57 EN-2.3-17

The Controller Based on Genetic Algorithm for Two-Cell Cascade Buck Converter

Santi Wangnipparnto[1], Surattikarn Suwannaprom[2], Anuwat Jangwanitlert[2]

[1]Department of Electrical Engineering,Faculty of Engineering, Pathumwan Institute of technology Bangkok, Thailand 10330

[2]Department of Electrical Engineering, Faculty of Engineering, King Mongkut's Institute of technology Ladkrabang, Bangkok, Thailand 10520

Sr.surattikarn@gmail.com.

Abstract. This paper proposes the design procedure of controller for two-cell cascade buck converter employing transfer function of practical operation with the system identification. The objective for using genetic algorithm and optimization algorithm is to find the answer by the integral time absolute error (ITAE). This controller can provide the performance better than that uses Ziegler-Nichols method which is not suitable because pole position is on imaginary axis. In addition, the simulation and experimental results verify the performance of the proposed controller.

Keywords: Integral Time Absolute Error, Cascade step-down converters

1. Introduction

Switching mode power supplies are extensively used, which are many advantages such as small size, high efficiency and light weight. One of the most interesting switching power supplies is dc-dc converter [1-3]. It uses as a supply source for electronic circuits and so on. Therefore, it needs to be more reliable and more accurate as operating. Because the system may be disturbed, the circuit needs be designed for controlling the dc-dc converter. This is interesting and essential for studying in order to get the results. It is more advantages than the circuit has no the controller. The paper describes the simulation and construction of the controller for dc-dc buck converter. In general, it uses for step-down voltage by variable duty-cycle control. Sometimes, when dc-dc buck converter is used, the voltage input is very high, so the duty cycle causes to be low. However, a step-down transformer is a choice for using in dc-dc buck converter. Moreover, there is a problem in switching surges of the switching devices. The solution for it needs constructing the step-down cascade converter [4]. It can work well in reducing output voltage to be very low by using not too small duty cycle, unlike the traditional buck converter. Therefore, to operate circuit works as designed, the controller should be designed suitably.

The paper presents the controller of a good performance response when it is compared with that of Ziegler-Nichols method. The simulation and experimental results are good agreement with the designed controller.

2. TWO-CELL CASCADE BUCK CONVERTER AND MATHEMATICAL MODEL [4]

Fig. 1 shows two-cell cascade buck converter. The input voltage, V_i, is dc voltage and duty cycle, K, is used for adjusting the output voltage, Vo. Two switches, S_1 and S_2, are operated simultaneously. Therefore, the circuit is operated by receiving voltage input, and duty cycle of two switches is variable in order to adjust voltage output simultaneously. There are two modes of operation: Mode 1 indicates that two switches conducts shown in Fig. 2(a). Mode 2 indicates that switches are turned off, but two diodes are turned on at the same time as shown in Fig. 2(b). Followed by KCL and KVL law, the voltage across switches and diodes are neglected as turned on. The relationship of voltage and current of two modes are expressed by:

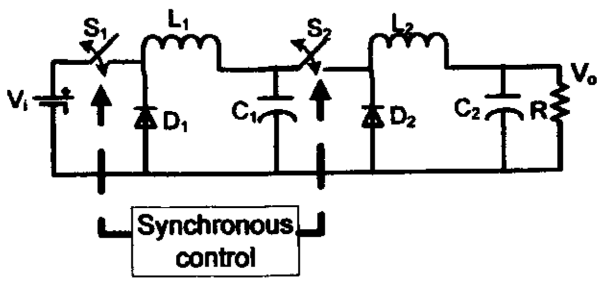


Fig. 1 Two-cell cascade buck converter

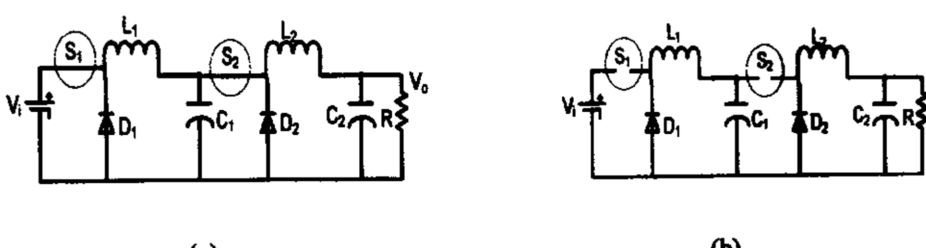


Fig. 2 Operation circuit: (a) switches are turned on, (b) switches are turned off

TABLE I. VOLTAGE AND CURRENT AS TURNED-ON AND TURNED-OFF SWITCHES.

Turn-on Switches	Turn-off Switches
$V_{L1} = V - V_{C1}$	$V_{L1} = -V_{C1}$
$V_{L2} = V_{C1} - V_{C2}$	$V_{L2} = -V_{C2}$
$i_{C1} = i_{L1} + i_{L2}$	$i_{C1} = i_{L1}$
$i_{C2} = i_{L2} + i_R$	$i_{C2} = i_{L2} + i_R$

A.Relationship of voltage output and other parameters [4]

$$V_o = \frac{(RK^2)V_i}{K_2 r_1 + r_2 + R} \quad (1)$$

The small-signal transfer function duty cycle [5] to voltage output is given by:

$$\frac{\tilde{v}_o}{\tilde{d}} = \frac{V_i K(R(1+sC_2 r_c) + K(K-1)(L_1 s + r_1) + RC_1 s((1+sC_2 r_c)(L_1 s + r_1)))}{[\Delta_p + ((K^2)(L_1 s + r_1) + (L_2 s + r_2)(1+sC_2(R+r_c))) + R(1+sC_2 r_c)(C_1 s(L_1 s + r_1)+1)]} \quad (2)$$

Where $\Delta_p = sC_1(sL_1 + r_1)(sL_2 + r_2)(1 + sRC_2)$

K is duty cycle, r_1 is parasitic resistance of inductor L_1, r_2 is parasitic resistance of inductor L_2, r_c is parasitic resistance of capacitor C

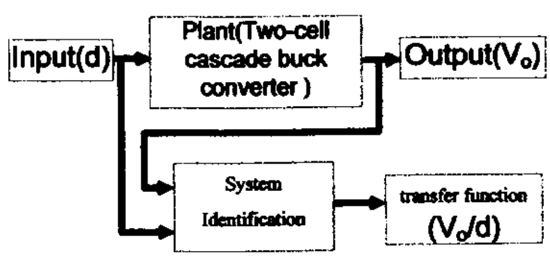


Fig. 3 Procedure of system identification.

B.System Identification

Due to various parameters, such as parasitic resistance of capacitor or inductor with in-exact values, the method for finding relationship with (2) may be inaccurate as well. We will accept the error value if we measure the parameter to be in- exact or operating disturbance. It causes the relationship with (2) changing or error. Therefore, the relationship equation between input and output parameters, derived from the experiment al data, will give the practical mathematical equation. The input is provided for system and output response is measured by experiment which can have the system relationship. This paper employs the MATLABR program with System Identification Toolbox for analyzing as shown in Fig.3. The results are shown in the experiment.

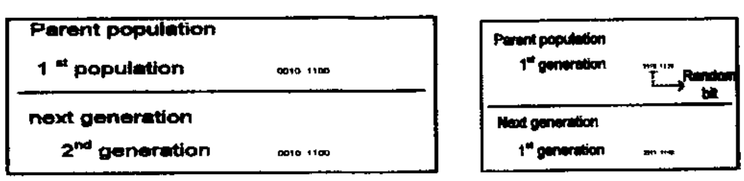
3. GENETIC ALGORITHM

There are many methods for finding of optimization solution. One of them is called Genetic algorithm [5-6]. It is the method having more efficiency than others. The operation is simulated for selecting good and appropriate genes to solve the answer followed by objective conditions and functions. First, the answers are random that are called population and each member is called chromosome. The chromosome is composed of genetic line-up connection. Then, population is replaced into objective function. The results are suitable and then these are selected as genetic parents to become a parent chromosome. These transfer to next generation and repeat this procedure again and again. This principle or other methods is that appropriate chromosome will be more chosen. The genetic algorithm has three main types for producing next generation. First type is reproduction. Second type is crossover and the last one is mutation. Procedure of genetic algorithm is shown in Fig.4.

4. PROPOSED TECHNIQUE

The structure of controller is firstly defined. The controller will have parameters that can be changed. The equation of controller is given by:

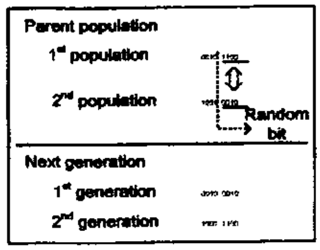
$$Controller_{PI} = K_P + \frac{K_I}{S} \tag{3}$$



(a) (b)

Fig. 4 Genetic algorithm for producing the next generation (a) reproduction (b) mutation

(c) crossover



(c)

Fig. 4 Genetic algorithm for producing the next generation (a) reproduction (b) mutation (c) crossover

Next, the genetic algorithm is used for finding suitable parameters in order to obtain smallest ITAE, effecting J_{cost} to be biggest value. This objective function Jcost is expressed by:

$$J_{cost} = \frac{1}{ITAE} = \frac{1}{\int_0^\infty t|e(t)|dt} \tag{4}$$

Where ITAE is Integral Time Absolute Error.

Designing controller is used to find Jcost function. The appropriate function will be defined as a very small value. If parameters of controller cause,

- percentage of overshoot is over than 3%
- rise time is over than 5ms

Fig. 5 shows the procedure of finding controller by using genetic algorithm which can be concluded as follows:

Procedure 1: Define parameters and boundary of controller and use genetic algorithm to find appropriate parameters

Procedure 2: Define parameters for 1st generation by random using genetic algorithm

Procedure 3: Find appropriate function of each chromosome. If any chromosome gets maximum suitable value, it will be the answer of this generation.

Procedure 4: Select gene to be genetic parent and transfer to next generation

Procedure 5: Feedback to Procedure 3. If the next generation is equal to defined generation, the procedure stops. The chromosome gives the value of maximum suitable function. This is the answer.

5. SIMULATION AND EXPERIMENTAL RESULTS

The parameters from experiment will be defined as follows in Table 2 [4].

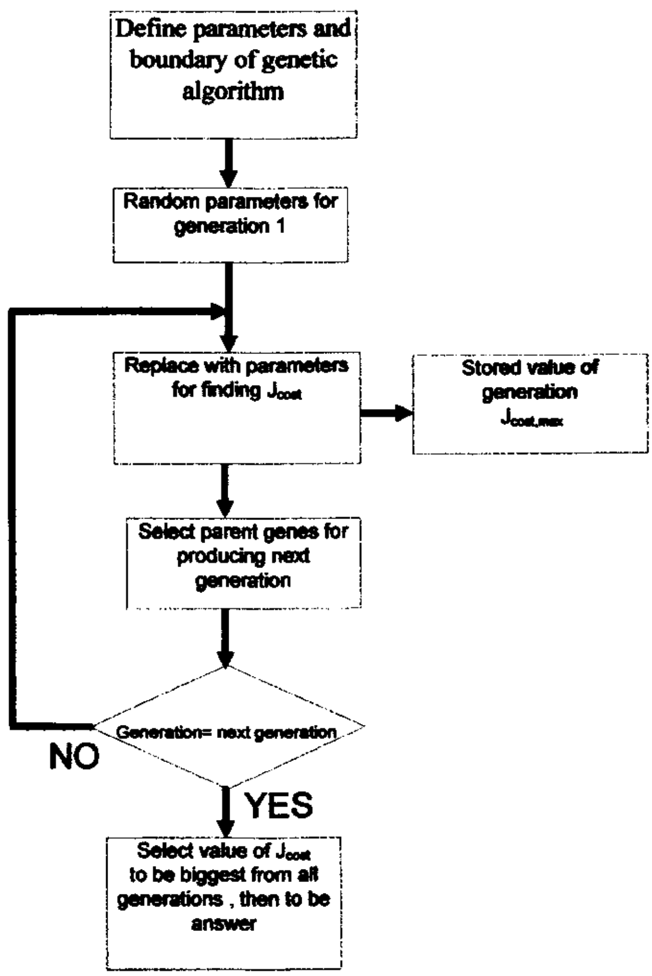


Fig. 5 Procedure of finding controller by using genetic algorithm.

TABLE II. SYSTEM PARAMETERS.

Parameters	Value
V_i	16 V
V_o(set point)	4 V
R	10 ohm
L_1	124uH
L_2	127uH
K	0.5
C_1	93uF
C_2	92.86uF
r_l	0.049 ohm
r_l	0.053 ohm
r_c	0.259 ohm

Fig. 6 shows the stored voltage output signal and duty cycle, respectively. The voltage output oscillates between 0 and 4 volts followed by duty cycle of 0 to 0.5, respectively. Fig. 7 shows the procedure of finding transfer function of system. The value from system identification toolbox is closed to the practical system of 94.37%. The transfer function from duty cycle to voltage output is given by:

$$\frac{v_o}{d}=\frac{-6007s^3+6.896x10^8s^2+6.518x10^{11}s+4.36x10^{13}}{s^4+9080s^3+1.08x10^8s^2+8.51x10^{10}s+5.556x10^{12}} \quad (5)$$

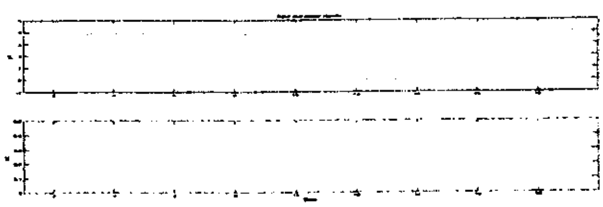


Fig. 6 (a) voltage output (top) and duty cycle (bottom)

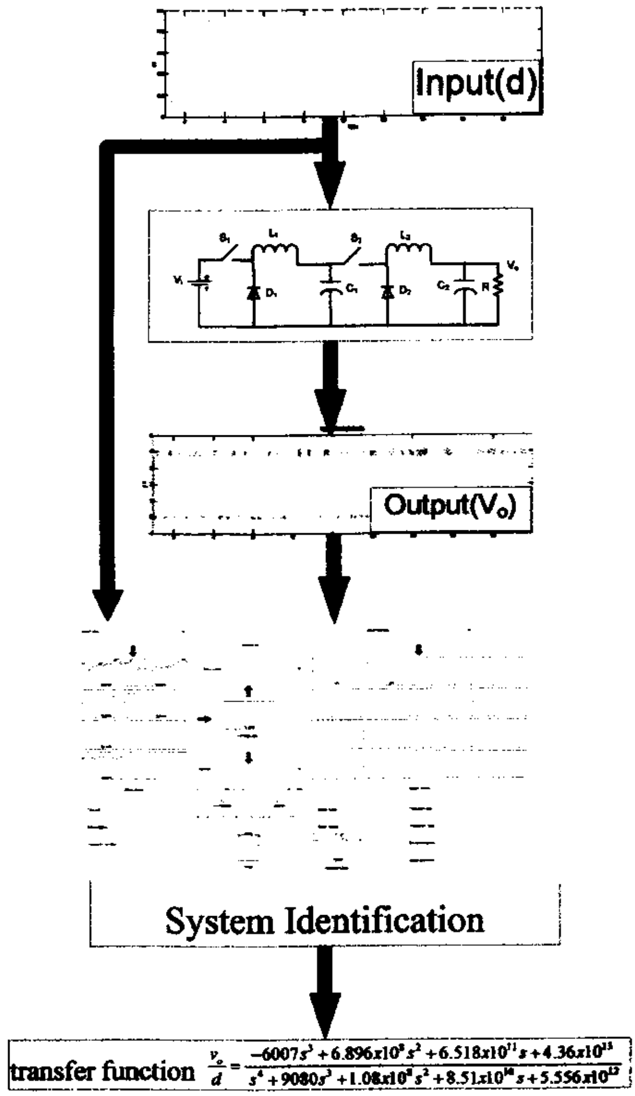


Fig. 7 Procedure of finding transfer function of system.

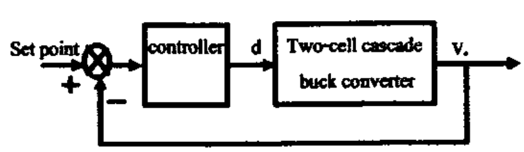


Fig.8 Closed-loop control.

When transfer function of system is derived, the value of controller is gotten and put it on followed by Fig.8. The proposed controller is based on Genetic Algorithm (GA) principle which defines the structure of controller as follows:

$$Controller_{PI} = K_P + \frac{K_I}{S}$$

where K_P and K_I are variables for controller.

The defined boundary of controller variables will be suitable. There are:

$K_P \in [0 \quad 1]$, $K_I \in [0 \quad 500]$, and numbers of generation are equal to 200 generations

The simulation result is obtained for the best appropriate function. The fitness value from Fig. 9 is 691.859108. The best result is converged to 61st generation and constant at 200th generation. Table 3 shows the results of proposed controller, compared with those of Ziegler-Nichols controller for tuning method from SISO Design tool.

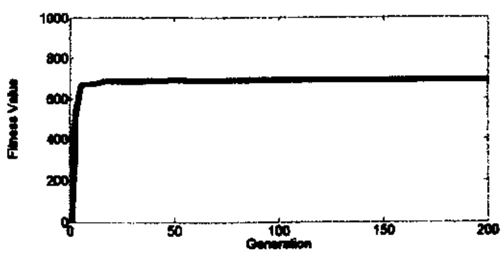


Fig. 9 Fitness for the best result in each generation from 1st generation to 200th generation.

TABLE III.SYSTEM PARAMETERS.

	Proposed controller	*Ziegler Nichols*'s controller
	$0.009993 + \frac{89.78}{s}$	$\frac{1921.6(1+0.00015s)}{s}$
% Overshoot	0	52.6
Rise time	$3.06X10^{-3}$	$7.64X10^{-5}$

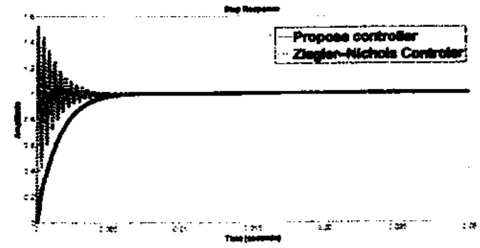
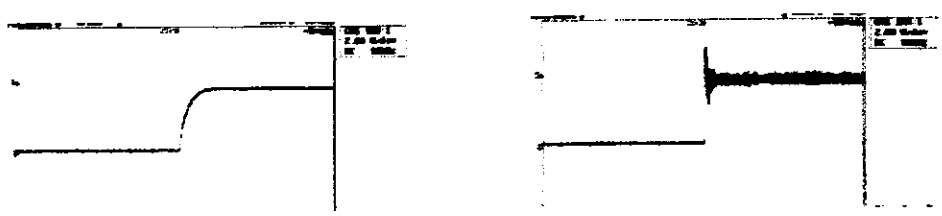


Fig. 10 Response voltage output of simulation from step input.

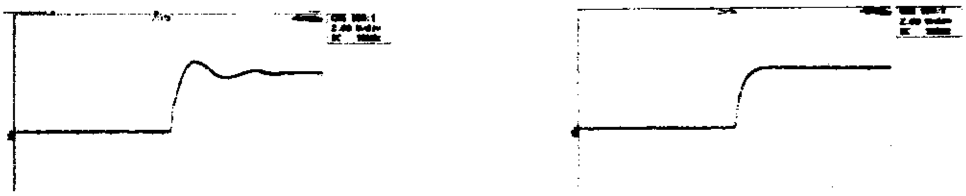


(a) Proposed controller(Time/div=5ms)   (b) Ziegler-Nichols's controller(Time/div=10ms)

Fig. 11 Response voltage output of experiment from step input. Volt/div=2

The simulation response voltage from step input is shown in Fig. 10. The proposed system controller gets better performance than the controller of Ziegler Nichols tuning method. The output response of Ziegler Nichols controller has more oscillation and overshoot from using step input. However, steady- state time of Ziegler Nichols is closed to the proposed one. Also, when both controllers are created, the response voltage from experiment is similar to simulation results as shown in Fig. 11.

From testing system by changing load resistor from 10 to 85 ohm and 10 to 20 ohm, it is found that the response voltage is followed by Fig. 12 (a) and (b) , respectively. The system oscillation is also converged to set point although there is disturbance in the system. On the other case, when the input voltage is changed from 16 V to 10 V and from 16 to 20 V, the voltage response is followed by Fig. 13(a) and (b), respectively. It can be observed that the system can work well although there is disturbance in the system.

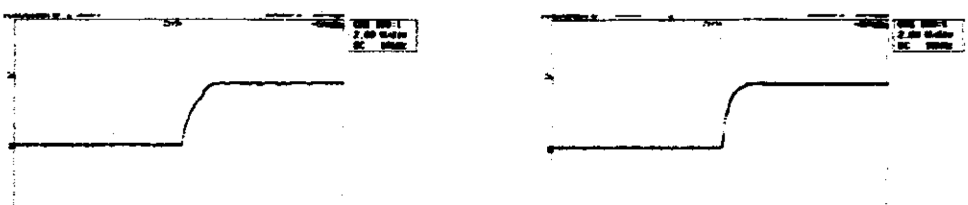


(a) (b)

Fig. 12 Output response voltage of proposed controller:

(a)Changing resistor from 10 to 85 ohm, (b) Changing resistor from 10 to 20 ohm.

Volt/div=2 , Time/div=5ms



(a) (b)

Fig. 13 Voltage output response from step voltage input: (a) input voltage changing from 16 V to 10 V, (b) input voltage changing from 16 V to 20 V. Volt/div= 2 , Time/div= 5ms.

6. CONCLUSION

The Genetic Algorithm (GA) is proposed technique for designing controller because of simple structure. Moreover, the integral time absolute error (ITAE) is also used for an objective function. From the simulation and experimental results, the proposed controller has a better performance than the controller of Ziegler-Nichols tuning method.

References

[1] P. Mao, H. Jia, C.-Y. Wang, and M. Xu: Boost-Buck power factor correction converter with integrated different current control methods, *Proc. IEEE ECCE Asia*, (2013),826 - 828.

[2] X. Du, L. Zhou, and H.-M. Tai: Double-Frequency Buck Converter, *IEEE Trans. Ind. Power Electron.*, vol. 56 (2009), 1690 – 1698.

[3] B. ChittiBabu, S.R. Samantaray, N.Saraogi, M.V Ashwin Kumar, and Sriharsha, R. ;

and S. Karmaker: Synchronous Buck Converter based PV Energy System for Portable Applications, *in Proc. IEEE TechSym*, (2011), 335 – 340.

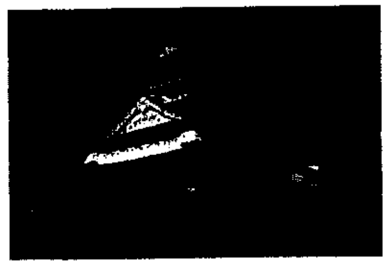
[4] M. Veerachary: Modelling and analysis of cascade step-down converters, *in Proc. IEE Electric Power Appl.*, vol. 152(2005), 41 – 50.

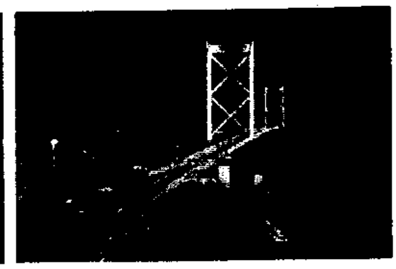
[5] S.M. Khazraei, A.M.Z. Jasour, A.V. Rahmati, and A. Abrishamifar: Improved large signal performance of linear controlled input-series and output-parallel dc-dc converter using genetic algorithm optimization, *in Proc. Int. OPTIM*,(2008), 31 – 36.

[6] K.S. Kostov and J.J Kyyra: Genetic algorithm optimization of peak current mode controlled buck converter , *in Proc. IEEE SMCIA*, (2005), 111 – 116.

AsiaSim & JSST 2014

14th Asia Simulation Conference on Modeling and Simulation & The International Conference on Simulation Technology, October 26 – 30, 2014, Kitakyushu, Japan





Fourth Call for Papers

The AsiaSim conference is an annual international conference that started in 1999, and had primarily been organized by the three Asian simulation societies, Chinese Association for System Simulation (CASS), Japanese Society for Simulation Technology (JSST), and Korea Society for Simulation (KSS). In 2011, the Federation of Asia Simulation Societies (ASIASIM) was set up, adding council members from Singapore and Malaysia, to promote the advancement of modeling and simulation in industry, research and development in Asia and beyond.

International Conference on Simulation Technology (JSST 2014), which is annually organized by Japan Society for Simulation Technology (JSST), will be held to disseminate progress in the state-of-the-art of simulation methods and report their applications in natural and social sciences. This event is to bring together outstanding researchers in modeling, simulation and scientific computing areas to share their expertise and experience.

We are soliciting original research papers in the areas below (but not limited to the list):

- Modeling and Simulation Technology
- High Performance Computing and Simulation
- Simulation Related to Big Data
- Parallel and Distributed Simulation
- Verification, Validation and Accreditation
- Visualization and Virtual Reality
- Business Process Simulation
- Simulation of Complex Systems
- Network Simulation
- Cloud Simulation
- Agent-based Simulation
- Distributed Virtual Environments
- Symbiotic Simulation
- Serious Games
- High Level Architecture

Paper and Extended Abstract Submission

In this year, the two conferences AsiaSim 2014 and JSST 2014 are held together. Authors are invited submit full papers for the "AsiaSim 2014 session" or extended abstracts for the "JSST 2014 sessions". It is also possible to submit full papers for the JSST 2014 sessions. Both the full papers and the extended abstracts are peer-reviewed. Papers that are not accepted for the AsiaSim 2014 session are automatically reviewed again for the JSST 2014 sessions.

Accepted full papers of the AsiaSim 2014 session will be published in a Conference Proceedings published from Springer.

The submission should be done in PDF format via the web site: http://asc2014.jsst.jp
Only online submissions will be available.

Call for Papers of "AsiaSim Session" of AsiaSim & JSST 2014 :
http://asc2014.jsst.jp/wp-content/uploads/2013/10/cfp_asiasim_session_v002a.pdf

Important Deadlines

• Deadline of full paper and extended abstract submission:	May 1, 2014
• Notification of Acceptance:	June 15, 2014
• Camera-Ready manuscript submission:	July 15, 2014
• Early Registration:	July 15, 2014
• Late Registration:	September 30, 2014

Co-Organizors
Japan Society for Simulation Technology
Federation of Asia Simulation Societies (ASIASIM)

Co-Sponsor
City of Kitakyushu

ASIASIM Council
(International Program Committee)

President:
Satoshi Tanaka (President of ASIASIM, Ritsumeikan University)

Council Members:
Bo Hu Li (President of CASS)
Lin Zhang (Vice-President of CASS, Beihang University)
Osamu Ono (Meiji University)
Kyoko Hasegawa (Ritsumeikan University)
Yun-Bae Kim (President of KSS, Sungkyun Kwan University)
Kang Sun Lee (MyongJi University)
Gary Tan (Vice-President of SSAG, National University of Singapore)
Stephen John Turner (Professor of Nanyang Technological University)
Rubiyah Yusof (Universiti Teknologi Malaysia)
Yahaya Md Sam (Universiti Teknologi Malaysia)
Xiao Song (Beihang University)

Honorary Member:
Axel Lehmann (Professor of Universitat de Bundeswehr Munchen)

Organizing Committee
General Chair:
Satoshi Tanaka (Ritsumeikan University)

Executive Committee
General Chair:
Shin'ichi Oishi (Waseda University)

Local Arrangement Chair:
Shinji Kimura (Waseda University)

Program Co-Chairs:
Masahide Kashiwagi (Waseda University)
Takeshi Ogita (Tokyo Woman's Christian University)

Finance Chair:
Katsuhisa Ozaki (Shibaura Institute of Technology)

Publication Chair:
Takuma Kimura (Waseda University)

Publicity Chair:
Akitoshi Takayasu (Waseda University)

General Secretaries:
Xuefeng Liu (Waseda University)
Naoya Yamanaka (Waseda University)

For more information about AsiaSim & JSST 2014, please visit the web site : **http://asc2014.jsst.jp**