Controller of Parallel Inverters

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Abstract- *The virtual oscillator control (VOC) is a decentralized control strategy for islanded micro-grids where inverters are regulated to mimic the dynamics of the nonlinear oscillators. The VOC regulates the amplitude and frequency of the inverter output voltage. Consequently, the inverters output voltages are synchronizing. This technique ensures to share the load power proportional to the power ratings of the inverters and there is no communication between the inverters. The VOC works on the current feedback signals, this control technique introduce in the system of three single-phase inverters are operated in islanded mode. The energy supplied to the inverters by using photovoltaic energy sources. The simulation results for a system of inverters with VOC illustrate the merit of the controller.*

Keywords- virtual oscillator control, inverter, feedback signals

I. INTRODUCTION

Non-renewable energy sources are the significant wellspring of vitality on planet today. Factors obliging these deliberations are (1) demand for electricity is increasing in both developed and developing countries, (2) the resources needed to build power plants for distribution networks, because many of the flourishing countries are deficient of the resources, and (3) Insufficient power generation in some industrialized countries, (4) ozone harming substance discharge and environmental change concerns.[7]

This novel pattern is creating near distribution generation, which implies that energy exchange system is arranged near energy customers and substantial units are replaced by littler ones. To the customer the potential lower cost, higher benefit dependability, excessive energy perfection, expanded energy efficiency, furthermore, autonomy of energy is the most part explained for Distributed energy sources.

Ridded by an inexorably stressed transmission plus circulation derives as channels falling behind the demand and also to reduce in general system the losses incurred during transmission and distribution. Also the expanded requirement required for unwavering quality and security in supply of power, control quality required by expanding number of exercises requiring UPS type of systems and also to counteract or change the extension of Central generator stations by providing the developing burdens.

The usage of renewable energy sources and also consumption of the local energy sources due to a large number of resources an extensive count of resources at the LV-grid. For most of the micro-turbines it is a direct current supply and changes over to an alternating current by the methods for inverters. The inverter is viewed as a fundamental segment at the network beside such systems because of the extensive range of capacities it needs to complete. It also needs to change from DC voltage to sinusoidal current used for the grid in an addition goes about as the platform between the ECSs, and the nearby load and the grid. It additionally needs to deal with varieties in power got because of various levels and Generation of RESs, burdens and also grid voltage. Inverters change the frequency and the voltage of the grid and appear to be the principle all inclusive particular building of the upcoming smart grids working mainly at low and medium voltages. Inverters are frequently made a parallel to electrical systems, to make become better present a performance of successfully reach a high system rating. Produced to high reliability because provide operation of parallel inverters, remained (n-1) models can convey required capacity to the load. [2][4][7].

The paper tells parallel coordinating method such controlling of a mimic oscillator as each inverter digitally called as Virtual oscillator control

This paper presents a strategy for planning parallel inverters to such an extent that every inverter is carefully controlled to copy the nonlinear oscillator. This strategy will be called virtual oscillator control

The VOC require current feedback signals, does not require computation of the real and reactive power output and does not require an explicit frequency and amplitude command for the inverter ac output [3]. The synchronization condition are demonstrated to be independent of number of inverters in the system and the load characteristics. Therefore the control paradigm is

a) Robust (Independent of load), b)Resilient (Requires no communication),

c) Modular (Independent of the number of inverters).

Oscillator Model Fundamentals

The inductor and capacitor constitute a LC tank oscillator shown in Fig.1, it can be give sustained oscillations as shown in Fig. 1. The frequency of the oscillations depends upon the inductor and capacitor values. The phase plot i.e. inductor current (i_L) with respect to the capacitor voltage The plot between the i_L and v_C is called a phase plot, gives a circle then the output voltage of the oscillator is pure sinusoidal [2][4].

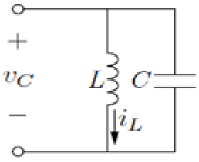

Figure 1: Harmonic oscillator [4].

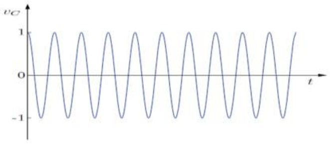

Figure 2: Output voltage of harmonic oscillator [4].

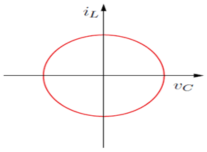

Figure 3: Phase plot of harmonic oscillator[4].

Where i_L is inductor current and v_C is capacitor voltage are specified by

$$\dot{i}_L = \frac{v_C}{L}$$

$$\ddot{v}_C + \frac{v_C}{LC} = 0$$

Damped harmonic Oscillator

The oscillator consists of inductor, capacitor and a resistor as shown in the Fig. 4. The inductor and capacitor constitute a LC tank oscillator, it can give sustained oscillations. The resistor is connected in parallel with LC tank circuit, it will dampen the oscillation as shown in the Fig. 5. Without a source connected to this oscillator the oscillation will damp out within few cycle. The frequency of the damped oscillations depends on the inductor and capacitor values. The phase plot of the harmonic damped oscillator is shown in the Fig. 6.

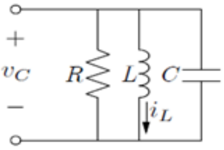

Figure 4: Damped harmonic oscillator [4].

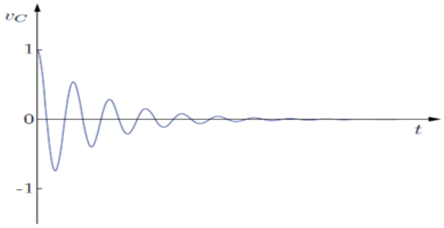

Figure 5: Output voltage of damped harmonic oscillator [4].

This dynamics for damped harmonic oscillator is are below equation

$$\dot{i}_L = \frac{v_C}{L}$$

$$\ddot{v}_C + \frac{1}{RC}\dot{v}_C + \frac{1}{LC}v_C = 0$$

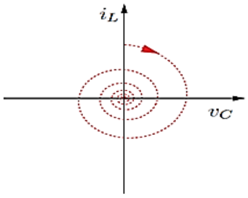

Figure 6: Phase plot of damped harmonic oscillator[4].

Nonlinear Oscillator

The oscillator consists of linear RLC circuit in parallel with a nonlinear negative conductance as shown in the Fig. 7. The RLC circuit can give damped oscillations. To maintain a sustained oscillations a negative conductance is connected parallel to the linear, passive RLC circuit. The voltage characteristic of the oscillator depends on the negative conductance. The nonlinear oscillator implementation is not possible in physically, it can be implemented on a microcontroller. The nonlinear oscillator results are shown in below fig with different initial conditions of the capacitor. The phase plot of the nonlinear oscillator is shown in Fig. 9 with different initial conditions of the capacitor. The nonlinear conductance is an important element to stabilize magnitude of oscillation. The characteristics of the nonlinear conductance will be explored in the forthcoming section [1][4].

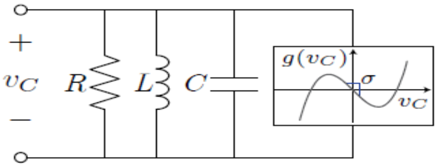

Figure 7: Nonlinear oscillator.[1]

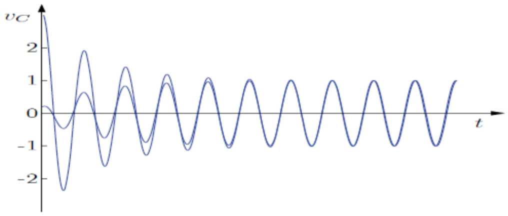

Figure 8: Output voltage of nonlinear oscillator [1].

The i_L, is Inductor current and v_C, is capacitor voltage. Can be

$$\ddot{v}_C + \frac{1}{C}\left(\frac{1}{R} + \frac{dg(v_C)}{dv_C}\right)\dot{v}_C + \frac{1}{LC}v_C = 0$$

$$w^* = \frac{1}{\sqrt{LC}}$$

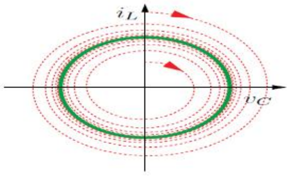

Figure 9: Phase plot of nonlinear oscillator.[1]

Nonlinear dead-zone oscillator

The electrical schematic nonlinear dead-zone oscillator is represented in Fig. 10. The development of the dead-zone oscillator is enlivened by the well-known Van der pol oscillator. The straight subsystem of the oscillator is aloof RLC circuit with impedance Z_{osc}

$$Z_{osc} = R \parallel_s L \parallel \frac{1}{sC} = \frac{\frac{s}{C}}{s^2 + \frac{R}{sC} + \frac{1}{LC}}$$

(3.2)

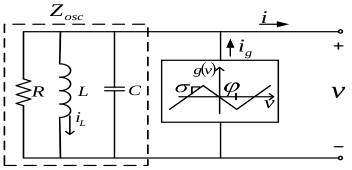

Figure 10: Electrical schematic dead-zone oscillator [1-3].

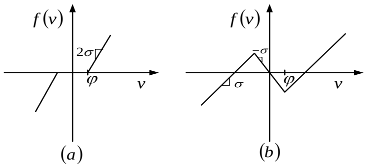

Figure 11: (a) Dead-zone function $f(v)$ (b) the nonlinear voltage dependent current source $g(v)$ are illustrated for dead-zone oscillator [2].

The nonlinear voltage dependent current source $g(v)$.

Where dead-zone function is $f(v)$ with a slope 2σ The capacities and are appeared in figs. 11(a) and (b), individually.

The elements of the oscillator's inductor current and the capacitor voltage (i_L, v) are defined as follows..

$$\frac{dv}{dt} = \frac{1}{C}\left[\left(\sigma - \frac{1}{R}\right)v - f(v) - i_L - i\right]$$

$$\frac{di_L}{dt} = \frac{v}{L}$$

Apply lienard's theorem to the system it can give exceptional and stable limit cycle, if $\sigma > \frac{1}{R}$. From Fig. 11(b), the nonlinear subsystem acts as a power source for $vg(v) < 0$, and as a resistor (with resistance $1/\sigma$) for $vg(v) > 0$. Due to the nonlinear subsystem action, the amplitude of large oscillations is damped and the amplitude of small oscillations is increased.

Lenard's Theorem:[3]

Consider a nonlinear 2nd order ordinary differential system

$$\ddot{x} + f(x)\dot{x} + g(x) = 0$$

$$g(v) = f(v) - \sigma v$$

$whare\ x: [0, \infty) \to R\ and\ f(x).g(x) : R \to R\ are\ differenti$
able. Even and odd.

The ordinary second order differential system has a unique and a stable limit cycle

Surrounding the origin in the phase plane if the following conditions are satisfied

- $g(x) > 0$ for all $x > 0$.
- $F(x)$ has exactly one positive root i. e P.
- $F(x) < 0$ when $0 < x < P$.

Description of the parallel inverter system

In this case energy source to the inverter is photovoltaic. If one of the inverter is not synchronized, then circulating currents will flow through the inverter and adjust its frequency proportional to the current until it synchronizes. In this each inverter share the load proportional to their ratings.

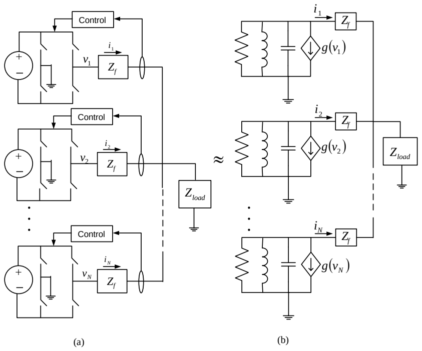

Figure 12: The system of the single-phase inverters in (a) will control to emulate the system oscillators in (b) [3].

Control implementation [2-3]

The dynamics of the nonlinear dead-zone oscillator will be used to control a single phase inverter system. The dynamics of the oscillator can be programmed on the digital controller of the inverter. Because, the nonlinear oscillator cannot be implemented physically, it is described as being “virtual”. A representative implementation of the control of a single-phase H-bridge inverter is given in Fig. 13. The oscillator voltage is then multiplied by k_v and used to generate a modulation signals, m. Lastly, the inverter switching signals are generated by applying a PWM technique, i.e., sine-triangle PWM or some other established technique. The oscillator voltage and scaled inductor current are orthogonal to each other.[3]

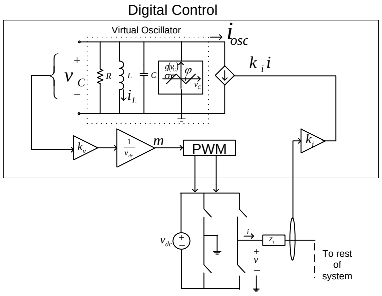

Figure 13: Single-phase voltage source inverter with virtual oscillator [2-3].

With the above proposed method, the inverter will emulate the dynamics of the inverter output voltage, v, and follows the scaled oscillator voltage, $k_v\ v_{osc}$. Furthermore, the current extracted from the virtual oscillator is equal to the scaled output current, $k_i\ i$. Later the scaling parameters, k_v , k_i. will be used to aid the design process.

As a rule asymptotic synchronization[2-4]

In a parallel arrangement of inverters associated with an typical load, the inverters must synchronize their terminal voltages. In [4], the synchronization condition derived for linear and nonlinear loads. The synchronization condition is

$$\max_{\omega\in R}\left\|\frac{k^{-1}Z_{net}(j\omega)Z_{osc}(j\omega)}{k^{-1}Z_{net}(j\omega)+Z_{osc}(j\omega)}\right\|_2 \sigma<1$$

In the synchronization condition, we have a few engaging highlights.

Results and discussions

In the synchronization condition, we have a few engaging highlights. To start with the synchronization autonomous of the load, the number of inverters and their capacity is evaluated. In this way, synchronization in the power framework can be guaranteed with no information around the load parameters then the quantity of inverters taking an interest in the system. Where k be the product of both K_v and K_i i.e. $k = K_v K_i$, Z_{net} be the filter impedance and Z_{osc} be the oscillator impedance[1][2][3].

Case studies

The schematic of the simulation model entails the three single-phase inverters connected in parallel and each inverter is interfaced to a PV array. The simulations are performed for the islanded micro-grid system illustrated. All inverters are connected to a common three phase resistive load.

Simulation Result:

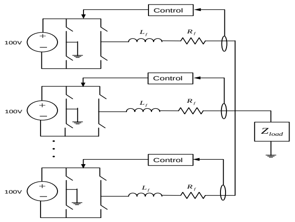

Figure 14: Simulation diagram of the system [2][3].

The inverters in the framework have ratings of 7.5 , 15 , 30 with the end goal that are parallel share the load current as per a proportion of 1: 2: 4as illustrated the steady state load sharing among the three inverters (same phase currents of each inverter). The single -phase modulating signal is used to generate the switching states of the inverter.

The output voltage of the inverters is synchronized, after synchronization the voltage waveforms is as depicted in Fig.8. Here same phase of the inverters have taken for the reference. The output voltage of the load current is the summation of the phase currents of each inverter as shown in the Fig.17.

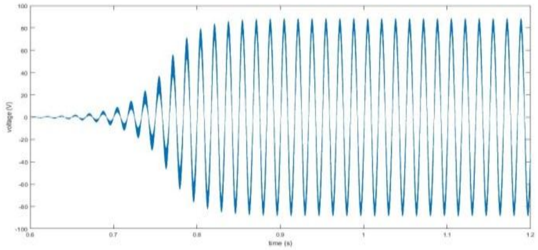

Figure 15: single phase load voltage.

The output voltage of the each inverter shares the load, proportional to their power ratings. The resulting micro-grid does not require communication between the inverters. The synchronization condition is independent ,based on the load parameters and the number of inverters are participating. The simulation results were presented to illustrate the merit of the controller.

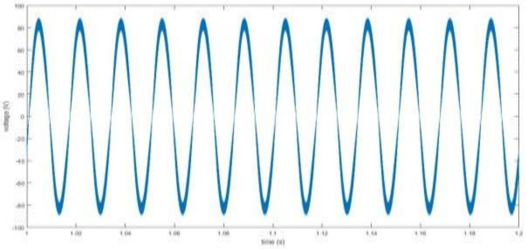

Figure 16: Load voltage after synchronization.

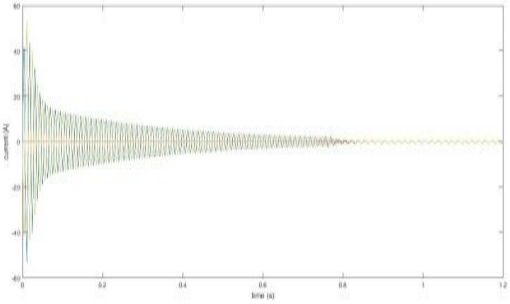

Figure 17: Single phase load current.

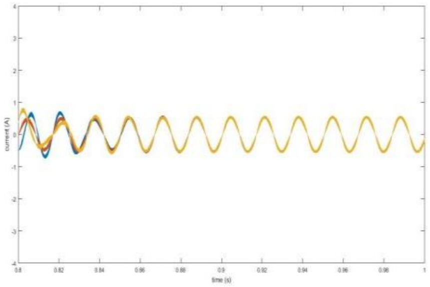

Figure 18: Load current after synchronization.

II. CONCLUSIONS

The virtual oscillator control is implemented in the system of parallel inverters, in which three single-phase inverters are present. The virtual oscillator synchronizes the output voltage of the each inverter shares the load proportional to their power ratings. The resulting micro-grid does not require communication between the inverters. The synchronization condition independent, and is based on the load parameters and number of inverters are participating. The simulation results are used to substantiate the analytical results and illustrate the merit of the proposed application.

REFERENCES

[1] B. B. Johnson, S. V Dhople, A. O. Hamadeh, and P. T. Krein, "Synchronization of Parallel Single-Phase Inverters With Virtual Oscillator Control," *IEEE Trans.*

Power Electron., vol. 29, no. 11, pp. 6124–6138, Nov. 2014.

[2] B. B. Johnson, M. Sinha, N. G. Ainsworth, F. Dorfler, and S. V. Dhople, "Synthesizing Virtual Oscillators to Control Islanded Inverters," *IEEE Trans. Power Electron.*, vol. 31, no. 8, pp. 6002–6015, 2016.

[3] Dhople SV, Johnson BB, Hamadeh AO, "Virtual oscillator control for voltage source inverters", *InCommunication, Control, and Computing (Allerton), 51st Annual Allerton Conference on* IEEE (pp. 1359-1363). 2013.

[4] Dhople, Sairaj V and Johnson, Brian B and Dorfler, Florian and Hamadeh, Abdullah O "Synchronization of Nonlinear Circuits in Dynamic Electrical Networks with General Topologies," *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 61, no. 9, pp. 2677–2690, 2014.

[5] R. Majumder, B. Chaudhuri, A. Ghosh, R. Majumder, G. Ledwich, and F. Zare, "Improvement of stability and load sharing in an autonomous microgrid using supplementary sdroop control loop," *IEEE Trans. Power Syst.*, vol. 25, no. 2, pp. 796–808, 2010.

[6] M. C. Chandorkar, D. M. Divan, and R. Adapa, "Control of parallel connected inverters in standalone AC supply systems," *IEEE Trans. Ind. Appl.*, vol. 29, no. 1, pp. 136–143, 1993.

[7] Mohd A, Ortjohann E, Morton D, Omari O, Review of control techniques for inverter parallel operation. Electrical power system Research 2010 Dec 1:80(12):1477-87.