

Modelling and Simulation of Control Circuit for Oscillator Based Inverter for Microgrids

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Abstract - This paper presents a control strategy for oscillator based inverter for microgrids to enable asymptotic synchronization in order to produce a stable power system. The microgrid is formed by paralleling of three 3-phase inverters; the output of the inverter is programmed to outdo the changing aspects of a non-linear oscillator. The virtual oscillator within the controllers is implicitly coupled through physical electrical network say RLC networks and coordinate transformations. Due to the self-sustaining capability of the oscillators, the inverter ac outputs are synchronized and communication between the inverters is not needed as the controller uses local signals as feedback elements. In this paper, the methodology of the controller is framed in such a way that the inverter output voltage is retained within prescribed limits although there are fluctuations in load. The simulation results prove that the controller retains the voltage fluctuations within $\pm 5\%$.

Keywords: Virtual oscillator, Microgrid, Asymptotic synchronization, Coordinate transformations, Dead zone oscillator, MatLab.

I. INTRODUCTION

Microgrids are alternative approach for integrating small scale distributed energy sources into low voltage electrical systems. Microgrids offer improved reliability, reduced transmission losses, reduces carbon footprint and are isolated from any grid disturbance or outages [1]-[5].

In this paper, an islanded microgrid is considered. The voltage source inverter is supplied through a DC source and any shortage in power is supplied by energy storage devices like battery, by this the system reliability can be improved in case there is any intermittency in the energy generation. The block diagram of the proposed system is shown in Fig 1.

The controller is designed to regulate the output voltage without involving any communication between the inverters. In this paper, the controller called virtual oscillator control (VOC) is employed to emphasize the fact that each inverter is digitally controlled to emulate the dynamics of a nonlinear oscillator, termed as dead zone oscillator. It is in self-sustaining oscillator. This control does not need any supervisory control [6]-[11] so there is no probability of single point failure and also there is no need for any explicit $\sin \theta$ command, no phase locked loop and also no PID controllers are required [12]-[17].

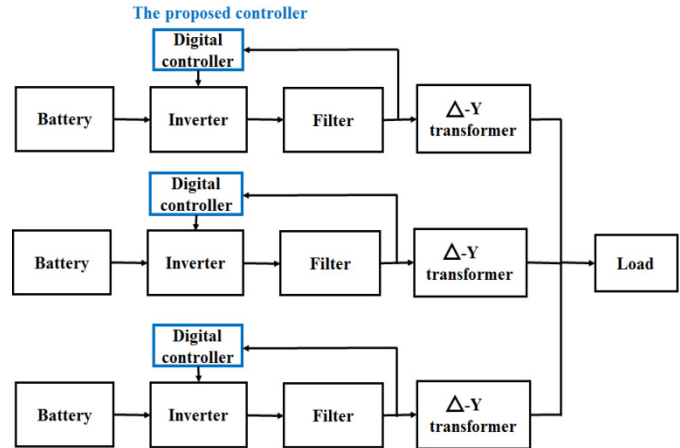


Fig 1. Block diagram of the proposed model

II. DESIGN OF DIGITAL CONTROLLER

The digital controller comprises of a dead zone oscillator along with transformations. The controller provides asymptotic synchronization, asymptotic synchronization means that once synchronisation is achieved, the effect of small perturbation that destroys synchronisation is rapidly damped and synchronisation is achieved again.

The dead zone oscillator comprises of a damping element (R), a resonant LC tank circuit to set the system frequency and a voltage dependent current source to withstand the oscillations. A dead band (sometimes called a neutral zone) is an interval of a signal domain or band where no action occurs, and is used to prevent oscillation or repeated activation-deactivation cycles. Because of the inherent coupling between the oscillators provided by the electrical network the output voltage is synchronize without the need for any communication between the inverters.

As stated above the basic microgrid topology under consideration comprises of three parallel voltage source inverters connected to a load. Each inverter is controlled to emulate the dynamics of the dead-zone oscillator by using the digital controller. In this paper, the controller design in the $\alpha\beta$ frame is focused. Mostly $\alpha\beta$ frame is used in inverters because it converts three phase variables into two phase stationery reference frame thus making the computation simpler [18]-[19].

The schematic diagram of the microgrid with digital controller is shown in Fig 2.

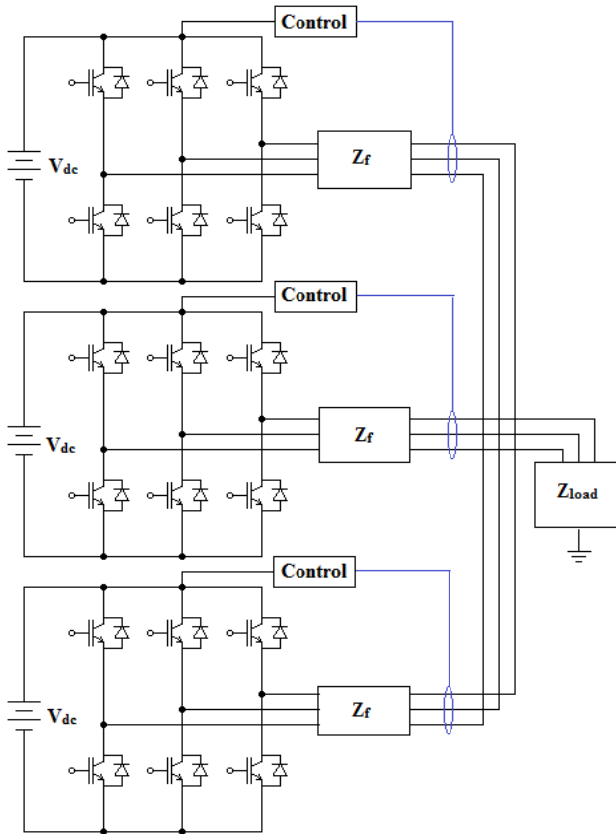


Fig 2. Microgrid composed of three parallel voltage source inverters

The relationship between the original three-phase signals and the transformed signals in the $\alpha\beta$ -frame is related as,

$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} \quad (2)$$

Three phase current i_a, i_b, i_c is drawn from the inverter after filtering. Then three phase to two phase transformation is done for current, here $\alpha\beta$ transformation is done as it converts three phase to two phase stationary reference frame, the conversion matrix for the transformation is given above. The association between the single phase equivalents of the three phase inverter is got by extracting the current i_α from the virtual oscillator.

A. Parameter selection and operation:

The transformed current i_α is given to the controlled current source and the controlled current source supplies the RLC branch. The values of R, L, C must be selected such that

$$R > \frac{1}{\sigma} \quad (3)$$

$$LC = \frac{1}{\omega^2}, \text{ where } \omega = 2\pi f \quad (4)$$

The output from the virtual oscillator is $v_c = V_m \sin \omega t$, the current through the inductor is i_L , the inductor current is multiplied with ωL thus gives inductor voltage v_L , then v_C & v_L are converted to three phase signal using inverse transformation.

The three phase inverter switching action is controlled by modulation signal. The modulation signal is obtained by multiplying the three phase output by v , where, $v = \sqrt{2} V_{rated}$ the output from v is clambered by a factor $2/V_{dc}$, that is, the dc-link voltage. This gives the three phase modulation signal m_a, m_b and m_c . The type of modulation used here is amplitude modulation; the modulation signal is given as input to mathematical sine source. The sine pulse width modulation (SPWM) scheme is used for generating gating pulse for switches in three phase inverter.

III. SIMULATION OF THE DIGITAL CONTROLLER FOR MICROGRID

The system shown in Fig 2 is simulated using MatLab – Simulink [20] and the MatLab schematic is shown in Fig 3.

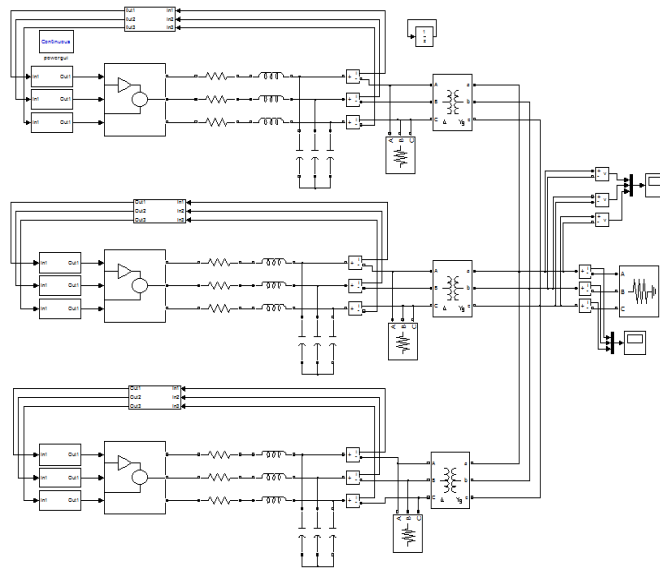


Fig 3. Simulation model of microgrid composed of three parallel inverters

The schematic of implementation of digital controller is shown in Fig 4.

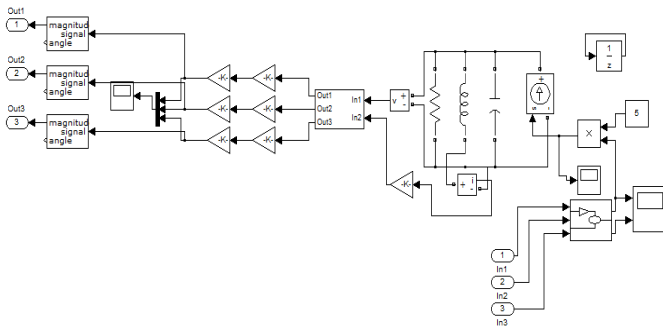


Fig 4. Simulation model of digital controller

The simulation parameters are listed in Table I.

TABLE II. THE PERCENTAGE VOLTAGE VARIATION WITH LOAD CHANGES

Parameters	Values
Input Specifications	
Input Voltage	415V
Frequency	50Hz
Oscillator parameters	
Resistance	10Ω
Inductance	250μH
Capacitance	24mF
Inverter output filter parameters	
Switching frequency	10kHz
Resistance	0.1Ω
Filter inductance	250μF
Filter capacitance	30mF

IV. RESULTS AND DISCUSSION

The microgrid with the proposed digital controller is simulated and the load voltage and load current waveforms are shown in Fig 5 and Fig 6.

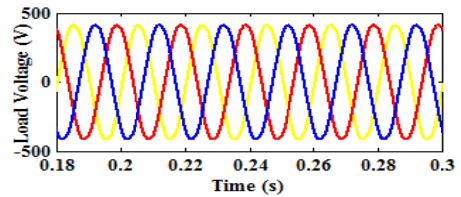


Fig 5. Output voltage of microgrid composed of three parallel inverters

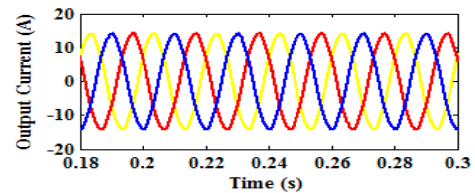


Fig 6. Output current of microgrid composed of three parallel inverters

The output voltage of the system should be within prescribed limits for variation in load. This is validated for the proposed system and the variation of the load voltage with respect to load changes are presented in Table II and Fig 7. Moreover the variation in voltage and current total harmonic distortion (THD) with load variation is shown in Fig 8 and Fig 9 respectively.

TABLE II. THE PERCENTAGE VOLTAGE VARIATION WITH LOAD CHANGES

Load (kW)	Voltage variation (%)
0.1	2.41
0.5	1.24
1	0.72
5	0.24
10	-0.07
15	-0.97
20	-1.7

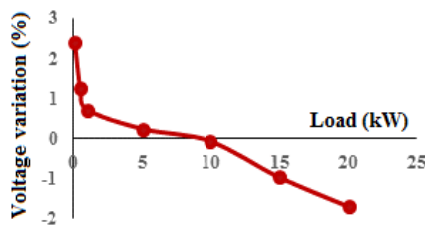


Fig 7. Load changes versus % voltage variation

The main aim of the controller is to maintain the output voltage within prescribed limits even for large load variations. The table and graph shows that the load voltage is maintained within $\pm 5\%$ of the rated voltage.

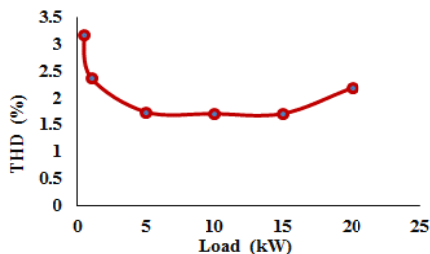


Fig 8. Load changes versus load voltage THD

According to IEEE standard 519, the voltage THD must be within 5% for voltage rating less than 69 kV. The graph shows that THD limits are satisfied for various loading conditions.

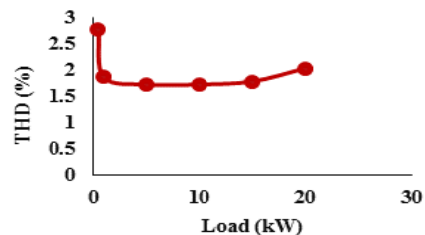


Fig 9. Load changes versus load current THD

According to IEEE standard 519, the current THD must be within 5% for current rating less than 20A. The graph

shows that THD limits are satisfied for various loading conditions.

V. CONCLUSION

A method for controlling a system of parallel inverters without communication between the inverters was introduced and the developed using oscillator-based control scheme in this paper. The concept is used for the design of microgrid for maximizing the energy availability even though there is any ambiguity in ambient conditions and variation of load. The current from the inverter is given as input to the controller, thus the controllers only require local measurements available at the ac terminals; thus shows that communication between inverters is not necessary. Each inverter is provided with a controller, this ensures that there is no centralized control hence there is no single point of failure and also any number of inverters can be connected in parallel. It was shown that due to the self-sustaining capability of the oscillators the system of three inverters synchronizes their ac outputs and share the load. Simulation results demonstrates that the system of inverters continually adjust their output to match load and the load voltage is maintained within $\pm 5\%$ of the rated value.

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REFERENCES

- [1] Brian B. Johnson, Sairaj V. Dhople, James L. Cale, Abdullah O. Hamadeh and Philip T. Krein, "Oscillator-based inverter control for islanded three-phase microgrids", *IEEE journal of photovoltaics*, Vol. 4, No. 1, pp. 387-395, January 2014.
- [2] R. H. Lasseter, "Microgrids", in *Proceedings of the IEEE Power Engineering Society Winter Meeting*, Vol. 1, pp. 305-308, 2002.
- [3] Ritwik Majumder, "Some aspects of stability in microgrids", *IEEE transactions on power systems*, Vol. 28, No. 3, pp. 3243-3252, August 2013
- [4] Salehi Dobakhshari, S. Azizi, and A. M. Ranjbar, "Control of microgrids: Aspects and prospects", *2011 International Conference on Networking, Sensing and Control Delft, the Netherlands*, pp. 11-13 April 2011
- [5] M. Chandorkar, D. 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, Jan. 1993.
- [6] Brian B. Johnson, Sairaj V. Dhople, Abdullah O. Hamadeh, and Philip T. Krein, "Synchronization of parallel single-phase inverters with virtual oscillator control", *IEEE transactions on power electronics*, Vol. 29, No. 11, pp. 6124-6138, November 2014.
- [7] Brian B. Johnson, Sairaj V. Dhople, Abdullah O. Hamadeh, and Philip T. Krein, "Synchronization of nonlinear oscillators in an LTI electrical power network", *IEEE transactions on circuits and systems—i: regular papers*, Vol. 61, No. 3, pp. 834-844, March 2014.
- [8] Sairaj V. Dhople, Brian B. Johnson, and Abdullah O. Hamadeh, "Virtual oscillator control for voltage source inverters", *Fifty-first Annual Allerton Conference Allerton House, UIUC, Illinois, USA October 2 - 3, 2013*.
- [9] Josep M. Guerrero, *Senior Member, IEEE*, Juan C. Vasquez, José Matas, Luis García de Vicuña, and Miguel Castilla,

- “Hierarchical control of droop-controlled AC and DC microgrids - A General Approach Toward Standardization”, *IEEE transactions on industrial electronics*, Vol. 58, No. 1, pp. 158-172, January 2011.
- [10] Mohd, D. Ortjohann, and O. Omari, “Review of control techniques for inverters parallel operation,” *Electr. Power Syst. Res.*, Vol. 80, No. pp. 1477–1487, Dec. 2010.
- [11] F. Katiraei and M. Iravani, “Power management strategies for a microgrid with multiple distributed generation units,” *IEEE Trans. Power Syst.*, Vol. 21, No. 4, pp. 1821-1831, Nov. 2006.
- [12] Maryam Babazadeh, Houshang Karimi, “Robust decentralized control for islanded operation of a microgrid”, *IEEE Power and Energy Society General Meeting*, June 2011.
- [13] J. M. Guerrero, M. Chandorkar, T. Lee, and P. C. Loh, “Advanced control architectures for intelligent microgrids -Part I: Decentralized and hierarchical control,” *IEEE Trans. Ind. Electron.*, Vol. 60, No. 4, pp. 1254-1262, Apr. 2013.
- [14] Josep M. Guerrero, Luis García de Vicuña, José Matas, Miguel Castilla, and Jaume Miret, “A wireless controller to enhance dynamic performance of parallel inverters in distributed generation systems”, *IEEE transactions on power electronics*, Vol. 19, No. 5, pp. 1205-1213, September 2004.
- [15] D. Holmes and T. Lipo, “Pulse width modulation for power converters”, Piscataway, NJ, USA: *IEEE Press*, 2003.
- [16] Mohammad N. Marwali, Jin-Woo Jung, and Ali Keyhani, “Control of distributed generation systems-Part II: Load sharing control”, *IEEE transactions on power electronics*, Vol. 19, No. 6, pp.1551-1561, November 2004.
- [17] Juan C. Vasquez, Josep M. Guerrero, Mehdi Savaghebi, IEEE, Joaquin Eloy-Garcia, and Remus Teodorescu, “Modeling, analysis, and design of stationary-reference-frame droop-controlled parallel three-phase voltage source inverters”, *IEEE transactions on industrial electronics*, Vol. 60, No. 4, pp.1271-1280, April 2013.
- [18] Miranda, L. G. B. Rolim, and M. Aredes, “A DQ synchronous reference frame current control for single-phase converters,” *Proc. IEEE Power Electron. Spec. Conf.*, pp. 1377–1381, 2005.
- [19] Sun Dan, “Clarke’s and Park’s Transformations”, *College of Electrical Engineering*, Zhejiang University, September 2009.
- [20] www.mathworks.com