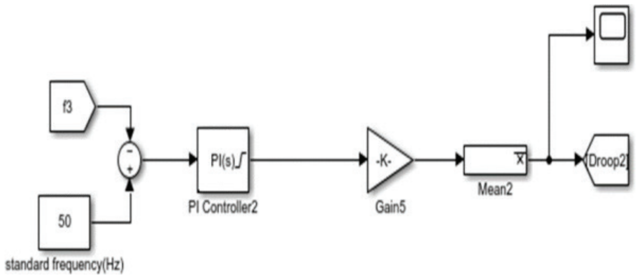

Fig. 9. Adaptive droop

The above figure illustrates the block for the droop control signal for the subsystem. The frequency of the inverter and reference standard frequency are compared with a difference block providing an error signal and the error is sent to a PI controller -reducing both the rise time and the steady state errors of the system. The output of the PI controller passes through a gain for signal conditioning by certain factors anda mean block for smoothing. This signal control will be the frequency of the system at which it needs to be operated. This control signal is called droop signal and droop is dynamic and changes by decreasing its value to make the frequency near to the standard reference frequency.

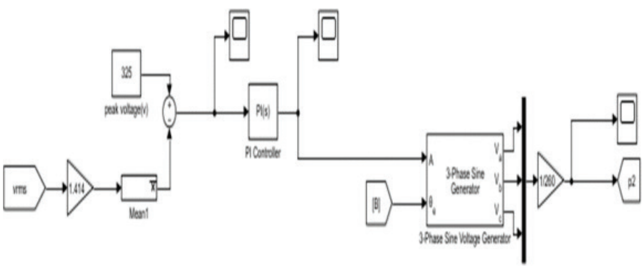

Fig. 10. Voltage regulation system

The voltage regulation circuits for adaptive and conventional control systems are the same.

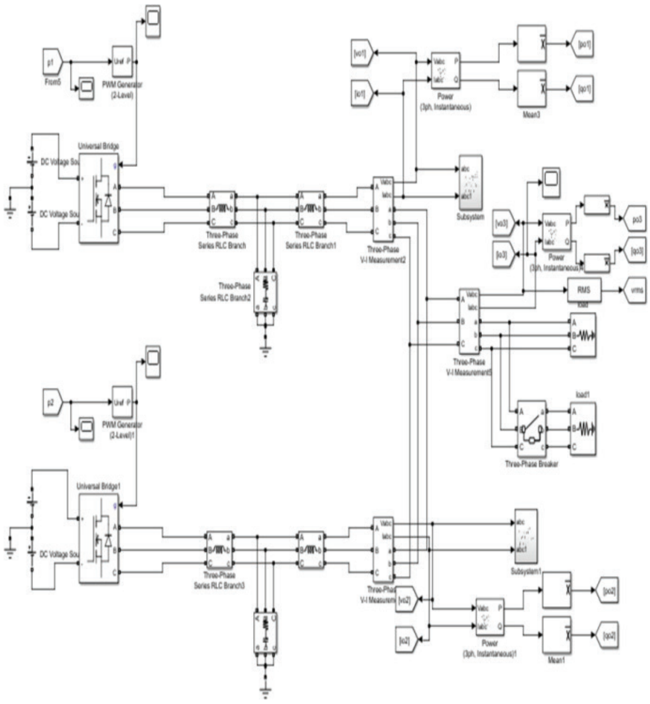

Fig. 11. Overall simulation model

Simulation and Results

A MATLAB-based Simulink model is developed to verify the proposed topology through simulation results. The simulation is carried out for two control algorithms, i.e., first, the conventional control algorithm is simulated, and then for the same scenario the proposed control approach is carried out. As the objective is to maintain the frequency above the acceptance level and proper power sharing between inverters the instant of switching on the loads are mentioned in the results figures.

A. Conventional System

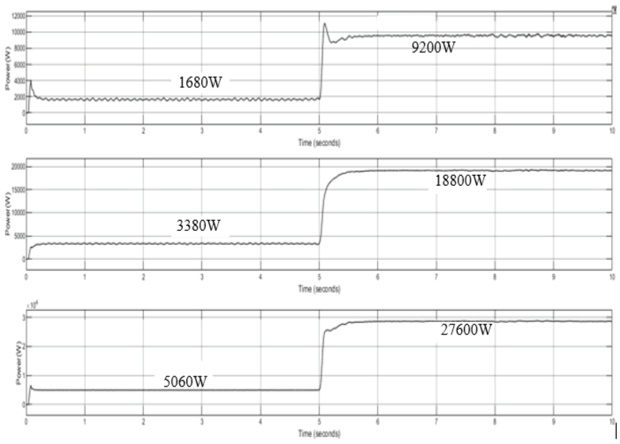

Fig. 12. Active power-sharing using conventional droop control

The performance of the parallel inverters adopting these two different control strategies is illustrated in Fig: 12 and Fig.15. The load switching condition in both cases is identical as illustrated in Fig.12. The real power can be shared accurately by the traditional scheme, and it can be seen that good load sharing between the modules has been achieved. The Load 1of 5kw is only applied within 0 1s, at t = 1s, a secondary load of 20kw is connected at t=5s and is cut off at t = 10s. Since the inverter II is double the capacity than that of inverterI and shared power accordingly. The active power shared by two inverters is shown above.

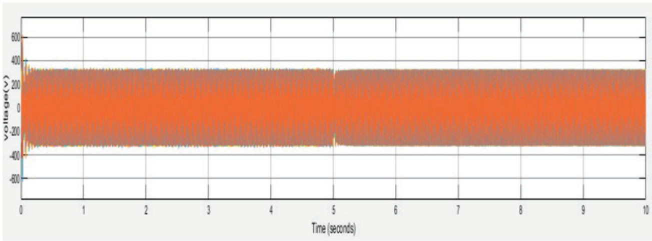

Fig. 13. Voltage across the load

Since the inverter is a non-linear load, the change in voltage at time t=5s after the addition of load 2 and cutoff at t=10s, the pure sinusoidal waveform was obtained as shown in Figure13.

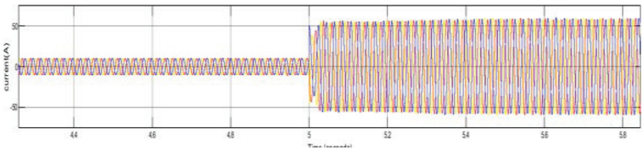

Fig. 14. Load current

As the system is in balanced condition (i.e., at stability). The current across the load is sinusoidal as shown in the above figures. Figure 14 shows the current across the load at the balance condition

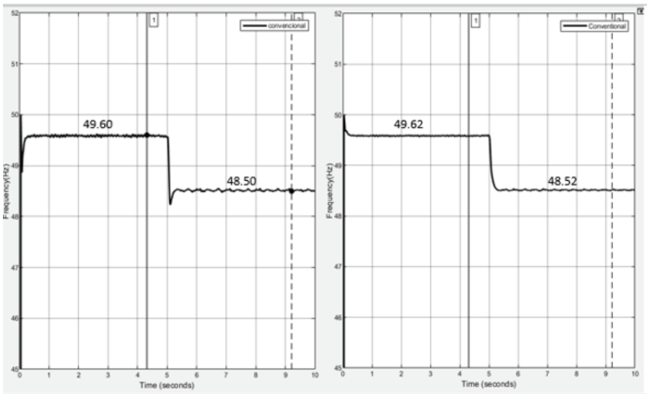

Fig. 15. Frequency response of the inverters in the conventional system

The frequency response of inverter I and inverter II are shown in above fig 15. When load1 is connected at t=0 1s, the frequency lies above the acceptance limit (50 ±1hz). At t=5s, load 2 is connected and the frequency wanes below 49Hz in both inverters.

B. Adaptive Droop Control System

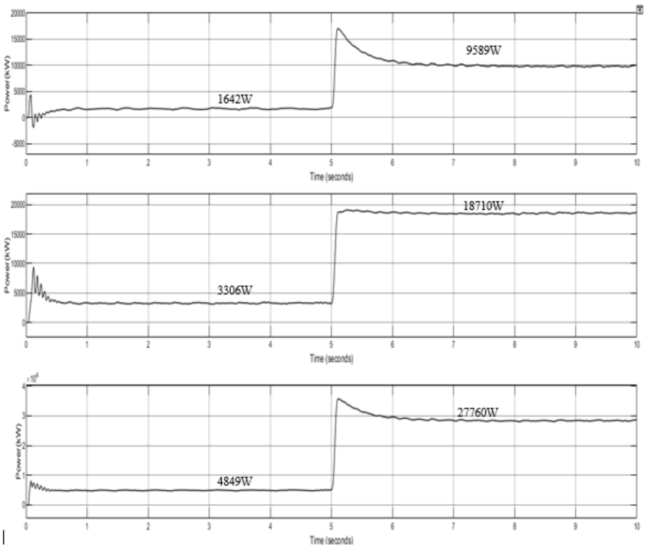

Fig. 16. Power sharing in Adaptive droop control system

At first, a 5KW load is connected after t=0 1s and a secondary load of 20KW load is connected after t=5s. Since the capacity rating of inverter II is double the size that inverter I. From the above figure, it can be clearly shown that both inverters supply power proportional to their capacities to meet the power of demand load.

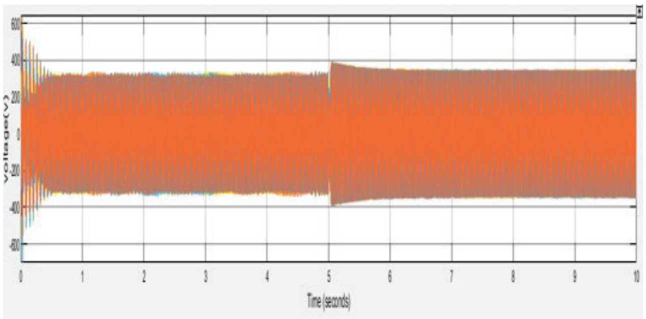

Fig. 17**.** Voltage across the load

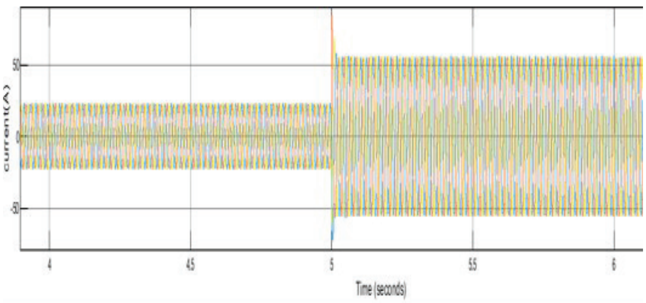

Fig. 18. Load current

As the system is in balanced condition (i.e., at stability). The current across the load is sinusoidal as shown in the above figures. Figure 18 shows the current across the load at the balance condition.

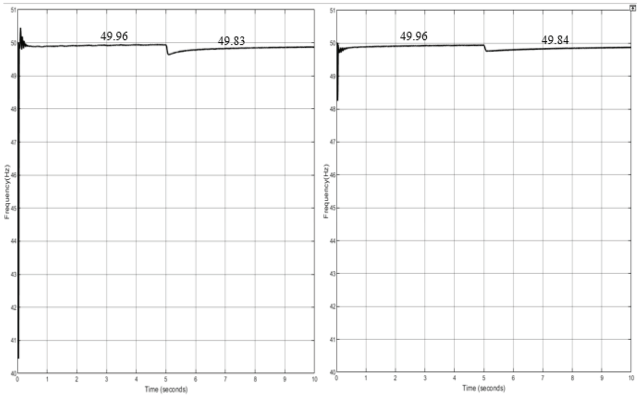

Fig. 19. Frequency response of the system with adaptive droop control

Figure 19 illustrates the frequency response of a system using an adaptive droop controller. At t=0 1s, the primary load is connected and frequency is observed. After t=5s, the secondary load is added the frequency of a system remains near the standard frequency

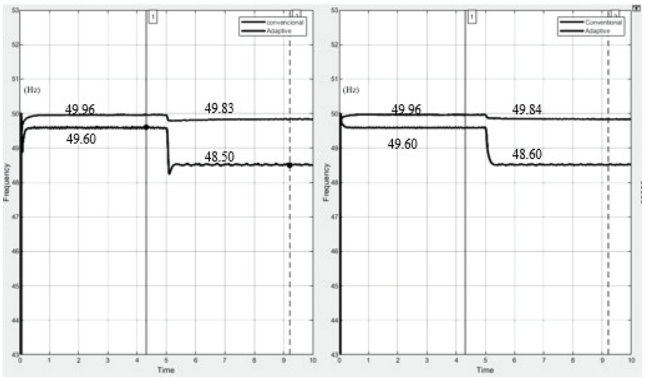

Fig. 20. Frequency comparison between the conventional and adaptive droop control

Here, the output frequency of each inverter is compared with the conventional and adaptive droop methods. In Figure 20, the waveform near the standard frequency uses adaptive droop, and the lower one uses the conventional droop method.At t=0 1s the primary load is connected and after t=5s, the secondary load is also added. When the conventional droopis applied, the frequency of a system drastically decreasesbelow the acceptance level after t=5s. However, with the adaptive droop, the frequency of a system remains near a standard reference frequency (i.e., 50Hz) after the addition ofa secondary load.

Conclusion

Hence, the problem of power-sharing between the parallel grid-connected inverter is solved by the proposed droop control with an adaptive droop control method. Firstly, the conventional droop control method was discussed and their drawbacks in parallel operation of inverter are highlighted such as frequency goes beyond the acceptance level. Then, an adaptive droop control method is analyzed and its drawback compared to the proposed control method is discussed. By using droop control proportional load sharing is obtained from each inverter in the microgrid, without using any communication. Simulation results show that the droop control method can effectively provide the required power to the load ensuring the system voltage drops and frequency are within the stable limit.

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