Lecture Notes in Electrical Engineering 365

Felix Pasila
Yusak Tanoto
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Editors

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Contents

Part I Invited Speaker

1 **Computational Intelligence Based Regulation of the DC Bus in the On-grid Photovoltaic System** 3
Mauridhi Hery Purnomo, Iwan Setiawan and Ardyono Priyadi

2 **Virtual Prototyping of a Compliant Spindle for Robotic Deburring** 17
Giovanni Berselli, Marcello Pellicciari, Gabriele Bigi and Angelo O. Andrisano

3 **A Concept of Multi Rough Sets Defined on Multi-contextual Information Systems** 31
Rolly Intan

Part II Technology Innovation in Robotics Image Recognition and Computational Intelligence Applications

4 **Coordinates Modelling of the Discrete Hexapod Manipulator via Artificial Intelligence** 47
Felix Pasila and Roche Alimin

5 **An Object Recognition in Video Image Using Computer Vision** 55
Sang-gu Kim, Seung-hoon Kang, Joung Gyu Lee and Hoon Jae Lee

6 **Comparative Study on Mammogram Image Enhancement Methods According to the Determinant of Radiography Image Quality** 65
Erna Alimudin, Hanung Adi Nugroho and Teguh Bharata Adji

7 **Clustering and Principal Feature Selection Impact for Internet Traffic Classification Using K-NN** 75
Trianggoro Wiradinata and P. Adi Suryaputra

8 **Altitude Lock Capability Benchmarking: Type 2 Fuzzy, Type 1 Fuzzy, and Fuzzy-PID with Extreme Altitude Change as a Disturbance** 83
Hendi Wicaksono, Yohanes Gunawan, Cornelius Kristanto and Leonardie Haryanto

9 **Indonesian Dynamic Sign Language Recognition at Complex Background with 2D Convolutional Neural Networks** 91
Nehemia Sugianto and Elizabeth Irenne Yuwono

10 **Image-Based Distance Change Identification by Segment Correlation** 99
Nemuel Daniel Pah

11 **Situation Awareness Assessment Mechanism for a Telepresence Robot** 107
Petrus Santoso and Handry Khoswanto

12 **Relevant Features for Classification of Digital Mammogram Images** 115
Erna Alimudin, Hanung Adi Nugroho and Teguh Bharata Adji

13 **Multi-objective Using NSGA-2 for Enhancing the Consistency-Matrix** 123
Abba Suganda Girsang, Sfenrianto and Jarot S. Suroso

14 **Optimization of AI Tactic in Action-RPG Game** 131
Kristo Radion Purba

15 **Direction and Semantic Features for Handwritten Balinese Character Recognition System** 139
Luh Putu Ayu Prapitasari and Komang Budiarta

16 **Energy Decomposition Model Using Takagi-Sugeno Neuro Fuzzy** 149
Yusak Tanoto and Felix Pasila

17 **Odometry Algorithm with Obstacle Avoidance on Mobile Robot Navigation** 155
Handry Khoswanto, Petrus Santoso and Resmana Lim

Part III Technology Innovation in Electrical Engineering, Electric Vehicle and Energy Management

18 **Vision-Based Human Position Estimation and Following Using an Unmanned Hexarotor Helicopter** 165
Jung Hyun Lee and Taeseok Jin

19 **The Role of Renewable Energy: Sumba Iconic Island, an Implementation of 100 Percent Renewable Energy by 2020** 173
Abraham Lomi

20 **Electromechanical Characterization of Bucky Gel Actuator Based on Polymer Composite PCL-PU-CNT for Artificial Muscle** 185
Yudan Whulanza, Andika Praditya Hadiputra, Felix Pasila and Sugeng Supriadi

21 **A Single-Phase Twin-Buck Inverter** 193
Hanny H. Tumbelaka

22 **Performance Comparison of Intelligent Control of Maximum Power Point Tracking in Photovoltaic System** 203
Daniel Martomanggolo Wonohadidjojo

23 **Vehicle Security and Management System on GPS Assisted Vehicle Using Geofence and Google Map** 215
Lanny Agustine, Egber Pangaliela and Hartono Pranjoto

24 **Security and Stability Improvement of Power System Due to Interconnection of DG to the Grid** 227
Ni Putu Agustini, Lauhil Mahfudz Hayusman, Taufik Hidayat and I. Made Wartana

25 **Solar Simulator Using Halogen Lamp for PV Research** 239
Aryuanto Soetedjo, Yusuf Ismail Nakhoda, Abraham Lomi and Teguh Adi Suryanto

26 **Artificial Bee Colony Algorithm for Optimal Power Flow on Transient Stability of Java-Bali 500 KV** 247
Irrine Budi Sulistiawati and M. Ibrahim Ashari

27 **Sizing and Costs Implications of Long-Term Electricity Planning: A Case of Kupang City, Indonesia** 257
Daniel Rohi and Yusak Tanoto

28 **Dynamic Simulation of Wheel Drive and Suspension System in a Through-the-Road Parallel Hybrid Electric Vehicle** 263
Mohamad Yamin, Cokorda P. Mahandari and Rasyid H. Sudono

29 **A Reliable, Low-Cost, and Low-Power Base Platform for Energy Management System** 271
Henry Hermawan, Edward Oesnawi and Albert Darmaliputra

30 **Android Application for Distribution Switchboard Design** 279
Julius Sentosa Setiadji, Kevin Budihargono and Petrus Santoso

Part IV Technology Innovation in Electronic, Manufacturing, Instrumentation and Material Engineering

31 **Adaptive Bilateral Filter for Infrared Small Target Enhancement** 289
Tae Wuk Bae and Hwi Gang Kim

32 **Innovative Tester for Underwater Locator Beacon Used in Flight/Voyage Recorder (Black Box)** 299
Hartono Pranjoto and Sutoyo

33 **2D CFD Model of Blunt NACA 0018 at High Reynolds Number for Improving Vertical Axis Turbine Performance** 309
Nu Rhahida Arini, Stephen R. Turnock and Mingyi Tan

34 **Recycling of the Ash Waste by Electric Plasma Treatment to Produce Fibrous Materials** 319
S.L. Buyantuev, A.S. Kondratenko, E.T. Bazarsadaev and A.B. Khmelev

35 **Performance Evaluation of Welded Knitted E-Fabrics for Electrical Resistance Heating** 327
Senem Kursun Bahadir, Ozgur Atalay, Fatma Kalaoglu, Savvas Vassiliadis and Stelios Potirakis

36 **IP Based Module for Building Automation System** 337
J.D. Irawan, S. Prasetio and S.A. Wibowo

37 **Influence of CTAB and Sonication on Nickel Hydroxide Nanoparticles Synthesis by Electrolysis at High Voltage** 345
Yanatra Budipramana, Suprapto, Taslim Ersam and Fredy Kurniawan

38 **Waste Industrial Processing of Boron-Treated by Plasma Arc to Produce the Melt and Fiber Materials** 353
S.L. Buyantuev, Ning Guiling, A.S. Kondratenko, Junwei Ye, E.T. Bazarsadaev, A.B. Khmelev and Shuhong Guo

39 **Design of Arrhythmia Detection Device Based on Fingertip Pulse Sensor** 363
R. Wahyu Kusuma, R. Al Aziz Abbie and Purnawarman Musa

40 **Analysis of Fundamental Frequency and Formant Frequency for Speaker 'Makhraj' Pronunciation with DTW Method** 373
Muhammad Subali, Miftah Andriansyah and Christanto Sinambela

41 **Design and Fabrication of "Ha (ﻫ)" Shape-Slot Microstrip Antenna for WLAN 2.4 GHz** 383
Srisanto Sotyohadi, Sholeh Hadi Pramono and Moechammad Sarosa

42 **Investigation of the Electric Discharge Machining on the Stability of Coal-Water Slurries** 393
S.L. Buyantuev, A.B. Khmelev, A.S. Kondratenko and F.P. Baldynova

43 **A River Water Level Monitoring System Using Android-Based Wireless Sensor Networks for a Flood Early Warning System** 401
Riny Sulistyowati, Hari Agus Sujono and Ahmad Khamdi Musthofa

44 **The Influence of Depth of Cut, Feed Rate and Step-Over on Surface Roughness of Polycarbonate Material in Subtractive Rapid Prototyping** 409
The Jaya Suteja

45 **Adaptive Cars Headlamps System with Image Processing and Lighting Angle Control** 415
William Tandy Prasetyo, Petrus Santoso and Resmana Lim

46 **Changes in the Rheological Properties and the Selection of a Mathematical Model of the Behavior of Coal-Water Slurry During Transport and Storage** 423
S.L. Buyantuev, A.B. Khmelev and A.S. Kondratenko

47 **Design of a Fetal Heartbeat Detector** 429
Nur Sultan Salahuddin, Sri Poernomo Sari, Paulus A. Jambormias and Johan Harlan

Part V **Technology Innovation in Internet of Things and Its Applications**

48 **Network Traffic and Security Event Collecting System** 439
Hee-Seung Son, Jin-Heung Lee, Tae-Yong Kim and Sang-Gon Lee

49 **Paper Prototyping for BatiKids: A Technique to Examine Children's Interaction and Feedback in Designing a Game-Based Learning** 447
Hestiasari Rante, Heidi Schelhowe and Michael Lund

50 **Tracing Related Scientific Papers by a Given Seed Paper Using Parscit** 457
Resmana Lim, Indra Ruslan, Hansin Susatya, Adi Wibowo, Andreas Handojo and Raymond Sutjiadi

51 **Factors Affecting Edmodo Adoption as Online Learning Medium** 465
Iwa Sungkono Herlambangkoro and Trianggoro Wiradinata

52 **Principal Feature Selection Impact for Internet Traffic Classification Using Naïve Bayes** 475
Adi Suryaputra Paramita

53 **Study on the Public Sector Information (PSI) Service Model for Science and Technology Domain in South Korea** 481
Yong Ho Lee

54 **Digital Natives: Its Characteristics and Challenge to the Library Service Quality** 487
Siana Halim, Felecia, Inggrid, Dian Wulandari and Demmy Kasih

55 **Web-Based Design of the Regional Health Service System in Bogor Regency** 495
B. Sundari, Revida Iriana and Bertilia Lina Kusrina

56 **Security Handwritten Documents Using Inner Product** 501
Syaifudin and Dian Pratiwi

57 **Augmented Reality Technique for Climate Change Mitigation** 511
Ruswandi Tahrir

58 **Cyber Security for Website of Technology Policy Laboratory** 521
Jarot S. Suroso

59 **TAM-MOA Hybrid Model to Analyze the Acceptance of Smartphone for Pediatricians in Teaching Hospital in Indonesia** 529
Oktri Mohammad Firdaus, Nanan Sekarwana, T.M.A. Ari Samadhi and Kah Hin Chai

60 **Development of the Remote Instrumentation Systems Based on Embedded Web to Support Remote Laboratory** 537
F. Yudi Limpraptono and Irmalia Suryani Faradisa

61 **Enhancing University Library Services with Mobile Library Information System** 545
Singgih Lukman Anggana and Stephanus Eko Wahyudi

62 **Multi Level Filtering to Classify and Block Undesirable Explicit Material in Website** 553
Mohammad Iqbal, Hifshan Riesvicky, Hasma Rasjid and Yulia Charli

63 **Query Rewriting and Corpus of Semantic Similarity as Encryption Method for Documents in Indonesian Language** 565
Detty Purnamasari, Rini Arianty, Diana Tri Susetianingtias and Reni Diah Kusumawati

64 **Securing Client-Server Application Design for Information System Inventory** 573
Ibnu Gunawan, Djoni Haryadi Setiabudi, Agustinus Noertjahyana and Yongky Hermawan

Part VI Technology Innovation in Information, Modelling and Mobile Applications

65 **Analyzing Humanitarian Logistic Coordination for Disaster Relief in Indonesia** 583
Tanti Octavia, I. Gede Agus Widyadana and Herry Christian Palit

66 **Surakarta Cultural Heritage Management Based on Geographic Information Systems** 589
Ery Dewayani and M. Viny Christanti

67 **Gray Code of Generating Tree of *n* Permutation with *m* Cycles** 599
Sulistyo Puspitodjati, Henny Widowati and Crispina Pardede

68 **Android and iOS Hybrid Applications for Surabaya Public Transport Information** 607
Djoni Haryadi Setiabudi and Lady Joanne Tjahyana

69 **Games and Multimedia Implementation on Heroic Battle of Surabaya: An Android Based Mobile Device Application** 619
Andreas Handojo, Resmana Lim, Justinus Andjarwirawan and Sandy Sunaryo

70 **Streamlining Business Process: A Case Study of Optimizing a Business Process to Issue a Letter of Assignment for a Lecturer in the University of Surabaya** 631
S.T. Jimmy

71 **Design of Adventure Indonesian Folklore Game** 639
Kartika Gunadi, Liliana and Harvey Tjahjono

72 **Measuring the Usage Level of the IE Tools in SMEs Using Malcolm Baldrige Scoring System** 649
I. Nyoman Sutapa, Togas W.S. Panjaitan and Jani Rahardjo

73 **Enumeration and Generation Aspects of Tribonacci Strings** 659
Maukar, Asep Juarna and Djati Kerami

74 **A Leukocyte Detection System Using Scale Invariant Feature Transform Method** 669
Lina and Budi Dharmawan

75 **The Diameter of Enhanced Extended Fibonacci Cube Interconnection Networks** 675
Ernastuti, Mufid Nilmada and Ravi Salim

76 **Prototype Design of a Realtime Monitoring System of a Fuel Tank at a Gas Station Using an Android-Based Mobile Application** 685
Riny Sulityowati and Bayu Bhahtra Kurnia Rafik

Introduction

This book includes the original, peer-reviewed research papers from the 2nd International Conference on Electrical Systems, Technology and Information (ICESTI 2015), held during 9–12 September 2015, at Patra Jasa Resort & Villas Bali, Indonesia.

The primary objective of this book is to provide references for dissemination and discussion of the topics that have been presented in the conference. This volume is unique in that it includes work related to Electrical Engineering, Technology and Information towards their sustainable development. Engineers, researchers as well as lecturers from universities and professionals in industry and government will gain valuable insights into interdisciplinary solutions in the field of Electrical Systems, Technology and Information, and its applications.

The topics of ICESTI 2015 provide a forum for accessing the most up-to-date and authoritative knowledge and the best practices in the field of Electrical Engineering, Technology and Information towards their sustainable development. The editors selected high quality papers from the conference that passed through a minimum of three reviewers, with an acceptance rate of 50.6 %.

In the conference there were three invited papers from keynote speakers, whose papers are also included in this book, entitled: "Computational Intelligence based Regulation of the DC bus in the On-Grid Photovoltaic System", "Virtual Prototyping of a Compliant Spindle for Robotic Deburring" and "A Concept of Multi Rough Sets Defined on Multi-Contextual Information Systems".

The conference also classified the technology innovation topics into five parts: "Technology Innovation in Robotics, Image Recognition and Computational Intelligence Applications", "Technology Innovation in Electrical Engineering, Electric Vehicle and Energy Management", "Technology Innovation in Electronic, Manufacturing, Instrumentation and Material Engineering", "Technology Innovation in Internet of Things and Its Applications" and "Technology Innovation in Information, Modeling and Mobile Applications".

In addition, we are really thankful for the contributions and for the valuable time spent in the review process by our Advisory Boards, Committee Members and Reviewers. Also, we appreciate our collaboration partners (Petra Christian

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On behalf of the editors Felix Pasila

Chapter 21
A Single-Phase Twin-Buck Inverter

Hanny H. Tumbelaka

Abstract This paper proposes a simple single-phase twin-buck inverter to interface a DC source such as a renewable energy source to AC loads. It consisted of two identical buck converters with a sinusoidal duty ratio. The first converter produced a positive half cycle of a 50 Hz sinusoidal output voltage, and the second converter produced the negative one. Then, both of them are integrated using transistors Q3 and Q4. By shifting the phase angle of signals for triggering transistor Q3 and Q4 from a sinusoidal reference signal, the distortion around zero crossing was reduced. The computer simulation results show that the output voltage and current were sinusoidal with harmonic distortion of 1.12 and 0.49 % respectively.

Keywords Buck converter · Single-phase inverter

21.1 Introduction

An inverter converts a DC voltage source or a DC current source to an AC voltage/current. It takes power from a DC source and sends the power to AC loads using power electronic devices. An inverter can be used to interface a renewable energy source such as PV panels to AC loads or a grid [1, 2]. A solar home system is one of the single-phase inverter application. Lamps and home appliances are connected to PV panels as well as to batteries through a single-phase inverter.

There are many types of a single-phase inverter. The most common inverter, especially a voltage source inverter (VSI) is a single-stage bridge pulse-width-modulation (PWM) inverter [2–4]. It generally consists of four switches configured as a bridge with a filter. PWM signals trigger the switches to generate a sinusoidal AC waveform. Recently, a dual-buck full-bridge inverter [5, 6] as well as a two identical boost or buck-boost inverter [1] has been proposed. The main idea in

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developing this inverter was to mitigate a shoot-through problem in a bridge voltage source inverter, which was usually overcome by a dead time to block the upper and lower transistors of each leg.

A different configuration for a single-phase stand-alone inverter comprising of two identical but independent step-down DC-DC converters is presented in this paper to generate a sinusoidal voltage. Basically, a step-down (buck) DC-DC converter changes a high DC value from a DC source to a low DC value needed by a DC load. Therefore, this proposed inverter is very simple and easy to implement. The controller is uncomplicated as well. By varying the duty ratio, it is possible to create a sinusoidal inverter.

21.2 Circuit Configuration

21.2.1 A Basic Step-Down DC-DC Converter

A Single-phase Twin-Buck inverter basically consists of two step-down DC-DC converters. A schematic diagram of a single step-down (buck) DC-DC converter is shown in Fig. 21.1. The working principle of a buck converter has been elaborated in [3, 4]. The transistor is switched ON (during t_{ON}) and OFF (during t_{OFF}). $t_{ON} + t_{OFF} = T_S = 1/f_S$, f_S is a fixed switching frequency. When the transistor is on (mode 1), the inductor current (i_L) builds up. Energy is transferred to the capacitor and the load from the DC voltage source (V_S). The inductor current for mode 1 ($0 \le t \le t_{ON}$) is:

$$V_S = V_O + L\frac{di_L}{dt} \tag{21.1}$$

$$i_L(t) = \frac{V_S - V_O}{L}t + I_{L1(0)} \tag{21.2}$$

where $I_{L1(0)}$ = initial value of i_L for mode 1, and V_O = output voltage

When the transistor is switched off (mode 2), the energy stored in the inductor (L) is released to the capacitor and the load through the free-wheeling diode (D_F). The inductor current decreases. The inductor current for mode 2 ($t_{ON} \le t \le T_S$) is:

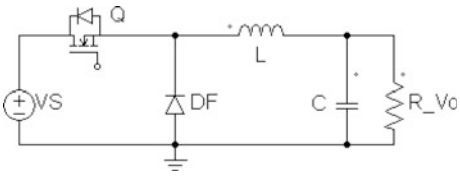

Fig. 21.1 A Step-down (buck) DC-DC converter

$$0 = V_O + L\frac{di_L}{dt} \tag{21.3}$$

$$i_L(t) = \frac{-V_O}{L}t + I_{L2(0)} \tag{21.4}$$

where $I_{L2(0)}$ = initial condition of i_L for mode 2.

In a stable operating cycle, the average inductor voltage is zero, then

$$(V_S - V_O)t_{ON} - V_O t_{OFF} = 0 \tag{21.5}$$

where $t_{ON} = KT_S$ and $t_{OFF} = (1\text{-}K)\,T_S$. K = duty ratio, constant value in a range 0–1.

Solving the Eq. (21.5), the relationship of the input-output voltage of the step-down converter is

$$\frac{V_O}{V_S} = \frac{t_{ON}}{t_{ON} + t_{OFF}} = K \tag{21.6}$$

The Eq. (21.6) is valid when the inductor current stays in a continues conduction mode (CCM), which is i_L (t) > 0. $I_{L1(0)}$ and $I_{L2(0)}$ never go to zero.

21.2.2 A Single-Phase Twin-Buck Inverter

In order to generate a sinusoidal output voltage using a buck converter, t_{ON} and t_{OFF} can be varied in proportion to the amplitude of a sine wave. In this case, the duty ratio K is not a constant but has to be controlled according to a sinusoidal pulse-width-modulation (SPWM) rule [3]. The duty ratio becomes k (t) = m_a sin t, where $0 \le m_a \le 100$ %. Then, from Eq. (21.6), the output voltage becomes

$$V_O = V_S m_a \sin t \tag{21.7}$$

However, the converter only produces a positive voltage. Therefore, to generate a complete 50 Hz sinusoidal output voltage, two identical step-down (buck) DC-DC converters are needed. The first converter produces a positive half cycle of a sine wave, while the second converter produces a negative half cycle of a sine wave by inverting the output voltage. Both of them are independent. Hence, each converter only operates in a half period (10 ms).

Figure 21.2 shows the two identical (twin) step-down (buck) DC-DC converter working as an inverter.

From Fig. 21.2, both the upper and the lower buck converter generate a positive half cycle of a 50 Hz sine wave. To produce a sinusoidal output voltage, transistors Q3 and Q4 are used to connect both converters to the load. When Q3 is switched on (Q4 is switched off), the load receives the voltage from the upper converter.

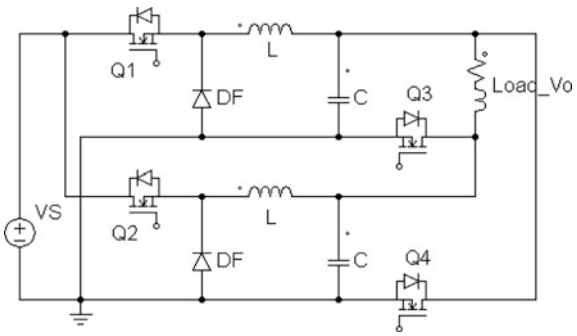

Fig. 21.2 A twin-buck inverter circuit

When Q4 is switched on (Q3 is switched off), the load receives the voltage (inverting) from the lower converter. The transition happens in zero crossing of a sine wave. Hence, for a full period (20 ms for 50 Hz), the load receives an AC sinusoidal voltage.

21.3 Inverter Controller

In order to generate a sinusoidal duty ratio (k(t)), a SPWM controller is used. The circuit diagram of the controller is shown in Fig. 21.3.

V_{REF} is a sinusoidal reference signal with frequency of 50 Hz and the amplitude of m_a. As carrier signals with a constant high switching frequency, V_{TRI} (1) is a triangular wave above the t axis, and V_{TRI} (2) is a triangular wave below the t axis. As a result, during a positive half cycle, the controller produces SPWM signals to trigger transistors Q1, while signals for Q2 are low. The controller also generates a 50 Hz signal for transistor Q3, which is high. During a negative half cycle, the controller produce SPWM signals to trigger Q2, while signals for Q1 are low. The controller also generates a 50 Hz signal for transistor Q4, which is high.

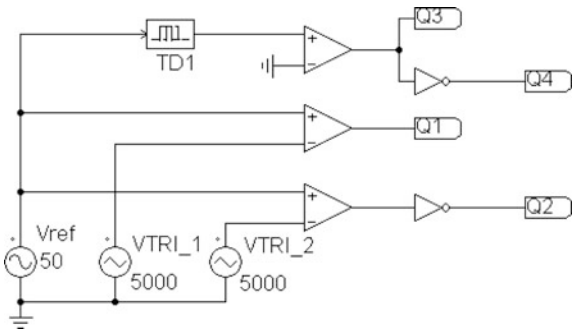

Fig. 21.3 Control circuit diagram

Figures 21.4 and 21.5 demonstrate the sinusoidal reference signal V_{REF} and the carrier signals V_{TRI} (1) and V_{TRI} (2). In this case, the V_{TRI} amplitude = 1 and the frequency is 5 kHz. The amplitude of V_{REF} (m_a) = 0.95 and the frequency is 50 Hz. By using comparators, the controller generates SPWM signals for triggering transistor Q1 and Q2 as shown in Fig. 21.6.

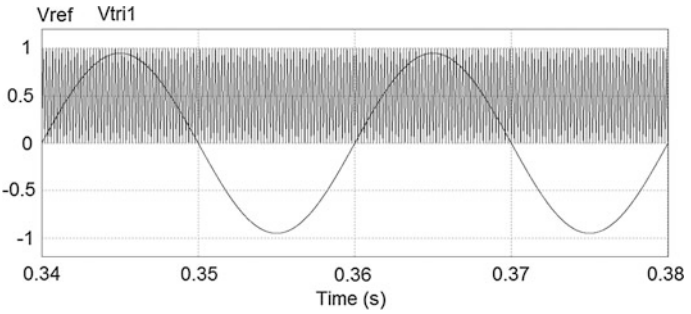

Fig. 21.4 V_{REF} and V_{TRI} (1)

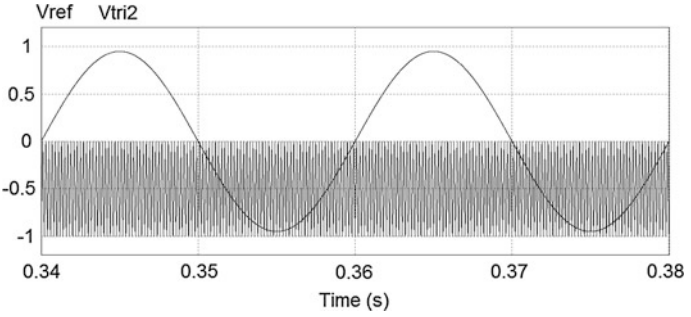

Fig. 21.5 V_{REF} and V_{TRI} (2)

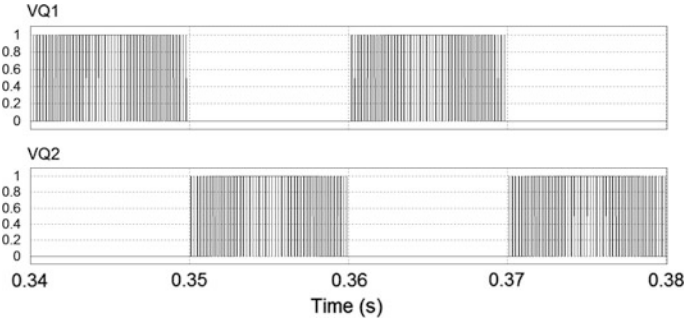

Fig. 21.6 SPWM signals for triggering transistors Q1 and Q2

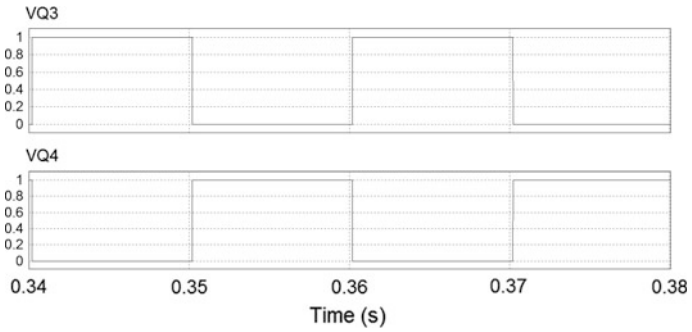

Fig. 21.7 Square signals for triggering transistors Q3 and Q4

Figure 21.7 shows signals for triggering transistors Q3 and Q4. V_{REF} is compared to a zero voltage. During a positive half cycle, the comparator output voltage (Q3) becomes high, and Q4 becomes low. During a negative half cycle, the comparator output voltage (Q3) becomes low, and Q4 becomes high. TD1 is used to shift V_{REF} for several degrees. As a result, the phase of the comparator output voltage Q3 and Q4 will also be shifted compared to the phase of V_{REF}.

21.4 Simulation Results

The circuits in Figs. 21.2 and 21.3 are tested using PSIM simulator to verify the concepts described in previous sections. Circuit parameter values for simulation: source voltage V_S = 24 V, L = 1.2 mH, C = 47 μF, Rload = 6 Ω and Lload = 1.4 mH.

Figure 21.8 demonstrates that the output voltage of the twin-buck inverter is sinusoidal similar to the sinusoidal reference signal V_{REF}. The amplitude equals to a

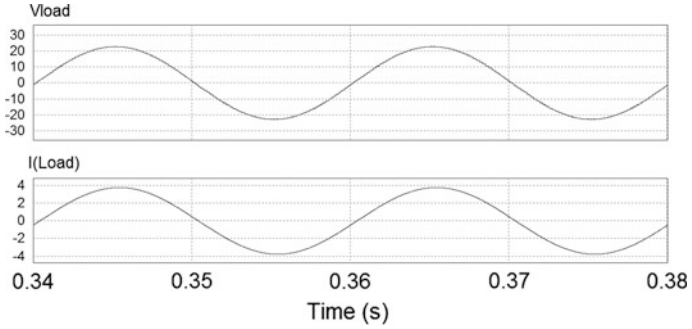

Fig. 21.8 Output voltage and current

DC input voltage (V_S) multiplied by m_a. It is proven that the twin-buck inverter is able to generate an AC sinusoidal voltage. The transition between a positive half cycle and a negative half cycle is smooth. The total harmonic distortion (THD) of this output voltage is 1.12 %. Figure 21.8 also shows the load current, which is an AC sinusoidal current. There is a small phase difference between the output voltage and current due to an inductive component of the load. The total harmonic distortion (THD) of this output current is 0.49 %.

The process to create an AC sinusoidal voltage can be seen from inductor currents i_L (Fig. 21.9) and capacitor voltages V_C (Fig. 21.10). The inductor currents is going up and down in high frequency when the transistor is switched on and off. Because t_{ON} and t_{OFF} are varied according to a sinusoidal duty ratio, then the inductor currents look like a sinusoidal waveform with ripples according to Eqs. (21.2) and (21.4). Figure 21.9b shows the inductor current in detail. The inductor currents are in continuous conduction. Figure 21.10 shows the capacitor voltages. The value of a capacitor determines the ripple of the output voltage. It can be seen that each step-down DC-DC converter operates in a half period and generates a positive half cycle of a sinusoidal waveform.

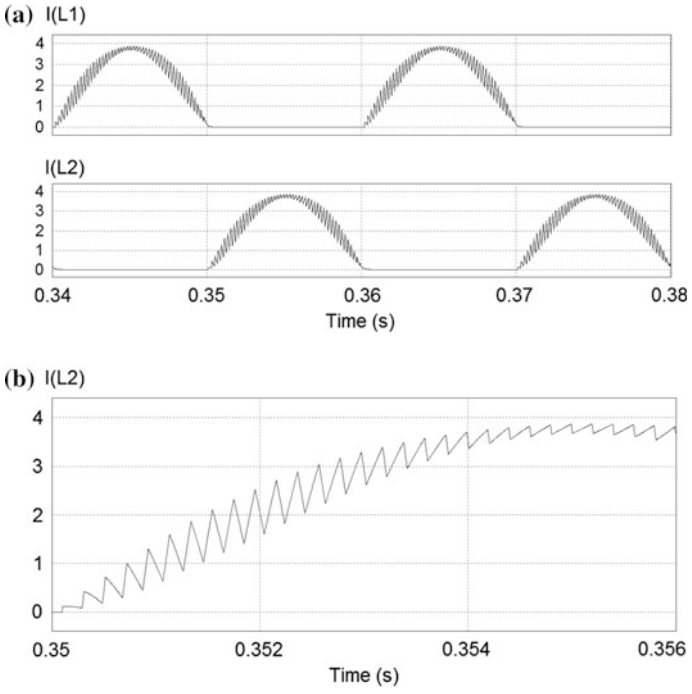

Fig. 21.9 **a** inductor current **b** inductor current in details for time period 0.35 s–0.356 s

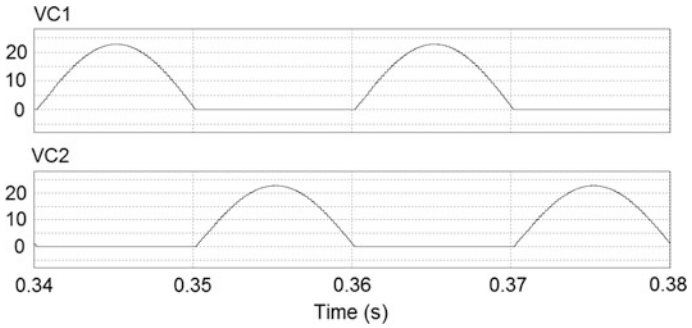

Fig. 21.10 Capacitor (output) voltages

21.4.1 V_{REF} Phase Delay

As mention before in Fig. 21.3, there is a function block TD1 that shifts V_{REF} for several degree. As a result, there is a phase difference between V_{REF} and square signals to trigger transistors Q3 and Q4. The phase shift is needed to overcome the problem of zero-crossing distortion [6]. In the simulation results above, the phase delay is selected to be 3.5°.

Figure 21.11 shows the output voltage and current without phase shift. It can be seen that there is a distortion around zero crossing of the sinusoidal waveform. The total harmonic distortion (THD) of the output voltage and current are 2.42 % and 1.43 % respectively. Compare to inductor current in Fig. 21.9b, the inductor current without phase shift (Fig. 21.12) goes to discontinuous conduction around zero crossing. Consequently, the capacitor voltage is distorted (Fig. 21.13).

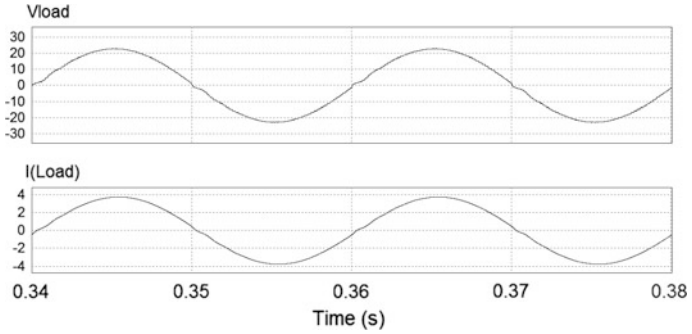

Fig. 21.11 Output voltage and current without phase shift

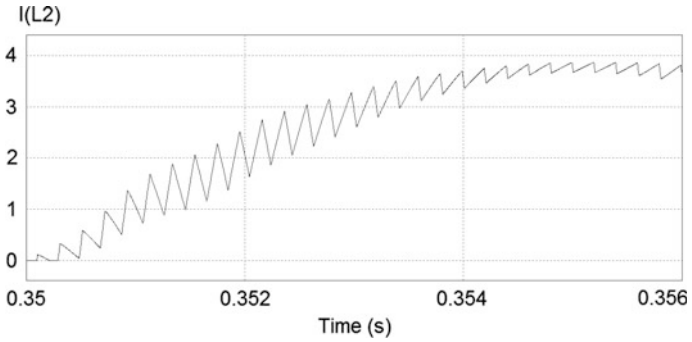

Fig. 21.12 Inductor current without phase shift

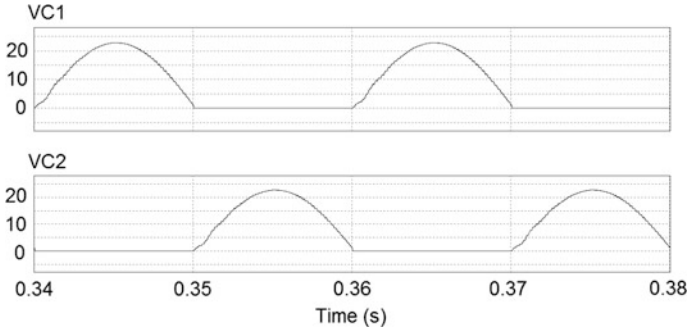

Fig. 21.13 Capacitor voltages without phase shift

21.5 Conclusion

This paper proposes a single-phase twin-buck inverter. The inverter interfaces a DC source to AC loads. It consists of two identical step-down (buck) DC-DC converters with a sinusoidal duty ratio. The first converter produces a positive half cycle of a 50 Hz sinusoidal output voltage, and the second converter produces the negative one. Each converter operates in a half period and generates a positive half cycle of a sinusoidal waveform. Then, both of them are integrated using 2 transistor that operate alternately every 10 ms. By shifting the phase angle of signals (3.5^{o}) for triggering transistor Q3 and Q4 from V_{REF}, the distortion around zero crossing is reduced. Simulation using PSIM shows that the inverter generates a 50 Hz sine wave. The output voltage THD becomes 1.12 %.

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