

Novel all-purpose high-power matching device for energy conversion applications



Hassan Fathabadi

School of Electrical and Computer Engineering, National Technical University of Athens (NTUA), Athens, Greece

ARTICLE INFO

Article history:

Received 11 March 2017

Received in revised form 30 June 2017

Accepted 4 July 2017

Keywords:

High-power matching device

Energy conversion

Photovoltaic/fuel cell hybrid system

Electric/hybrid vehicle

ABSTRACT

In this study, a novel all-purpose high-power matching device is proposed to be utilized in energy conversion applications. It is a 6 kW matching device with a low-cost structure consisting of three distinct stages that a complementary pair of unity-gain current mirrors has been utilized in each stage to provide appropriate output currents and voltages. The proposed device is the first and only all-purpose high-power matching device reported in the literature that can be widely used in energy conversion systems to minimize the cost of construction and maintenance. For instance, it can be utilized in a hybrid power generation system including different power sources such as photovoltaic array, fuel cell stack and battery to directly couple the power sources to each other. While, in the conventional method, the power sources are connected to a common Direct Current-link bus via several converters that significantly imposes extra cost. A prototype of the matching device has been built, and simulation and experimental results are presented to model its behavior at low and high frequency. To show some applications of the matching device, it is first utilized as an adjustable high-power (Direct Current)/(Direct Current) converter which is widely used in electric/hybrid vehicles. As the second application, a photovoltaic/fuel cell hybrid power generation system equipped with a maximum power point tracking controller has been built, and the matching device has been used as an interface unit to connect in parallel a fuel cell stack to a photovoltaic system.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Nowadays, energy conversion systems, in particular, renewable energy based power generation systems are widely used to produce a portion of electric power demand [1]. In practice, renewable power sources are combined to each other and other types of power sources to form a hybrid system [2]. This combination not only enhances the rated output power of the system but also increases its reliability [3]. For instance, a fuel cell (FC) stack can be combined with a battery to form a FC/battery hybrid power source to be used in a hybrid electric vehicle [4]. As another example, a photovoltaic (PV) array is combined with a plug-in electric vehicle used as the energy storage device to supply power demand of a smart home [5]. In industrial applications, higher rated power is needed, so solar and wind energies are generally taken into account [6]. Although, because of the uncertainty available in the mentioned renewable energy resources, a deterministic power source such as a FC stack is also added to the combination to form a solar/wind/FC hybrid power generation system [7]. The different power sources available in these hybrid systems are connected to a

common direct current (DC)-link bus via several DC/DC converters to add all the power productions up. This method not only significantly complicates the system implementation but also increases the construction cost [8]. A suitable high-power matching device used as an interface unit to directly connect the power sources to each other can be considered as a solution. In a PV system producing electric power by converting solar energy, a maximum power point tracking (MPPT) controller continually regulates the operating point of the PV module/array used in the system to its maximum power point (MPP) [9]. When this PV system is combined with another power source such as a FC stack to form a PV/FC hybrid system, the PV system plays the role of the main power generator, while the FC stack is used as a standby generator to provide supplementary electric power whenever the power production of the PV system is not enough to satisfy electric power demand. Since the PV output voltage is continually regulated to the MPP voltage using the MPPT controller, the FC stack can be directly connected in parallel to the PV module/array when the output voltage of the FC system exactly follows the PV output voltage (MPP voltage) [10]. The PV output voltage can be followed by connecting a high-power matching device with an appropriate functional design to the FC stack. As another example, in an

E-mail address: h4477@hotmail.com

electric/hybrid vehicle, electric power with different power and voltage levels is needed to meet different power demands [11]. For instance, electric power with the voltage level of +12 V is necessary to be supplied to the lighting loads. A high-power matching device designed based on a suitable multi-task function can perform this function too.

A survey of the current literature and available devices demonstrates that many electronic devices with special function generally implemented using bipolar junction transistor (BJT) [12] and complementary metal oxide semiconductor (CMOS) technologies have been reported or fabricated [13]. But, there is not any all-purpose high-power matching device which can be used to respond the mentioned demands and similar requirements in energy conversion systems [14]. In fact, all the available matching devices reported in the literature have been designed to carry out only one specific task, not even several tasks, in low-power applications in high-frequency communication systems [15] that some examples are as follows. A transmitting coil and a switchable impedance matching unit has been utilized to transfer wireless power to several communication devices, the matching unit in facts changes the input/output impedances to matches them [16]. A device to device matching unit has been designed to adapt the two devices connected to it to transfer data in a cellular network [17]. Design of some matching devices such as quarter-wave transformers all applicable to high-frequency transmission lines have been addressed in [18]. The key objective of this study is to fill the above-mentioned gap by designing, implementing and constructing a novel all-purpose high-power matching device applicable to different energy conversion applications, so the contribution of this work is to present the first and only all-purpose high-power matching device reported in the literature with the capability of utilizing in energy conversion systems to minimize the cost of construction and maintenance. The behavior of the matching device is modeled at low and high frequency by presenting simulated and experimental results. Two practical applications of the matching device are presented. As the first application, the matching device is utilized as an adjustable high-power DC/DC converter which is widely used in electric/hybrid vehicles. As the second application, the matching device is utilized as an interface unit to connect in parallel a FC stack to a PV system both implemented in a constructed PV/FC hybrid power generation system. The paper is organized as follows. The all-purpose high-power matching device is formulized in Section 2. The matching device is implemented and built in Section 3. Low- and high-frequency equivalent circuits of the proposed high-power matching device extracted from experimental and simulation results are given in Section 4. The two applications of the matching device and experimental verifications are presented in Section 5, and the paper is concluded in Section 6.

2. Formulizing the proposed all-purpose high-power matching device

The first step of design and implementation of the proposed high-power matching device is to formularize its behavior. The schematic diagram of the proposed matching device is shown in Fig. 1, and in theory, the functional relationship between the voltages and currents of the three ports is defined as:

$$\begin{pmatrix} V_X \\ I_{Y1} \\ I_{Y2} \end{pmatrix} = \begin{pmatrix} 0 & 1 & -1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} I_X \\ V_{Y1} \\ V_{Y2} \end{pmatrix} \quad (1)$$

In practice, the behavior of a constructed version of the matching device will be slightly deferent from Eq. (1) representing the ideal case. This is because of the limitations resulted from utilizing

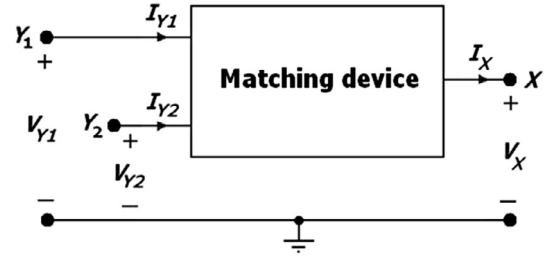


Fig. 1. Block diagram of the matching device.

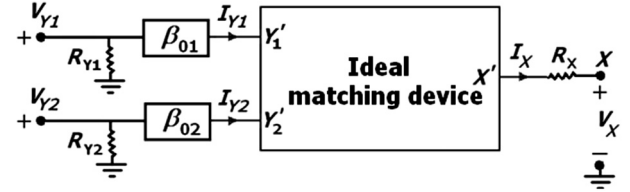


Fig. 2. Low-frequency model of the matching device.

semiconductor components all practically having finite input/output impedance (not infinite), so at low frequency, the behavior of a constructed matching device can be expressed as:

$$\begin{pmatrix} V_X \\ I_{Y1} \\ I_{Y2} \end{pmatrix} = \begin{pmatrix} -R_X & \beta_{01} & -\beta_{02} \\ 0 & G_{Y1} & 0 \\ 0 & 0 & G_{Y2} \end{pmatrix} \begin{pmatrix} I_X \\ V_{Y1} \\ V_{Y2} \end{pmatrix} \quad (2)$$

where R_X , $R_{Y1} = \frac{1}{G_{Y1}}$ and $R_{Y2} = \frac{1}{G_{Y2}}$ are the input resistances respectively observed from the ports X, Y₁ and Y₂. The parameters $\beta_{01} = 1 - \varepsilon_{V1}$ and $\beta_{02} = 1 - \varepsilon_{V2}$, where $|\varepsilon_{V1}| \ll 1$ and $|\varepsilon_{V2}| \ll 1$ are defined as “voltage tracking errors”, represent the deviation from the ideal case ($\beta_{01} = \beta_{02} = 1$). Considering Eq. (2), a constructed matching device can be modeled by adding some components to an ideal matching device as shown in Fig. 2.

3. Construction of the proposed high-power matching device

The circuit of the proposed high-power matching device is shown in Fig. 3. It provides an output current and power up to respectively 60 A and 6 kW, and needs only one supply voltage which ranges from 5 V to 100 V. The matching device consists of the three distinct and identical stages marked in Fig. 3. This point not only is the main deference between the presented design and other designs but also significantly makes easier understating of the device structure and operation. In the first stage, the common emitter node of the two transistors T5 and T6 has been used to perform terminal Y₁ that plays the role of a non-inverting input having very high impedance. The voltage on the non-inverting input is transferred to the inverting input (point A) with a low-offset voltage, ensured by the close matching of like polarity BJTs operating under essentially identical bias conditions, so it is ideally concluded that $V_{Y1} = V_A$. The inverting input (point A) is the common emitter node of a complementary pair of grounded base stages and behaves as a current summing node. A current applied to the point A is transferred to the complementary pair of the unity-gain current mirrors consisting of T1, T2, T3, T4, T9, T10, T11 and T12 that supply the same current to the internal node B, so it is ideally concluded that $I_1 = I_2$. The port Y₂ of the matching device has been connected to the non-inverting input of the second stage (point C) having very high impedance. Similarly, the voltage of the inverting input of the second stage (point D) is equal to the non-inverting

Download English Version:

<https://daneshyari.com/en/article/5012400>

Download Persian Version:

<https://daneshyari.com/article/5012400>

[Daneshyari.com](https://daneshyari.com)