European Association for the Development of Renewable Energies, Environment and Power Quality

International Conference on Renewable Energies and Power Quality (ICREPQ'09)

Valencia (Spain), 15th to 17th April, 2009

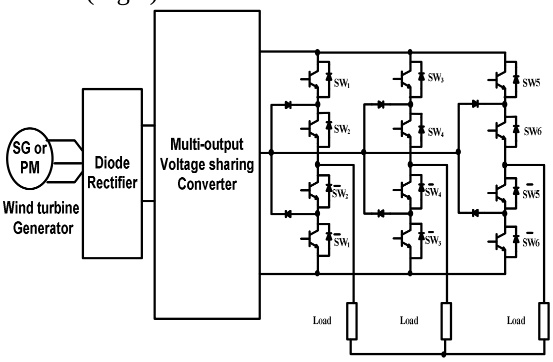
A Novel Configuration for Voltage Sharing in DC-DC Converters

A. Nami[1], A. A. Boora[1], F. Zare[1], A.Ghosh[1], F. Blaabjerg[2]

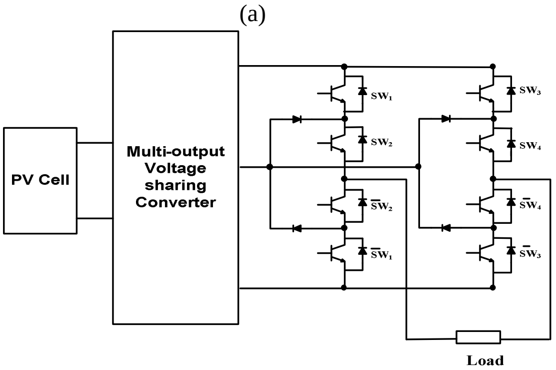
[1]School of Electrical Engineering Queensland University of Technology GPO Box 2434, Brisbane, QLD, 4001, Australia E-mail: namia@qut.edu.au

[2]Aalborg University, Institute of Energy Technology, 9220 Alborg East, Denmark fbl@iet.aau.dk

Recently, multi-output converters are employed with multiple inductors, in which, for M output voltages, M inductors are required. As the number of output voltages increase, the number of required inductors will be increased which leads to an increase of the cost and size of the system. Single inductor in the configuration of multi-output DC-DC converters can decrease losses substantially as well as decoupling losses between parallel inductors. Single-inductor multi-output voltage sharing DC-DC converters are suitable for renewable energy systems based on diode-clamped inverter where there is a need for series regulated DC voltage to supply a DC link (Fig.1).



(a)



(b)

Fig.1. Using MOVS converters in renewable energy systems for (a) three-phase and (b) single phase applications with three-level diode-clamped inverter

This paper presents new configurations of Multi-Output voltage Sharing (MOVS) converter with minimum number of switches for voltage sharing where the output voltages are connected in series. Furthermore, capacitor voltage unbalancing problem can be eliminated as the DC link voltages are generated by the MOVS converters. Two different configurations for a double-output MOVS converter is proposed based on number of switches. Steady state and dynamic analysis of both topologies are discussed as well as control strategies.

Double-output Voltage sharing converter

Fig.2 shows a new double-output voltage sharing converter with one switch. In the first subinterval when S_1 is turned "on", the diode (D_2) obstructs the charging current through C_2 as the voltage across the diode will be negative. Thus, the switch S_1 conducts and directs the inductor current to C_1. However, during the second subinterval, S_1 is "off" and the diode (D_2) can direct the inductor current to both C_1 and C_2.

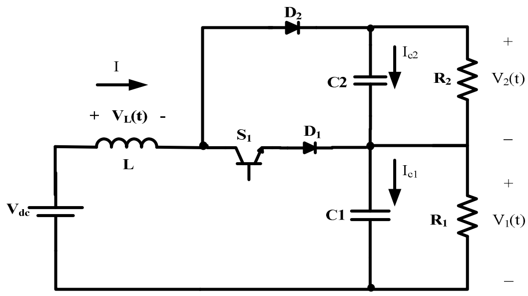


Fig.2. Basic circuit configuration of a double-output voltage sharing

The steady state equations can be derived as follow:

$$V_1 = \frac{nV_{dc}}{(n + D_1'^2)} \quad (1)$$

$$V_2 = \frac{D_1' V_{dc}}{(n + D_1'^2)} \quad (2)$$

$$I = \frac{V_1}{R_1} \quad (3)$$

where $n = \frac{R_1}{R_2}$. By substitution of the small signal part of the variables and using linearization technique, averaging equations can be rewritten to derive small signal equations:

$$\begin{bmatrix} C_1 & 0 & 0 \\ 0 & C_2 & 0 \\ 0 & 0 & L \end{bmatrix} \begin{bmatrix} \hat{v}_1 \\ \hat{v}_2 \\ \hat{i} \end{bmatrix}^{\bullet} = \begin{bmatrix} -\frac{1}{R_1} & 0 & 1 \\ 0 & -\frac{1}{R_2} & D_1' \\ -1 & -D_1' & 0 \end{bmatrix} \begin{bmatrix} \hat{v}_1 \\ \hat{v}_2 \\ \hat{i} \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & -I \\ 1 & V_2 \end{bmatrix} \begin{bmatrix} \hat{v}_{dc}(t) \\ \hat{d}_1(t) \end{bmatrix} \quad (4)$$

Double-output Step-down Voltage sharing Converter

To be able to control all output capacitors voltages in a voltage sharing converter, a new circuit diagram of the voltage sharing converter with two output-voltages is presented in Fig.3. This circuit includes a buck converter series with a voltage sharing converter. When S_B is turned on the inductor can be charged and the power circuit can operate in two different subintervals when S_1 is “on” or “off”. In the next two subintervals, S_B remains off and S_1 operates to direct the inductor current either through only C_1 or both C_1 and C_2 when it is on or off respectively. In both switching cases of S_B, when S_1 is “off”, the inductor current can charge both C_1 and C_2 to produce v_1 and v_2, respectively. On the other hand, when S_1 is “on”, C_2 is being discharged through R_2 as reverse current flow is prohibited by the diode, while C_1 is being charged by the inductor current.

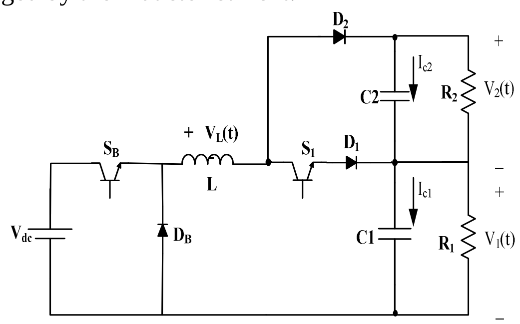


Fig.3. A circuit diagram of a double-output step-down voltage sharing

Regarding the fact that in the steady state operation, the average capacitor current and inductor voltage over one switching cycle is equal to zero, the average output voltage can be calculated:

$$V_1 = \frac{D_B V_{dc}}{(1 + nD_1'^2)} \quad (5)$$

$$V_2 = \frac{nD_B D_1' V_{dc}}{(1 + nD_1'^2)} \quad (6)$$

Also, the average inductor current equation is same as Eq.3.

By substitution of a small signal part of the variables and linearization of averaging equations, small signal modeling equations for a double-output step-up voltage sharing converter are written as a state space format as below:

$$\begin{bmatrix} C_1 & 0 & 0 \\ 0 & C_2 & 0 \\ 0 & 0 & L \end{bmatrix} \begin{bmatrix} \hat{v}_1 \\ \hat{v}_2 \\ \hat{i} \end{bmatrix}^{\bullet} = \begin{bmatrix} -\frac{1}{R_1} & 0 & 1 \\ 0 & -\frac{1}{R_2} & (1-D_1) \\ -1 & -(1-D_1) & 0 \end{bmatrix} \begin{bmatrix} \hat{v}_1 \\ \hat{v}_2 \\ \hat{i} \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & -I \\ D_B & V_{dc} & V_2 \end{bmatrix} \begin{bmatrix} \hat{v}_{dc}(t) \\ \hat{d}_B(t) \\ \hat{d}_1(t) \end{bmatrix} \quad (7)$$