Bond Graph Modelling and Simulation of Buck ZVS Quasiresonant DC-DC Power Converter

Shaik Hussain Vali, Ganesh Vulasala

Abstract: *Modeling of Buck Zero voltage switching (ZVS) Quasiresonant DC-DC power converter using bond graph approach is being presented here. The development of steady-state, small signal and large signal AC bond graph models of Buck ZVS Quasiresonant converter will be presented. The bond graph model will be simulated in MATLAB/SIMULINK and are compared with the simulated results obtained in PSIM.*

Keywords: *Bond graphs, buck converter, Modelling, Quasiresonant, Zero voltage switching.*

I.   INTRODUCTION

Quality, efficiency, compactness, reliability and more power density are the required demands of power electronic systems of modern days [1]. Linear regulators are suffering from low power density and poor efficiency. Pulse width modulated (PWM) converters [2] are generally used in low and moderate power applications. In PWM converters, high switching frequencies benefits size reduction of filter components, transformers, improves the dynamic and frequency response characteristics but suffers from high switching losses, switching stresses, electromagnetic interference problems (EMI) and harmonics. One of the solutions to these problems is to shape the voltage and current waveforms as sinusoidal instead of rectangular as in case of PWM converters. The sinusoidal wave shaping of voltages and currents can be obtained with the inclusion of additional resonant circuits to the PWM converters. This leads to Quasiresonant DC-DC converters. Either ZVS-(zerovoltage switching) or ZCS –(zerocurrent switching) techniques are used in these converters [3]-[4].

Modeling of a system is essential before executing it practically. The converters are being designed after they are modeled and simulated. There are several modeling techniques for power electronic converters available in the literature. Bond graph modeling [5]-[7] is one of its types that have been used mostly in mechanical systems. This modeling is an excellent tool for multi domain systems. It has lot of scope in power electronic systems as the power electronic systems are multi domain systems involving electrical, thermal, mechanical systems..etc.

   Shaik Hussain Vali, Research Scholar, Department of Electrical Engineering, Jawaharlal Nehru Technological University, Anantapur, India. Email: hussainvali4@gmail.com

   Ganesh Vulasala, EEE department, JNTUA College of Engineering Pulivendula, India. Email: ganivg@gmail.com

II.   BOND GRAPH APPROACH

Bond graph [5]-[7] is a pictographic form of a physical system in the form of a graph. The graph is divided into number of bonds. Each bond contains labels and directions. It is one of the easiest ways of representing the systems. It is domain independent. It depends only on energy flow or power flow in the system. Multiple domains such as electrical, magnetic, mechanical and thermal systems etc. are easily integrated because energy and power are very common terms. Every bond has an effort and a flow, the multiplication of which equals power. Even the effort and flow are common terms, but every domain has specific efforts and flows. For example, current and voltages are respectively the flow and effort variables in electrical domain. The energy or power flow is graphically shown by a half-arrow. The direction of half-arrow is decided by the causality. After assigning the causal bars, the state equations are obtained with the help of basic laws applicable in the particular domains. The number of state equations are decided by the number of state variables. An appendix is given at the end of paper [5]-[7].

These techniques can be applied to model power electronic converters [8]-[10]. The switched power junctions (SPJ) [11] are used to model switched mode power converters (SMPCs). The bond graph techniques improve the understanding of the system graphically. This technique unifies the large and small-signal models and steady-state models for SMPCs [12]. The techniques are applicable to Quasiresonant DC-DC converters also.

III.   MODELLING OF CONVERTER

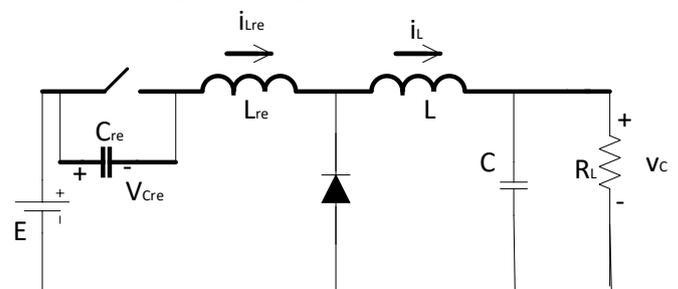The circuit of the Buck ZVS quasiresonant DC-DC converter [13] is given in Fig.1.

Fig 1. Buck ZVS Quasiresonant DC-DC Converter

The bond graph models [12] for the converter in the four possible switching positions which are (i) switch ON, Diode ON (ii) switch ON, diode OFF (iii) switch OFF, diode OFF (iv) switch OFF, diode ON are developed and given in figures from 2(a)- 2(d) respectively.

Retrieval Number: A9817109119/2019©BEIESP
DOI: 10.35940/ijeat.A9817.109119

3759

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

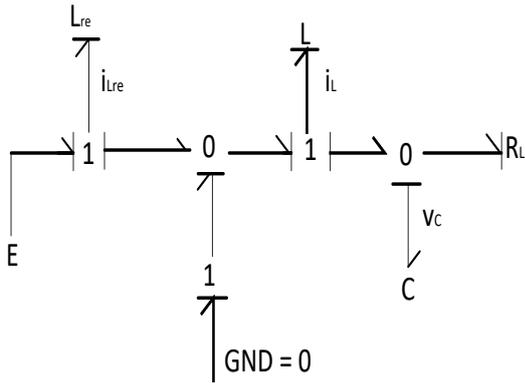The complete large signal model of the converter is arranged in Fig. 2(e).

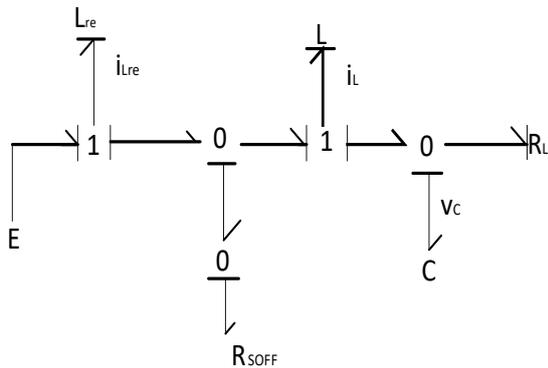**Fig. 2(a). Bond graph model of Buck ZVS Quasiresonant DC-DC converter (ON switch & ON Diode)**

Fig. 2(b). Bond graph model of Buck ZVS Quasiresonant DC-DC converter (ON switch & OFF Diode)
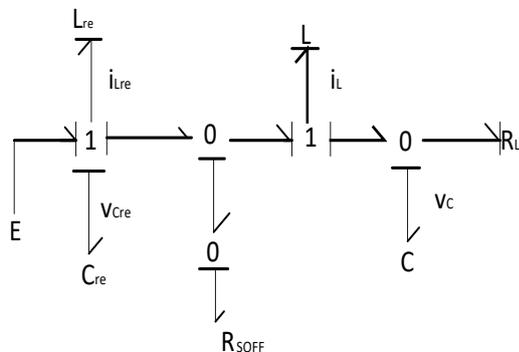

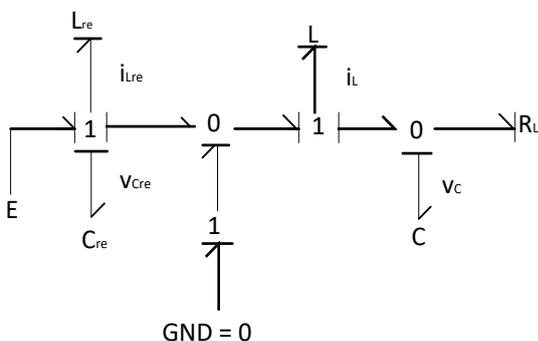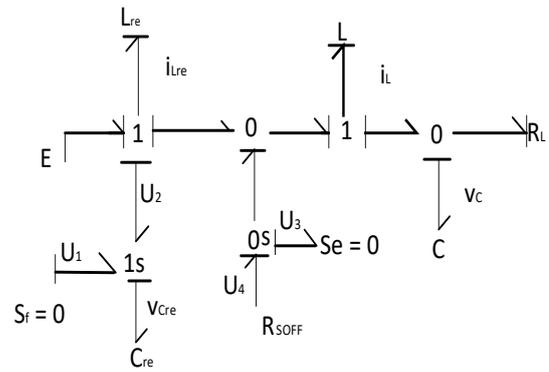**Fig. 2(c). Bond graph model of Buck ZVS Quasiresonant DC-DC converter (OFF switch & OFF Diode)**

Fig. 2(d). Bond graph model of Buck ZVS Quasiresonant DC-DC converter (OFF switch & ON Diode)

Fig. 2(e). Large signal Bond graph model of Buck ZVS Quasiresonant DC-DC converter

The steady state bond graph model and the small signal ac bond graph model for the converter is obtained by following the reduction steps [12] are shown in Fig. 2(f) and 2(g) respectively.
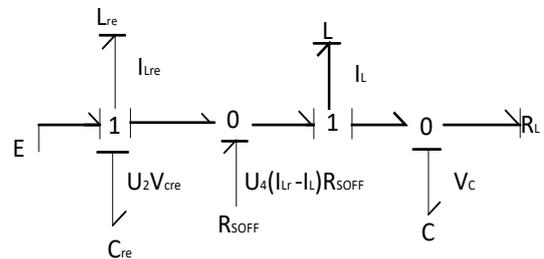

Fig. 2(f). Steady state Bond graph model of Buck ZVS Quasiresonant DC-DC converter

When the status of diode is OFF, both the inductors come in series making the state of one inductor dependable on other. To avoid this situation, a very high value of resistance RSOFF is introduced in place of OFF diode so that the causality is maintained. This RSOFF is shown in Fig. 2(b) and 2(c). The state variables are the current in inductors and the voltage across capacitors which are i_L, i_{Lre}, v_C and v_{Cre}. The state equations are obtained by applying KVL and KCL on the steady state model as in Fig. 2(f) and are given by (1) to (4).
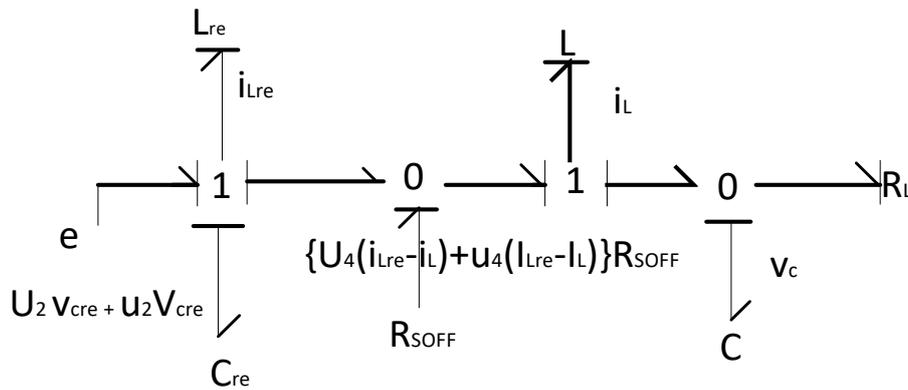
Fig. 2(g). Small-signal AC Bond graph model of Buck ZVS Quasiresonant DC-DC converter

$$v_{Lre} = E - U_2 v_{Cre} + U_4 (i_L - i_{Lre}) R_{soff} \qquad (1)$$

$$v_L = -v_0 - U_4 (i_L - i_{Lre}) R_{soff} \qquad (2)$$

$$i_{Cre} = U_2 i_{Lre} \qquad (3)$$

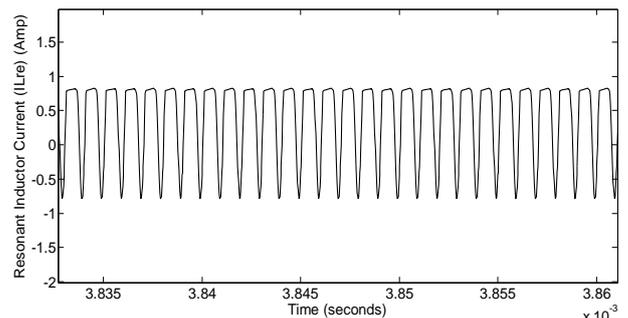$$i_C = i_L - \frac{v_0}{R_L} \qquad (4)$$

IV. SIMULATED WAVEFORMS

Consider the values, E = 20 V, L = 100 µH, C = 6.25 µF, R = 10Ω, fs = 1 MHz, D = 0.5454, Lre = 1.75 µH and Cre = 4.376 nF. The simulation results in MATLAB/SIMULINK using the toolbox [14] are represented in Fig. 3(a) to 3(f).
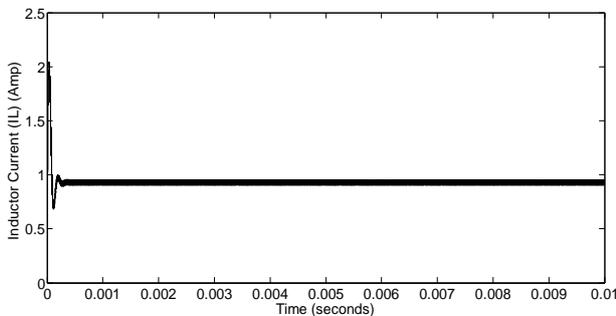

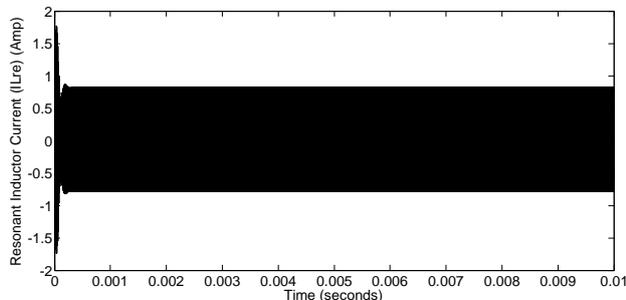**Fig. 3(a). Inductor Current (IL) – Buck ZVS Quasiresonant DC-DC Converter**

Fig. 3(b). Resonant Inductor Current (ILre) – Buck ZVS Quasiresonant DC-DC Converter

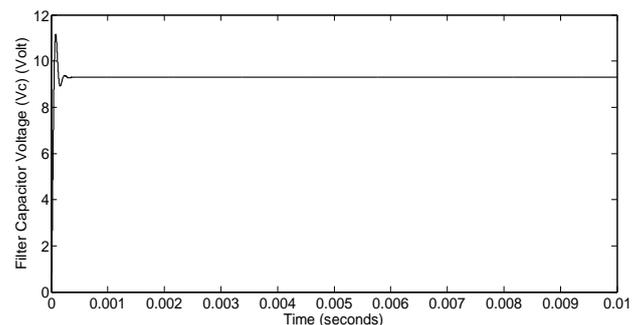**Fig. 3(c). Resonant Inductor Current (ILre) – Buck ZVS Quasiresonant DC-DC Converter**

Fig. 3(d). Filter Capacitor Voltage (Vc) – Buck ZVS Quasiresonant DC-DC Converter
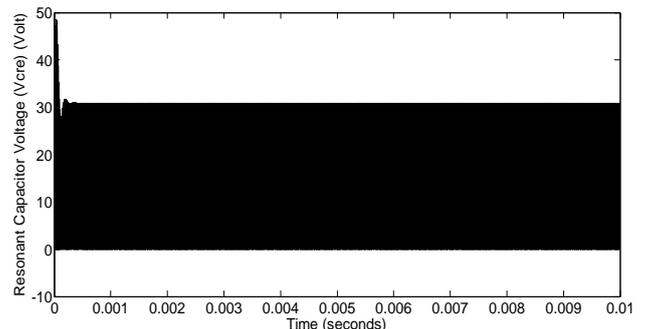

Fig. 3(e). Resonant Capacitor Voltage (Vc) – Buck ZVS Quasiresonant DC-DC Converter

Fig. 3(f). Resonant Capacitor Voltage (Vc) – Buck ZVS Quasiresonant DC-DC Converter

The simulation results for the same values in PSIM are represented in Fig. 4(a) to 4(f).

Fig 4(a). Inductor Current (IL) – Buck ZVS Quasiresonant DC-DC Converter

Fig 4(b). Resonant Inductor Current (ILre) – Buck ZVS Quasiresonant DC-DC Converter

Fig 4(c). Resonant Inductor Current (ILre) – Buck ZVS Quasiresonant DC-DC Converter
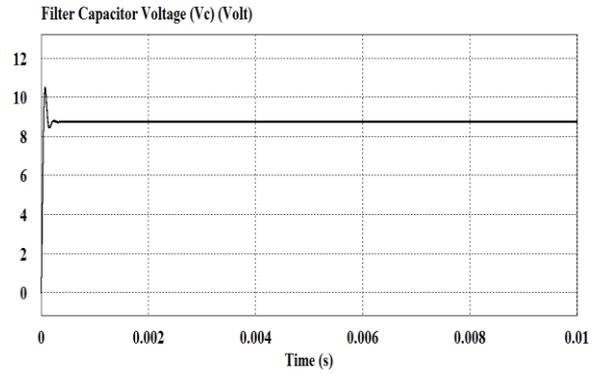
Fig 4(d). Filter Capacitor Voltage (Vc) – Buck ZVS Quasiresonant DC-DC Converter
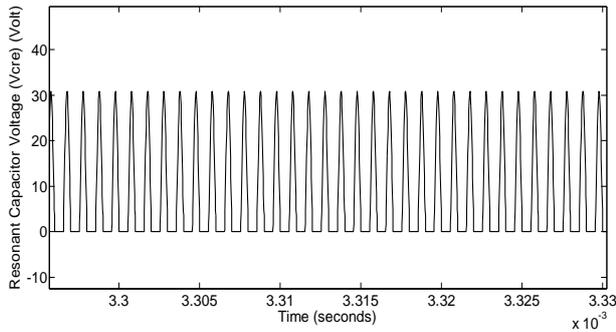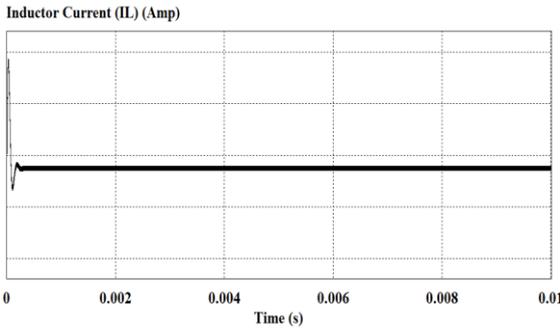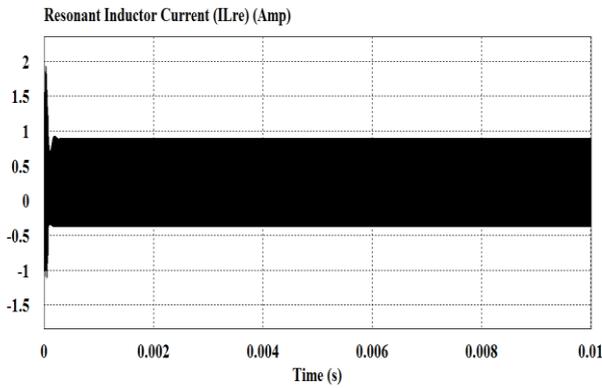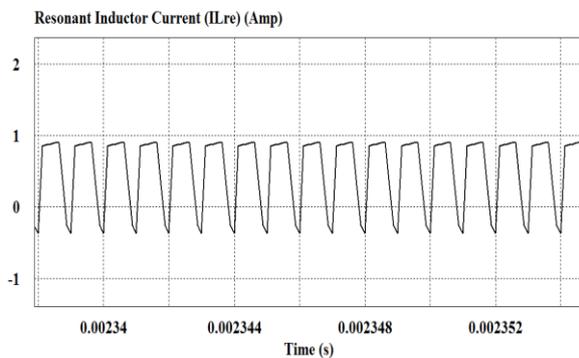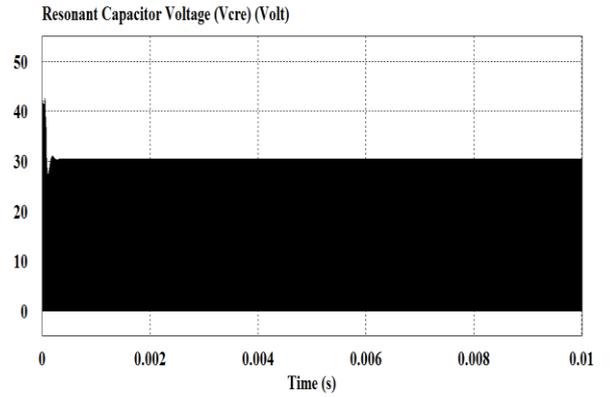

Fig 4(e). Resonant Capacitor Voltage (Vc) – Buck ZVS Quasiresonant DC-DC Converter
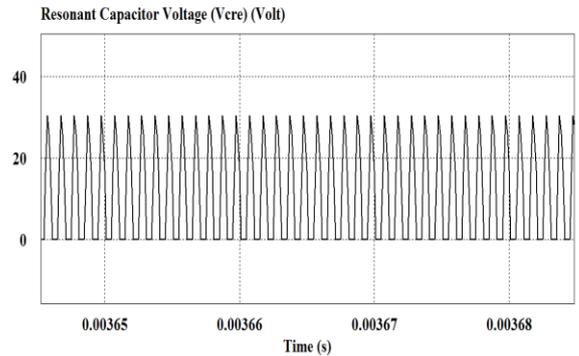
Fig 4(f). Resonant Capacitor Voltage (Vc) – Buck ZVS Quasiresonant DC-DC Converter

V. TABULATED RESULTS

The simulation results obtained both in MATLAB/SIMULINK and PSIM for buck ZVS Quasiresonant DC-DC converter is tabulated in Table I. The results obtained in both the simulations are found approximately same.

Table I. Simulated Results - Buck ZVS Quasiresonant DC-DC Converter

S.No.	Variable	MATLAB/SIMULINK	PSIM
1	Steady state Inductor Current (IL) (Amp)	0.9	0.9
2	Peak Resonant Inductor Current (ILre) (Amp)	1.7	1.8
3	Steady state filter capacitor voltage (Vc) (Volt)	9.1	9.0
4	Peak Resonant Capacitor Voltage (Vcre) (Volt)	48	45

VI. CONCLUSION

Buck ZVS Quasiresonant DC-DC converter is modeled using bond graphs. The steadystate, large and small signal AC bond graph models of the ZVS Quasiresonant converter are developed. The models are simulated in MATLAB/SIMULINK. The circuit is simulated in PSIM and the simulated results are in direct agreement with the results obtained by simulating the model developed. As the bond graphs are domain independent, this model can be used to integrate the converter with its other domain applications such as thermal, magnetic and mechanical systems…etc.

APPENDIX

*Bond graphs and equations for the 1-junction & 0-junction:*

0-junction:

Fig. 5 represents a 0-junction. Only one bond at the 0-junction, decides the effort. It is called effort decider bond. Remaining all bonds has the same effort. Here in the bond graph, bond 1 is the effort decider bond. So, the effort at remaining bonds 2-4 is same as that at bond 1. The flow at the bond 1 is determined by knowing the flows at the remaining bonds 2-4. In equation form

$$e_2 = e_1$$
$$e_1 = e_3$$
$$e_1 = e_4$$

$$f_1 - f_2 = f_3 + f_4$$
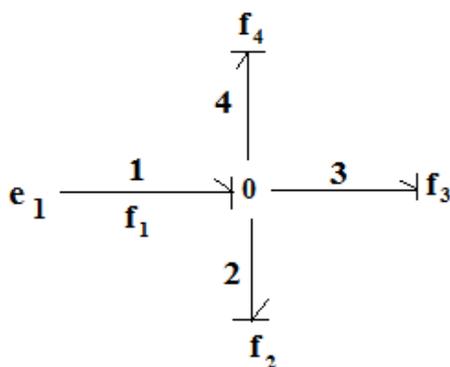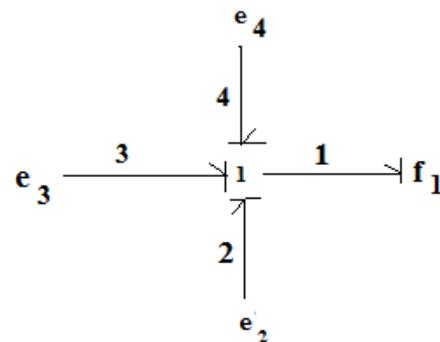

Fig.5. 0-junction

1-junction:

Fig. 6 shows a 1-junction. At the 1-junction, the flow is determined by only one bond. It is called flow decider bond. Remaining all bonds has the same flow. Here in the bond graph, bond 1 is the flow decider bond. So, the flow at remaining bonds 2-4 is same as that at bond 1. The effort at the bond 1 is determined by knowing the efforts at the remaining bonds 2-4. In equation form

$$f_2 = f_1$$
$$f_3 = f_1$$
$$f_4 = f_1$$

$$e_1 = e_2 + e_3 + e_4$$

Fig.6. 1-junction

Switched Power Junctions:

In general, bond graphs are associated with two junctions namely 0-junction and 1-junction. The efforts of the bonds of 0-junction are decided by effort decider. The flows of the bonds of 1-junction are decided by flow decider. In power electronic systems where there is a continuous change in the states of the switches and diodes, the effort decider and the flow decider are not same for all states. To model this type of switches and diodes, switched power junctions are used. There are two types: 0s-junction and 1s-junction.

0s-junction:

Fig. 7 represents a 0s-junction. It contains four bonds. Out of the four bonds, causal bars are associated with two bonds near the junction. They are called the effort deciders. Here, bonds 1 and 2 are effort deciders during U_1 and U_2 durations respectively. So, the efforts of the bonds 3 and 4 are calculated by either the effort at bond 1 or the effort at bond 2. The flow of either bond 1 or bond 2 is equal to the algebraic sum of the flows at bonds 3 and 4 which depend on the states U_1 or U_2. The equations are

$$e_3 = U_1 e_1 + U_2 e_2$$
$$e_4 = U_1 e_1 + U_2 e_2$$
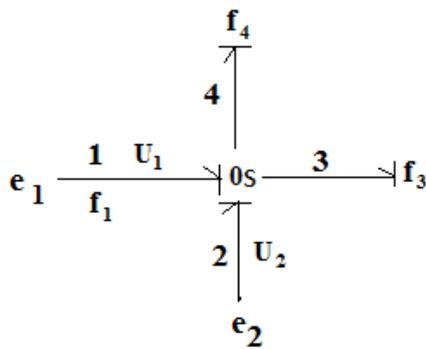$$f_1 = U_1(f_3 + f_4)$$
$$f_2 = U_2(f_3 + f_4)$$

Fig.7. 0s-junction

1s-junction:

Fig. 8 represents a 0s-junction. It contains four bonds. Out of the four bonds, causal bars are associated with two bonds away from the junction. They are called the flow deciders. Here, bonds 1 and 2 are flow deciders during U_1 and U_2 durations respectively. So, the flows of the bonds 3 and 4 are decided by either the flow at bond 1 or the flow at bond 2. The effort of either bond 1 or bond 2 is equal to the algebraic sum of the efforts at bonds 3 and 4 depends on the switched state U_1 or U_2. The equations are

$$f_3 = U_1 f_1 + U_2 f_2$$
$$f_4 = U_1 f_1 + U_2 f_2$$
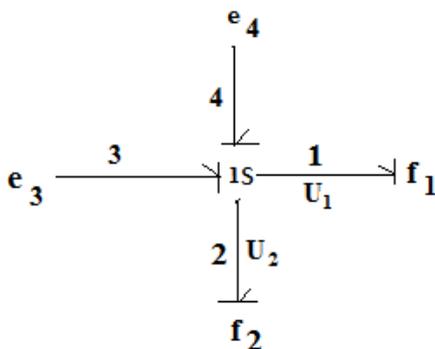$$e_1 = U_1(e_3 + e_4)$$
$$e_2 = U_2(e_3 + e_4)$$

Fig.8. 1s-junction

REFERENCES

1. R. Severns, Modern DC-to-DC switchmode Power Converter Circuits: Van Nostrand Reinhold Electrical/Computer Science and Engineering Series, April 2014.
2. Marian K. Kazimeirczuk, PulseWidth Modulated DC-DC Power Converters, 2nd Edition, John Wiley & Sons, 2016.
3. KH.Liu and Fred CY Lee, " Zerovoltage switching technique in dc-dc converters," IEEE Transactions on Power Electronics, vol. 5, no. 3, pp. 293-304, July 1990.
4. G.Hua and F.C.Lee, "Softswitching techniques in PWM converters," IEEE Transactions on Industrial Electronics, Vol. 42, Issue: 6, pp. 595-603, Dec 1995.
5. Dean C. Karnopp, Donald L. Margolis and Ronald C. Rosenberg, System Dynamics: A Unified Approach, 2nd Edition, John Wiley & Sons, 1990.
6. A. Mukherji and R. Karmakar, Modeling and Simulation of Enginering Systems through BondGraphs, Alpha Science International Ltd, August 2000
7. W.Boretzky, G.D.Tanguy and J.U.Thoma, "Advances in bondgraph modeling-theory, software, applications," Journal of Mathematics and Computer in Simulation, volume.39, No: 5-6, pp. 465-475, Nov 1995.
8. R.Andouisi, A.Mami, G.D.Tanguy, M.Anabi, Bondgraph "Modeling and Dynamic Study of a Photovoltaic System Using MPPT Buck-Boost Converter," IEEE International Conference on Systems, Man and Cybernetics, vol. 3., page: 6, Oct. 2002.
9. Marisol Delgedo and Hebert Sira-Remiraz, "A bondgraph approach to the modeling and simulation of regulated dc-to-dc power supplies," Simulation Practise and Theory, Vol. 6, Issue:7, pp. 631-646, Nov 1998.
10. Allerd.B., Hilale H., Lin.C.C. and Morell. H, "Power Converter average model computasion using the bondgraph and PetriNet Techniques," Proceedings of PESC '95 - Power Electronics Specialist Conference, pp. 830-836, 18-22 June1995.
11. A.C.Umarikar and L.Umanand, "Modeling of switching systems in bondgraphs using the concept of swithced power junctions," Journal of the Frankline Institute, volume 342, Issue:2, pp.131-147, March 2005.
12. A.C.Umarikar and L.Umanand, "Modeling of switched_mode power converters using bondgraphs," IEE Procedings - Electric Power Applications, volume 152, Issue.1, pp. 51-60, Jan 2005.
13. Marian K. Kazimeirczuk and J.Jazwik, "Analysis and design of buck zerovoltage switching resonant dc-to-dc converter," Proceedings of 12th International PCI'86 Conference on power conversion, Boston, MA, 1986, pp. 35-54.
14. A.C.Umarikar, T.Mishra and L.Umanand, "Bondgraph Simulation and Symbolic Extration tool box in MATLAB/SIMULINK," J. Indian Inst. Science (IISc), Vol. 86, No. 1, pp. 45-68, January-February 2006.

AUTHORS PROFILE

Shaik Hussain Vali, Research scholar in department of Electrical Engineering, Jawharlal Nehru Technological University Anantapur, India. He completed his B.Tech in Electrical and Electronics Engineering and M.Tech in Machine drives and Power Electronics from JNTU Hyderabad, India nd IIT Kharagpur, India respectively. His research interests include switched mode power supply design and renewable energy applications.

Ganesh Vulasala, Professor in department of Electrical and Electronics Engineering, Jawaharlal Nehru Technological University Anantapur College of Engineering. Pulivendula, India. He completed his B.Tech in Electrical and Electronics Engineering, M.Tech in Electrical Power systems and PhD in Electrical and Electronics Engineering from JNTU Hyderabad, SVU Tirupati and JNTU Anantapur respectively all from India. His research interests include Smart grid technologies and renewable energy applications.