Single Phase Boost Inverter Using Hybrid Modelling Approach

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***Abstract*—Boost inverters provide the ac voltage from lower dc voltage source without additional transistor switches compared to the conventional inverters. Somecontrolshave already been proposedtocontrolboostinverters, but mostcontrol methodsarebased onsmall signalanalysisandnonlinearmodelswhichmakecomputationcomplicatedandrequirefinetuning. Inthis paper, the authorsproposea controlscheme based onthe hybridmodel. Themethod does notrequirecomplicatedmathematicalformulasandallows easiertuning. The simulation resultsshow that theboostinvertercanachievea good performance using this control approach.**

Keywords–boost inverter, hybrid modelling.

I. INTRODUCTION

Voltage source inverter known as a buck inverter is commonly used to obtain ac voltage fromdc source. Inverters are widely used in various applications such as UPS, motor drives, and utility interfaces. One of the characteristics of this inverter is that the average output voltage is lower than the dc input. If the required output voltage is greater than the input, it will need dc-dc boost converters.

Boost inverter has been introduced by [1], in order to obtain acouput that is greater than the dcinput. It is obtained by using two types of dc-dc boost converter as shown in figure 1. The use of inverter boost for uninterruptible power supply (UPS) presented in [2], the use for photovoltaic given by [3] [4], and the possibility of interconnection to the grid is given by [7].

Control used by [1] is the sliding mode control. This concept was developed by [5] which adopts the principle of current control mode. Control method based on small signal analysis has been proposed by [6]. The use of energy shaping-based control has also been published [7]. Development of more advanced control concept has been done by [8]. This concept uses sliding mode to control both dc-dc converters simultaneously.

In this study the authors propose boost inverter control based on hybrid modelling, i.e. the min-projection control. This control has been used in the boost converter [9] [10] [11]. In contrast to some of the boost inverter controls explained above, the proposed control in this paper is simpler and easier in the tuning process.

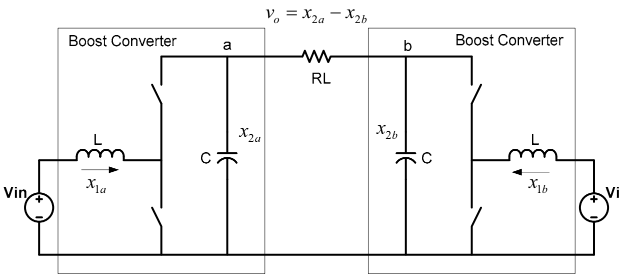

Figure 1. Boost inverter.

II. BOOST INVERTER HYBRID MODELING

Hybridsystemisa mathematicalmodelthat canrepresentcomplexsystemswithhierarchicalstructureandmay consistofcontinuousanddiscretesubsystemsthat interactwith each other. The evolution ofdiscretesubsystemsdependsonthe continuousinformation, and theevolution of thecontinuoussubsystemdependson thediscrete information.

Hybridsystemis expressedby$H = (Q, X, f, I, E, G)$, where: $Q = \{q_1, \ldots q_n\}$is a set of discretestates,$X \subseteq R^n$is continuous state spaces, $f: Q \to (X \to R^n)$ assign every discretestate toaLipschitzcontinuous vector fieldon X , i.e.thedynamicequation$\dot{x} = f(x,t)$,$I: Q \to 2^x$assign each$q \in Q$ aninvariant set, $E \subseteq QxQ$ is a collection ofdiscretetransitionsthat mayoccur, and $G: E \to 2^x$ is guardsequationsforeach$e = (q, q') \in E$.

Power electroniccircuitsareincluded as part of thehybridsystem. The continuousstateisthe current and voltagegeneratedbypassivecomponentssuch ascapacitorandinductor. The discrete stateis generatedby theswitchingcomponentssuch asMOSFET, IGBT, anddiode. Controlfor power electronicshybridmodel isguardsthat determine thetransition ofa discretestate toanotherdiscretestate, toobtainthe desiredcontinuoussubsystemsresponse.

There is no DCM (discontinuous conduction mode)condition because the current must flow bidirectional in the boost inverter circuit.In contrast to[12] [13] [14]whohaveDCM conditionon the hybrid model.

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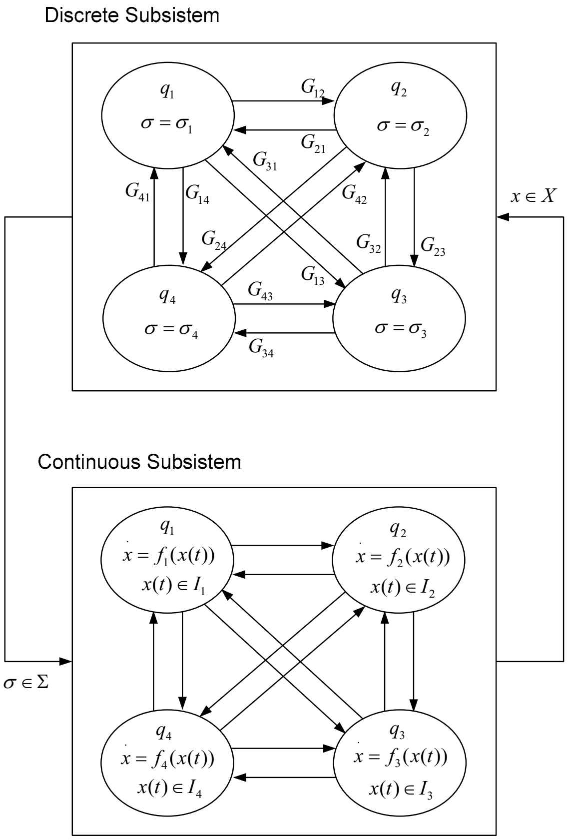


Figure 2. Boost inverter hybrid model.

The boostinvertermodelis shown in Figure2.The set ofdiscretestateis $Q = \{q_1, q_2, q_3, q_4\}$. There arefourcontinuous states, i.e. $X = \{i_{La}, v_{oa}, i_{Lb}, v_{ob}\} = \{x_{1a}, x_{2a}, x_{1b}, x_{2b}\}$. The Lipshitzvector fieldf_i for each Q are as follows:

1. $Q = q_1$ (Mode 00)

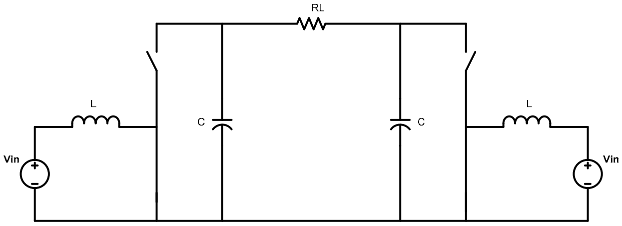


Figure 3. Mode 00.

$$\dot{x}_{1a} = \frac{V_{in}}{L} \tag{1a}$$

$$\dot{x}_{2a} = -\frac{1}{RC}x_{2a} + \frac{1}{RC}x_{2b} \tag{1b}$$

$$\dot{x}_{1b} = \frac{V_{in}}{L} \tag{1c}$$

$$\dot{x}_{2b} = \frac{1}{RC}x_{2a} - \frac{1}{RC}x_{2b} \tag{1d}$$

The above equations can be presented in state space as:

$$\dot{x} = f_1 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & -\frac{1}{RC} & 0 & \frac{1}{RC} \\ 0 & 0 & 0 & 0 \\ 0 & \frac{1}{RC} & 0 & -\frac{1}{RC} \end{bmatrix} x + \begin{bmatrix} \frac{V_{in}}{L} \\ 0 \\ \frac{V_{in}}{L} \\ 0 \end{bmatrix} \tag{2}$$

2. $Q = q_2$ (Mode 01)

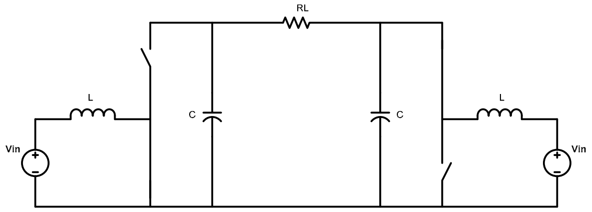


Figure 4. Mode 01.

$$\dot{x}_{1a} = \frac{V_{in}}{L} \tag{3a}$$

$$\dot{x}_{2a} = -\frac{1}{RC}x_{2a} + \frac{1}{RC}x_{2b} \tag{3b}$$

$$\dot{x}_{1b} = -\frac{1}{L}x_{2b} + \frac{V_{in}}{L} \tag{3c}$$

$$\dot{x}_{2b} = \frac{1}{C}x_{1b} + \frac{1}{RC}x_{2a} - \frac{1}{RC}x_{2b} \tag{3d}$$

The above equations in state space is

$$\dot{x} = f_2 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & -\frac{1}{RC} & 0 & \frac{1}{RC} \\ 0 & 0 & 0 & -\frac{1}{L} \\ 0 & \frac{1}{RC} & \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} x + \begin{bmatrix} \frac{V_{in}}{L} \\ 0 \\ \frac{V_{in}}{L} \\ 0 \end{bmatrix} \tag{4}$$

3. $Q = q_3$(Mode 10)

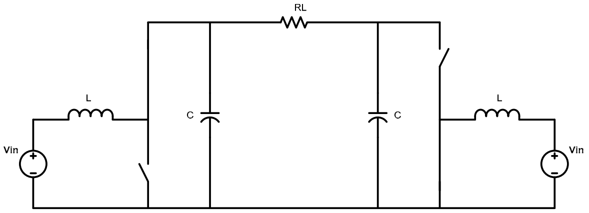


Figure 5. Mode 10.

$$\dot{x}_{1a} = -\frac{1}{L}x_{2a} + \frac{V_{in}}{L} \tag{5a}$$

$$\dot{x}_{2a} = \frac{1}{C}x_{1a} - \frac{1}{RC}x_{2a} + \frac{1}{RC}x_{2b} \tag{5b}$$

$$x_{1b} = \frac{V_{in}}{L} \tag{5c}$$

$$\dot{x}_{2b} = \frac{1}{RC}x_{2a} - \frac{1}{RC}x_{2b} \tag{5d}$$

The above equations in state space is:

$$\dot{x} = f_3 = \begin{bmatrix} 0 & -\frac{1}{L} & 0 & 0 \\ \frac{1}{C} & -\frac{1}{RC} & 0 & \frac{1}{RC} \\ 0 & 0 & 0 & 0 \\ 0 & \frac{1}{RC} & 0 & -\frac{1}{RC} \end{bmatrix} x + \begin{bmatrix} \frac{V_{in}}{L} \\ 0 \\ \frac{V_{in}}{L} \\ 0 \end{bmatrix} \tag{6}$$

4. $Q = q_4$ (Mode 11)

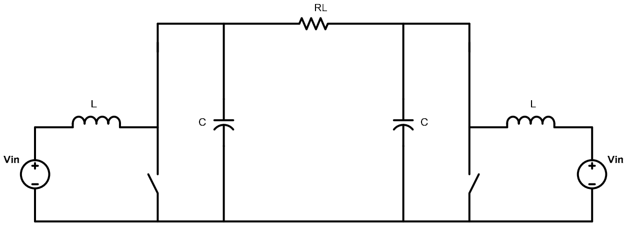


Figure 6. Mode 11.

$$\dot{x}_{1a} = -\frac{1}{L} x_{2a} + \frac{V_{in}}{L} \tag{7a}$$

$$\dot{x}_{2a} = \frac{1}{C} x_{1a} - \frac{1}{RC} x_{2a} + \frac{1}{RC} x_{2b} \tag{7b}$$

$$\dot{x}_{1b} = -\frac{1}{L} x_{2b} + \frac{V_{in}}{L} \tag{7c}$$

$$\dot{x}_{2b} = \frac{1}{C} x_{1b} + \frac{1}{RC} x_{2a} - \frac{1}{RC} x_{2b} \tag{7d}$$

The above equations can be written in state space representation as:

$$\dot{x} = f_4 = \begin{bmatrix} 0 & -\frac{1}{L} & 0 & 0 \\ \frac{1}{C} & -\frac{1}{RC} & 0 & \frac{1}{RC} \\ 0 & 0 & 0 & -\frac{1}{L} \\ 0 & \frac{1}{RC} & \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} x + \begin{bmatrix} \frac{V_{in}}{L} \\ 0 \\ \frac{V_{in}}{L} \\ 0 \end{bmatrix} \tag{8}$$

The set of discrete transition is:

$$E = \left\{ \begin{matrix} (q_1, q_2)(q_1, q_3)(q_1, q_4)(q_2, q_1)(q_2, q_3)(q_2, q_4) \\ (q_3, q_1)(q_3, q_2)(q_3, q_4)(q_4, q_1)(q_4, q_2)(q_4, q_3) \end{matrix} \right\} \tag{9}$$

The guardequationsare:

$$G(2,1) = \left\{ \begin{bmatrix} x_{1a} \\ x_{2a} \\ x_{1b} \\ x_{2b} \end{bmatrix} \in R^4 : Q = q_1 \right\} \tag{10a}$$

$$G(3,1) = \left\{ \begin{bmatrix} x_{1a} \\ x_{2a} \\ x_{1b} \\ x_{2b} \end{bmatrix} \in R^4 : Q = q_1 \right\} \tag{10b}$$

$$G(4,1) = \left\{ \begin{bmatrix} x_{1a} \\ x_{2a} \\ x_{1b} \\ x_{2b} \end{bmatrix} \in R^4 : Q = q_1 \right\} \tag{10c}$$

$$G(1,2) = \left\{ \begin{bmatrix} x_{1a} \\ x_{2a} \\ x_{1b} \\ x_{2b} \end{bmatrix} \in R^4 : Q = q_2 \right\} \tag{10d}$$

$$G(3,2) = \left\{ \begin{bmatrix} x_{1a} \\ x_{2a} \\ x_{1b} \\ x_{2b} \end{bmatrix} \in R^4 : Q = q_2 \right\} \tag{10e}$$

$$G(4,2) = \left\{ \begin{bmatrix} x_{1a} \\ x_{2a} \\ x_{1b} \\ x_{2b} \end{bmatrix} \in R^4 : Q = q_2 \right\} \tag{10f}$$

$$G(1,3) = \left\{ \begin{bmatrix} x_{1a} \\ x_{2a} \\ x_{1b} \\ x_{2b} \end{bmatrix} \in R^4 : Q = q_3 \right\} \tag{10g}$$

$$G(2,3) = \left\{ \begin{bmatrix} x_{1a} \\ x_{2a} \\ x_{1b} \\ x_{2b} \end{bmatrix} \in R^4 : Q = q_3 \right\} \tag{10h}$$

$$G(4,3) = \left\{ \begin{bmatrix} x_{1a} \\ x_{2a} \\ x_{1b} \\ x_{2b} \end{bmatrix} \in R^4 : Q = q_3 \right\} \tag{10i}$$

$$G(1,4) = \left\{ \begin{bmatrix} x_{1a} \\ x_{2a} \\ x_{1b} \\ x_{2b} \end{bmatrix} \in R^4 : Q = q_4 \right\} \tag{10j}$$

$$G(2,4) = \left\{ \begin{bmatrix} x_{1a} \\ x_{2a} \\ x_{1b} \\ x_{2b} \end{bmatrix} \in R^4 : Q = q_4 \right\} \tag{10k}$$

$$G(3,4) = \left\{ \begin{bmatrix} x_{1a} \\ x_{2a} \\ x_{1b} \\ x_{2b} \end{bmatrix} \in R^4 : Q = q_4 \right\} \tag{10l}$$

III. HYBRID CONTROL (MIN-PROJECTION CONTROL)

A controllershould be designed to minimize thecosinebetween $x - x_d$ and $f_i(x)$ using the followingalgorithmbelow

$$\sigma_i = arg\min_{i \in \Lambda} \frac{\langle x - x_d, f_i(x) \rangle}{\|x - x_d\| \|f_i(x)\|} \tag{11}$$

Where $e = x - x_d$. Since $\|x - x_d\|$does not dependon$i$, it is ignored in the control computation.

Illustration ofthe above algorithmis shownin Figure7.

By selecting theminimumvalue ofcosinebetween thevectors $f(x)$ and $e = x - x_d$, it will make $x(t)$ closer to thedesiredx_d.

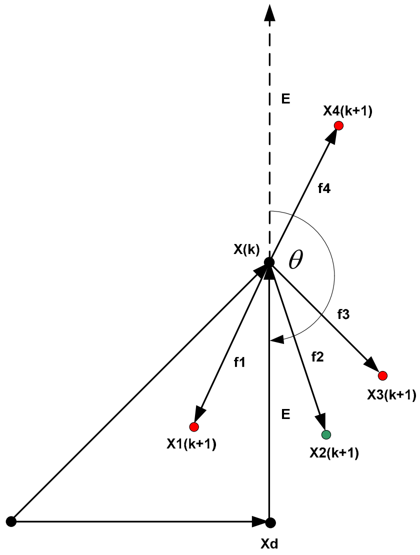


Figure 7. Control algorithm illustration.

IV. SIMULATION RESULT

Simulationshave been made using PSIM9withthe followingspecifications.

Tabel 1. Boost inverter specification.

Input voltage	5V
Output voltage	$7 \sin 100t$V
Inductance	150 uH
Capacitance	110 uF
Load	Resistor 6 Ohm

Voltage reference signals have been obtained using values in table 1 based on [1]. Whereas current reference signal have been derived based on some formulas in [15]. The voltage and current references are:

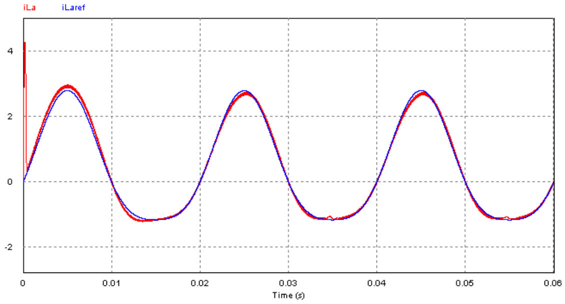
1. $v_{aref} = 8{,}5 + 3{,}5 \sin{(100t)}$
2. $v_{bref} = 8{,}5 - 3{,}5 \sin{(100t)}$
3. $i_{Laref} = (V_{oa} - V_{ob}) \frac{V_{oa}}{RV_{in}}$
4. $i_{Lbref} = (V_{ob} - V_{oa}) \frac{V_{ob}}{RV_{in}}$

Figure 8 exposessome of control algorithm program lines.

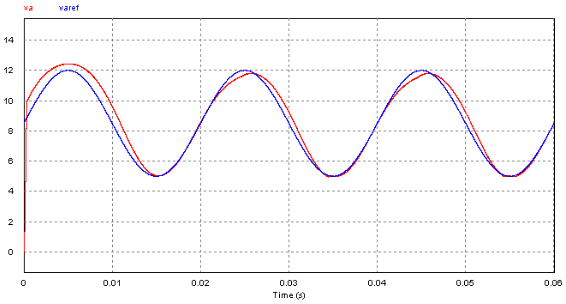
```
.......

ua = 1;  ub = 1;
f1a4 = (Vin - x2a)/L;
f2a4 = -(x2a - x2b)/(R*C) + x1a/C;
f1b4 = (Vin - x2b)/L;
f2b4 = (x2a - x2b)/(R*C) + x1b/C;
f4mag = sqrt(f1a4*f1a4 + f2a4*f2a4 + f1b4*f1b4 +
        f2b4*f2b4);

deltaia = x1a -  iLaref;
deltaib = x1b -  iLbref;
deltava = x2a -  varef;
deltavb = x2b -  vbref;

delta1 = (deltaia*f1a1 + deltava*f2a1 + deltaib*f1b1
        +deltavb*f2b1)/f1mag;
delta2 = (deltaia*f1a2 + deltava*f2a2 + deltaib*f1b2
        +deltavb*f2b2)/f2mag;
delta3 = (deltaia*f1a3 + deltava*f2a3 + deltaib*f1b3
        +deltavb*f2b3)/f3mag;
delta4 = (deltaia*f1a4 + deltava*f2a4 + deltaib*f1b4
        +deltavb*f2b4)/f4mag;

if (delta1<delta2 && delta1<delta3 && delta1<delta4)
        {
        out[0] = 0;
        out[1] = 0;
        }
......
```

Figure 8. Algorithm of the program

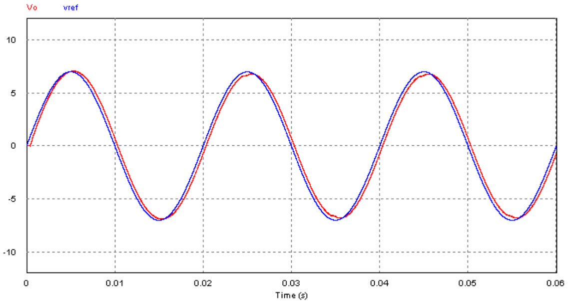
The simulation resultsare shown in Figure9and 10. It can be seenthat theboostinvertercanachievea stable condition. The use ofgreater voltagereferencecausesan offseterror ineach dcconverteroutput. Because thecontrol algorithmis tunedbased onthe systemmodel, the selection of componentvaluesmust be consideredtogetbetter controlresponse.



(a)

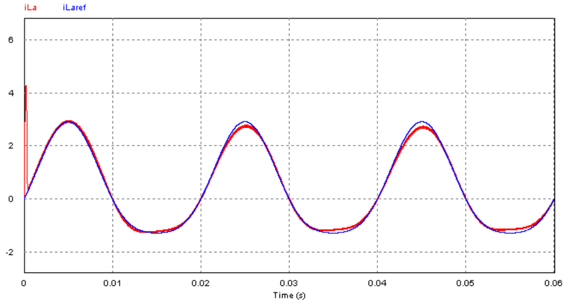


(b)

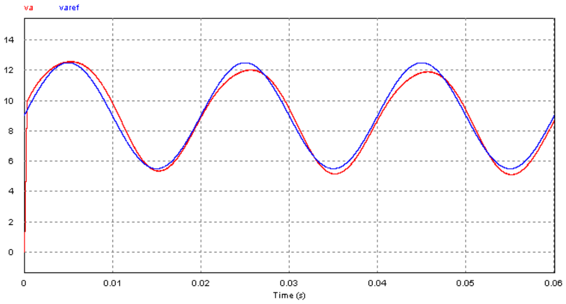


(c)

Figure 9. The simulation resultswhen$v_{aref} = 8{,}5 + 3{,}5 \sin{(100t)}andv_{bref} = 8{,}5 - 3{,}5 \sin{(100t)}$: (a) current$i_{La}$, (b) voltage$v_{oa}$, and (c) output voltage$v_o$.



(a)



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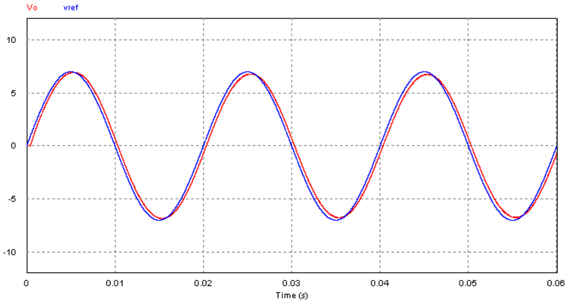

(c)

Figure10. The simulation results when$v_{aref} = 9 + 3{,}5 \sin{(100t)}andv_{bref} = 9 - 3{,}5 \sin{(100t)}$: (a) current$i_{La}$, (b) voltage$v_{oa}$, and (c) output voltage$v_o$.

V. CONCLUSION

Boost inverter control based on hybrid model has been simulated. The result showed a stable response, but an offset error still appears. Further researchis needed todeterminethe more appropriate values ofcomponents andsensitivity againtsparametervaluesvariation.The authorsare planningto conduct experiments toprove the validity of the simulation result.

REFERENCES

1. R. O.Caceres and I. Barbi, “A boost dc-acconverter:analysis, design, and experimentation”, IEEE Transactions on Power Electronics, Vol.14, No.1, pp. 134-141, January 1999.
2. N. Vázquez, C. Aguilar, J. Arau, R. O. Cáceres, I.Barbi, and J. A. Gallegos, “A novel uninterruptible power supply system with active power factor correction”, IEEE Transactions on Power Electronics, Vol.17, No.3, pp. 405-412, May 2002.
3. R. Akhter, “A new technique of pwm boost inverter for solar home application”, BRAC University Journal, Vol. IV, No. 1, pp. 39-45, 2007.
4. R. K. Dhar, Md S. I. Islam, K. J. Siddiqua, Md T. Hasan, S. Azgar, Md Jakaria Rahimi, ”Performance analysis of boost inverter for photovoltaic system”, IJETSE International Journal of Emerging Technologies in Sciences and Engineering, Vol.5, No.2, pp. 7-20, Dec. 2011.
5. P. Sanchis, A. Ursaea, E. Gubía, and L. Marroyo, “Boost dc-acinverter: A new control strategy”, IEEE Transactions on Power Electronics, Vol.20, No.2, pp. 343-353, March 2005.
6. A. A. Shahjamal Khan and K. M. Rahman, “Voltage mode control of single phase boost inverter”, 5th International Conference on Electrical and Computer Engineering (ICECE), pp. 665-670, Dec. 2008.
7. C. Albea, F. Gordillo, andJ. Aracil, “Control of the boost dc-acconverter by energy shaping”, The 32nd Annual Conference of the IEEE Industrial Electronics Society, Paris : France (2007).
8. D. Cortes, N. Vázquez, J. Alvarez-Gallegos, “Dynamical sliding-mode control of the boost inverter”, IEEE Transactions on Industrial Electronics, Vol. 56, No.9, pp. 3467-3476, September 2009.
9. M. Senesky, G. Eirea, and T. J. Koo, “Hybrid modeling and control of power electronics”, in Hybrid Systems: Computation & Control. Berlin, Germany: Springer-Verlag, pp. 450–465, 2003.
10. Xia Wang, Yujun Tang, Xiaoping Zong, Peiguang Wang, “Switched Control of dc/dc Converter Based on Hybrid Model”, 2nd International Conference on Information Engineering and Computer Science (ICIECS), pp. 1-3, Dec. 2010.
11. C. Sreekumar and V. Agarwal, “Hybrid control of a boost converter operating in discontinuous current mode”, Power Electronics Specialists Conference,pp. 1-6, June 2006.
12. M.Hejriand H. Mokhtari, “Global hybrid modeling and control of dc-dc converters: aboost converter topology”, 24th International Power System Conference PSC2009, pp. 1-12, 2009.
13. E. Zulueta, T. Rico, J. M. Gonzales de Durana, “Hybrid modeling of open loop dc-dc converters”, Revista facultad de ingenieria, U.T.A. (Chile), Vol. 11 No. 2, pp. 41-47, 2003.

14. C. Sreekumar and V. Agarwal, “A hybrid control algorithm for voltage regulation in dc-dc boost converter”, IEEE Transactions on Industrial Electronics, Vol. 55, No. 6,pp. 2530-2538, June 2008.
15. L. Atmopawiro, *Pemodelan hibrida pada boost inverter menggunakan matlab, simulink, dan psim* (Theboostinverterhybrid modelingusingmatlab, simulinkandpsim), BSc Thesis, Institute of Technology Bandung, 2011.