International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-5, March 2020

Simulation of Phase Angle Control and Condition Based Synchronization Techniques for Parallel Inverters

K. V. Santhosh Kumar, R. Senthil Kumar, T. Alex Stanley Raja, A. Nandhakumar

Abstract— Parallel connection of inverters is one useful method for solving the high power requirements. It reduces the current stress on inverter switches and makes the way for continuous supply to the load.Though any one of the inverter supplying the load gets faulted, the other inverter connected would supply the load. But the problem in this kind of set up is that it needs synchronization techniques for parallel operation or else the inverters will operate in unsynchronized manner and the supply would be in distorted form for the motor load leading to overheating of the load. This paper proposes two software drive control techniques for the parallel operation of inverters in synchronized condition.These software techniques are implemented and results are analysed in the MATLAB environment.

Keywords—Parallel Inverters; Synchronization; Phase difference

I. INTRODUCTION

The power conversion system with large capacity, high reliability, and standard structure, which is realized by multiple power modules operating in parallel mode, is one of the developing trends in modern power electronics technology. Parallel set operation of power modules offers way to increase the power handling capacity of the inverter sets. The total load power is shared among the parallel power modules, the current stress of the power switches of each module is quite small, and the high reliability of the parallel system is obtained. The N+1 redundant parallel operation manner is the optimal scheme for the large power capacity system with high reliability because the fault tolerant power is obtained at low expense. The parallel operation of power converters is the most helpful technique in the industries running critical load. This technique helps to run the load continuously without stopping it and buys time to get replace faulted inverter and put it back on track for supply. Besides these advantages the parallel operation of inverters have synchronization problem. It occurs mainly due to the difference in switching time of the inverters.It can be avoided by providing similar pulses for both the inverters. The inverters should be operated at synchronized condition for proper current sharing and eliminate circulating current.

Revised Manuscript Received on March 30, 2020.
* Correspondence Author
K V Santhosh Kumar*, Asst Prof, Department of EEE, Bannari Amman Institute of Technology**,** Sathy, Tamilnadu, India.
R Senthil Kumar, Professor, Department of EEE, Bannari Amman Institute of Technology, Sathy, Tamilnadu, India.
T Alex Stanley Raja, Asst Prof, Department of EEE, Bannari Amman Institute of Technology, Sathy, Tamilnadu, India.
A Nandhakumar , Asst Prof, Department of EEE, Bannari Amman Institute of Technology, Sathy, Tamilnadu, India.

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

If they are not synchronized then there would be phase differencebetween the outputs of two inverters leading to flow of circulating current in the circuit and the motor load would be affected.

So the synchronization method is essential for parallel operation.

There are several synchronization techniques available for the parallel operation of inverters. The hardware control techniques includes current control scheme[1], controlling the circulating current using balancing reactors[3], decoupled control[2],[4].In this study software drive control technique is discussed and analysed.As the Pulse Width Modulation(PWM) inverters are useful and easy to control the output voltage, it is used as adrive for supplying the three phase ac induction motor load in this study.The software drive control technique done by controlling the phase angles of input reference waveforms of parallel inverters is simulated in the MATLAB environment and the performance of the motor is observed.

II. PARALLEL OPERATION OF INVERTERS

The two three phase PWM inverters are connected in parallel to perform the parallel operation of inverters. The source for the inverters can be separate or same DC source can be used. In this study the parallel inverters are fed from a common rectified DC source. The output from the parallel inverters is given to a single three phase induction motor load. Since the two inverters are connected in parallel the current for the load is equally shared by the two inverters. This makes the reduction in current stress on inverter switches. Fig.2 shows the parallel connection of inverters which is supplying asingle three phase induction motor load. Table 1 shows the parameters of the system.

Parameters	Ratings	
AC Source	440V(rms), 50Hz	
Rectifier	Input - 440V(rms) Output - 600V(avg)	
Parallel Inverters	Input Modulation index Output voltage Output current	600V 0.9 400V(rms) 10A(rms)
Motor load	Rated power Rated voltage Rated speed	4kW 400V 1430rpm

Fig.1 Parameters of the parallel inverter system

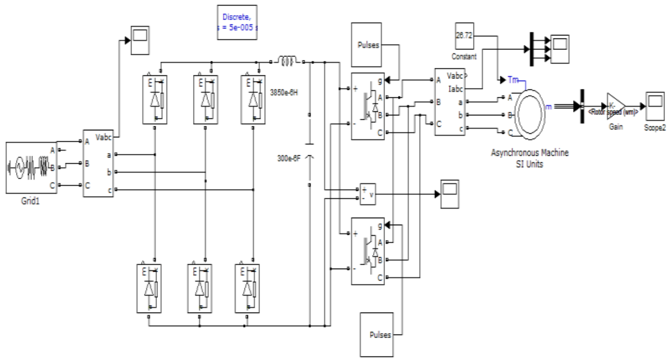

Fig.2 Parallel inverters configuration

In Fig.2, the two inverters are in synchronized condition as pulses for two inverters are similar and are given directly from the pulse generators. Therefore there would be no phase difference between the inverters voltage and current.

III. PROPOSED METHODOLOGY

A. Phase angle control

Since the phase difference of two inverters causes the unsynchronized mode of operation, the software drive technique proposes this phase angle control method. This method makes the control on phase angles of the input reference voltages of two inverters. This method makes sure that phase angles of both the reference voltages are similar. Fig.3 shows the phase angle control block used in the parallel inverter set operation.

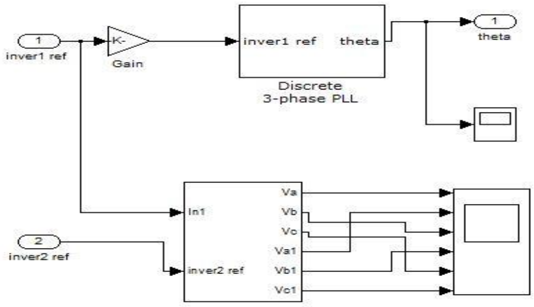

Fig.3 Phase angle control block

The Fig.3 shows that the phase angle control involves the controlling of phase of the second inverter through the first inverter. The phase angle of first inverter reference is given as input for the phase angle of second inverter reference so that there is no phase difference between the reference voltages and hence the inverters would be in synchronized condition. The discrete Phase Locked Loop(PLL) is used to match the phase angles of both the inverters. It measures the phase angle of the input waveform and gives it as output. This block plays the important role in this synchronization technique.

B. Phase difference control using conditional block

The parallel inverters can be operated in a synchronized way once the phase difference between the inverters becomes zero. The phase difference control block measures the phase angles of two inverters references and subtract it, and gives the error value that is subtracted from the phase of second inverter reference. Hence it makes the phase difference between the two inverter references to zero. Fig.4 shows the phase difference control with conditional block.

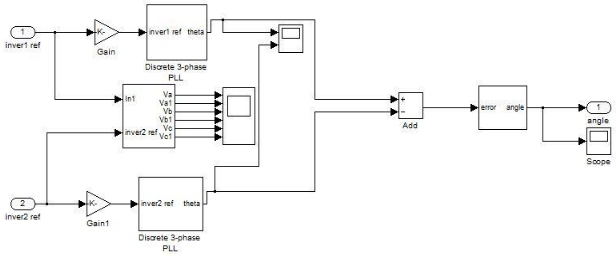

Fig.4 Phase angle difference control using conditional block

The condition is given to maintain the error of phase angle to vary from 0 degrees to 180 degrees so that the sinusoidal reference for second inverter would be in positive values. Fig.5 shows the flowchart for the conditional block.

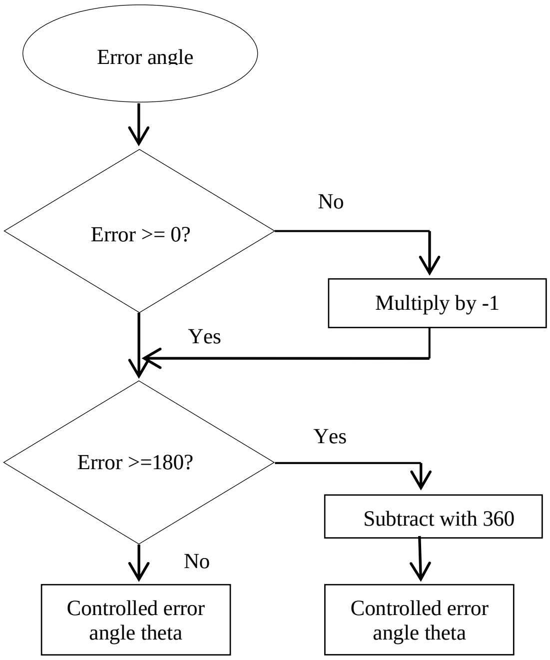

Fig.5 Flowchart for conditional block

IV. SIMULATION AND RESULTS

A. Open loop parallel inverters

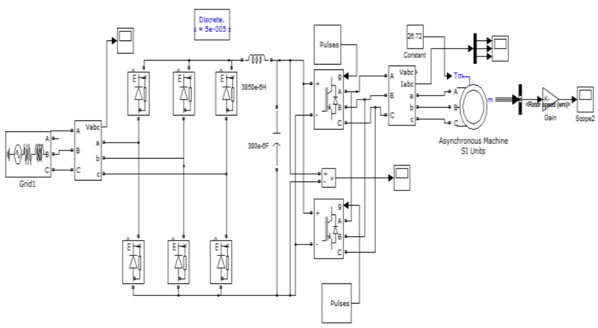

Fig .6 Parallel Inverters supplying a single motor load in open loop

Fig.6 shows the simulation of parallel inverters supplying a single motor load with pulses directly given to the inverters from pulse generators. The phase difference between the pulses is zero and hence both inverters would be operated in synchronized condition. The motor load considered is a three phase induction motor with the rated parameters of 4-pole, 400V, 50Hz, 1430 rpm and full load torque of 26.72 N.m.the modulation index of 0.9 is chosen to get the rated output. The supply from the parallel inverters is given to the motor load and speed of the motor is verified. Fig.7-10 shows the comparison of simulation results of parallel inverters in open loop condition. Fig.7 shows the current shared by the two inverters without having any phase difference between them. Fig.8 shows the current waveform of parallel inverters. From fig.8 it

isobserved that the maximum current of 15 Amps is achieved from the parallel inverters to supply the motor load. From fig.9 it is observed that the maximum voltage of 600V is achieved from the parallel inverters to supply the motor load. Fig.10 shows the speed waveform of motor. It shows that the motor is running linearly without any distortion.

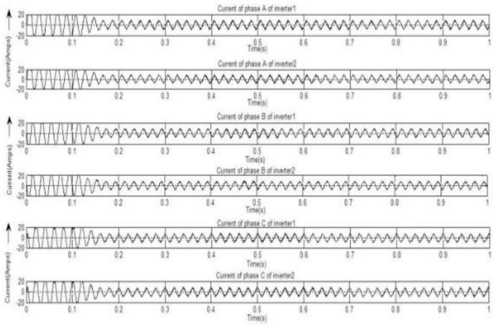

Fig.7Current waveforms of both the inverters

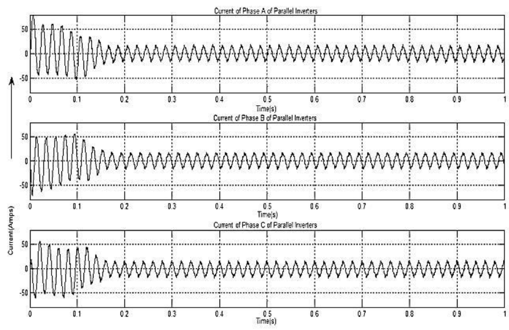

Fig.8 Three phase current waveform of parallel inverters in open loop

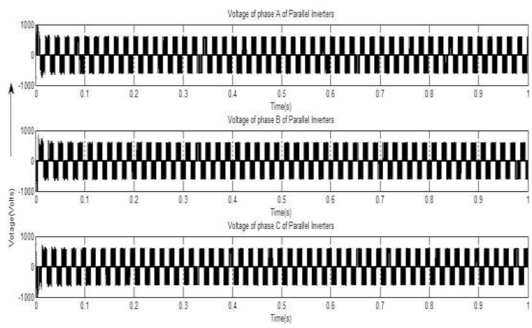

Fig.9 Three phase voltage waveform of parallel inverters in open loop

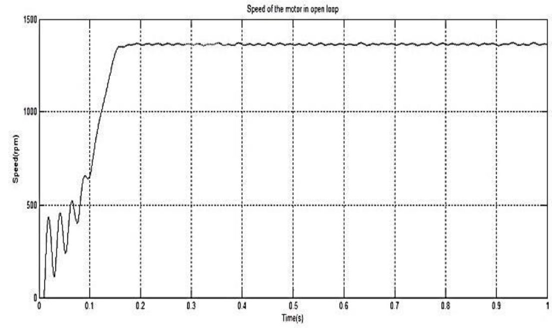

Fig.10 Speed waveform of the motor supplied from parallel inverters in open loop

B. Phase angle control

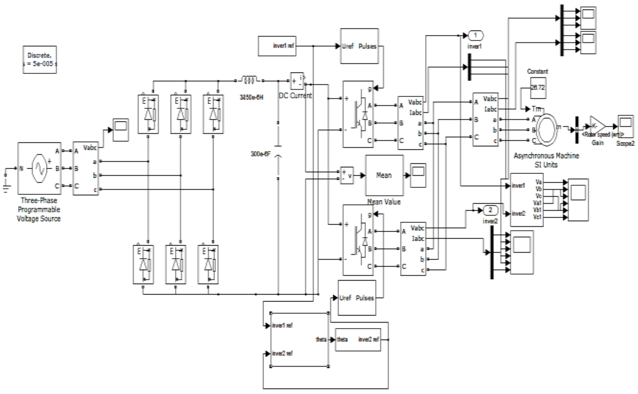

Fig.11 Circuit of parallel inverters using phase angle control

Fig.11 shows the circuit of parallel inverters using the phase angle control. The control block contains the conditionof controlling the phase angle of second inverter reference using the phase angle of first inverter reference. The voltage and current of the parallel inverters obtained are similar to that of in open loop.

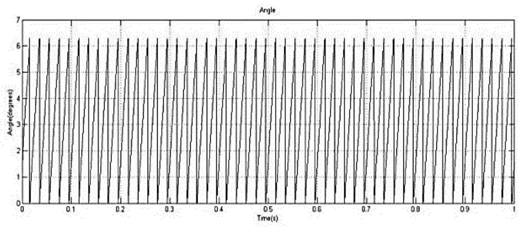

Fig.12Phase angle waveform of first inverter

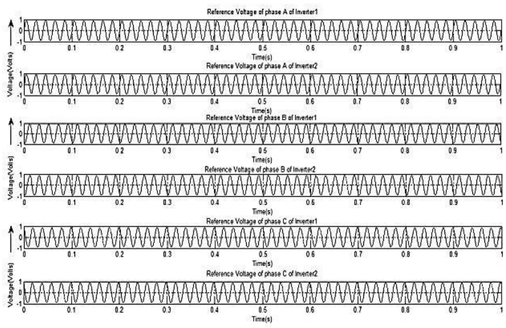

Fig.13 Synchronized reference voltage waveform of parallel inverters

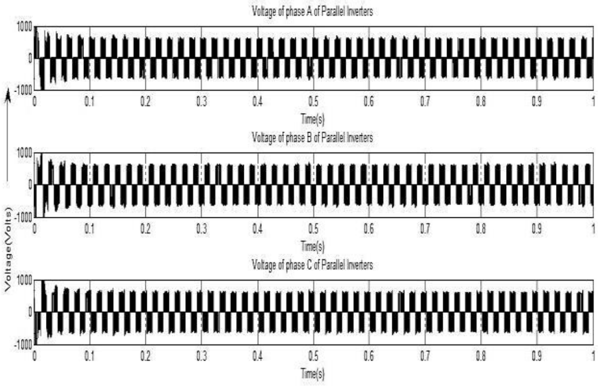

Fig.14 Voltage waveform of parallel inverters using phase angle control

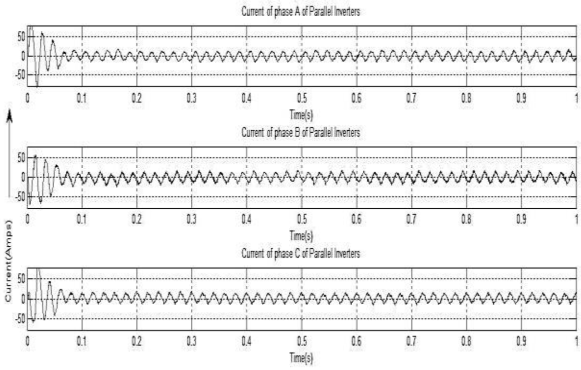

Fig.15 Current waveform of parallel inverters using phase angle control

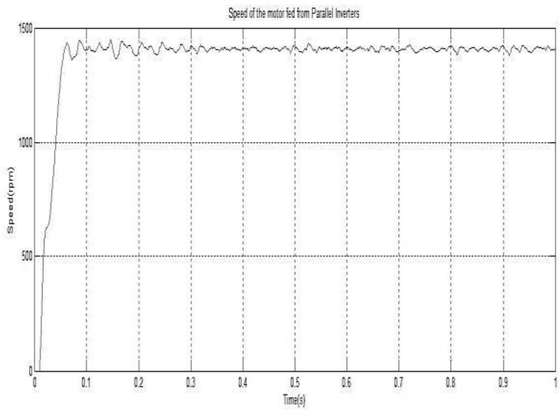

Fig.16 Speed waveform of the motor supplied from parallel inverters using phase angle control

Fig.12 shows the mechanical degrees of phase angle of first inverter reference which is given to the second inverter reference as input. Fig.13 shows the synchronized voltage reference waveform of both the inverters. It shows that the reference waveforms are in phase and hence the inverters are synchronized. Fig.14 and Fig.15 indicates the voltage and current waveforms of parallel inverters using phase angle control which are similar to that of achieved in open loop. Fig.16 shows the speed waveform of the motor which indicates that motor is running linearly using the phase angle control of parallel inverters.

C. Phase difference control

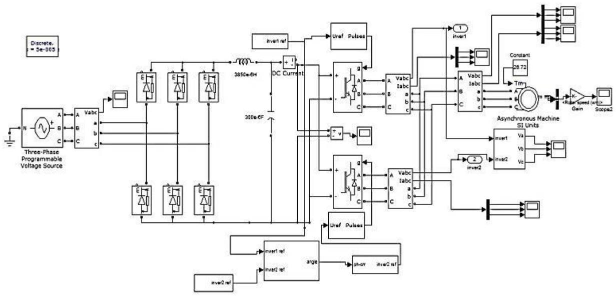

Fig.17 Circuit of parallel inverters using phase difference control

Fig.17 shows the circuit of parallel inverters controlled using phase difference control. The references for two inverters are generated separately and phase difference between the two references is found. The phase angle difference between the two inverters is subtracted from the phase angle of second inverter reference. Hence the parallel inverters are operated in synchronized condition as the phase difference was eliminated. Fig.18 shows speed of the motor supplied from the parallel inverters controlled using the phase difference condition.

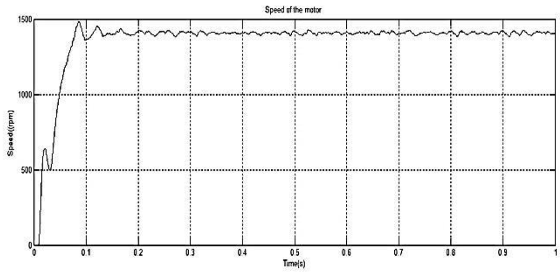

Fig.18 Speed waveform of the motor supplied from parallel inverters using phase angle difference control

V. CONCLUSION

Thus the phase angle control and condition based controlfor the parallel operation of inverters is explained and the output waveforms are obtained in the MATLAB environment. Theresult shows that synchronization of parallel inverters is successfully done using the above said methods.Both the methods are software drive control techniques which does not need any additional hardware set up for giving synchronized pulses to the parallel inverter. The programming of drive controller is enough for synchronization. The phase angle control is simple and best compared to condition based technique stated.

As a future work, filter at the output of parallel inverter would be designed to minimize the ripples in current. Further fuzzy controller or PI based controller can be applied for dynamic pulse generation.

REFERENCES

1. ToshifumiYoshikawa ,HiromiInaba, and Toshisuke Mine, "Analysis of Parallel Operation Methods of PWM Inverter Sets for an Ultra-High Speed Elevator", 0-7803-5864-3/00/,*2000* IEEE.

2. Ming Hua, Haibing Hu, *Member, IEEE*, Yan Xing, *Member, IEEE*, and ZhongyiHe,"Distributed Control for AC Motor Drive Inverters in Parallel Operation", IEEE Transactions On Industrial Electronics, Vol. 58, No. 12, December 2011.
3. Un-Kwan Cho, Jung-SikYim, Seung-Ki Sul," Parallel operation of PWM inverters for high speed motor drive system", 978-1-4244-4783-1/10, 2010 IEEE.
4. Ming Hua, Haibing Hu, Yan Xing, Zhongyi He," Decoupled Control of Inverters in Parallel Operation for AC Motor Drives", 978-1-4244-4649-0/09,2009 IEEE.
5. MitsuyukiHonbu, Yasuo Matsuda, Kouichi Miyazaki, AndYoritoJifuku, "Parallel Operation Techniques of GTO Inverter Sets for Large AC Motor Drives", IEEE Transactions On Industry Applications, Vol. Ia-19, No. 2, March/April 1983.
6. Y. Xing, L. Huang, and Y. Yan, "Redundant parallel control for current regulated inverters with instantaneous current sharing," in Proc. IEEEPower Electron. Spec. Conf., 2003, pp. 1438–1442.
7. A. Nasiri, "Digital control for three-phase series-parallel uninterruptible power supply systems",IEEE Trans. Power Electron., vol. 22, no. 4,pp. 1116–1127, Jul. 2007.
8. S.K. Khadem*, M. Basu, M.F. Conlon, "Parallel operation of inverters and active power filters in distributed generation system-A review", 1364-0321 , 10.1016/j.rser.2011.06.011 , ELSEIVER, 2011.

AUTHORS PROFILE

Santhosh Kumar K V, was born in Tamilnadu, India, on May 17, 1991. He received the B.E degree in Electrical and Electronics Engineering from Bannari Amman Institute of Technology and M.E (Power Electronics and Drives) from PSG College of Technology. He has 5 years of teaching experience. At present he is working as Assistant Professor in EEE Department, Bannari Amman Institute of Technology, Sathyamangalam. Currently he is doing research in power converters for Industrial Drives.

Senthill Kumar R, was born in Tamilnadu, India, on November 2, 1966. He received the B.E degree in Electrical and Electronics Engineering from Madurai Kamaraj University in 1989. He received his M.E (Power Systems) from Annamalai University, in 1991. He has 25 years of teaching experience. At present he is working as Professor in EEE Department, Bannari Amman Institute of Technology, Sathyamangalam. Currently his research includes power converters for renewable systems.

Alex Stanley Raja T, was born in Tamilnadu, India, on October 5, 1986. He received the B.E degree in Electrical and Electronics Engineering and M.E (Power Electronics and Drives) from Bannari Amman Institute of Technology. He has 7 years of teaching experience. At present he is working as Assistant Professor in EEE Department, Bannari Amman Institute of Technology, Sathyamangalam. Currently he is doing research in power converters for hybrid renewable systems.

Nandha Kumar A, was born in Tamilnadu, India, on October 12, 1985. He received the B.E degree in Electrical and Electronics Engineering and M.E (Power Electronics and Drives) from Anna University. He has 9 years of teaching experience. At present he is working as Assistant Professor in EEE Department, Bannari Amman Institute of Technology, Sathyamangalam. Currently his research includes power converters for Renewable systems and machine control.