

Analysis of Decoupler Controlled Three Input Multiport Boost Converter for Hybrid Electric Vehicle

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Abstract— In recent years, in quest of clean energy as a energy source for vehicles to replace fossil fuels has become important to reduce environmental pollution. Hybrid Electric Vehicles, powered by pure renewable energy sources like solar cells and fuel cells, are expected to revolutionize the transportation industry. This paper introduces an improved non-isolated three-input multiport boost converter for the Hybrid Electric Vehicles. The converter features three ports out of this , two port is supplied with the input power sources and one port with a battery, all formed into a single structure. The new converter use inverted decoupler feedback controller. Major benefit of using this controller is the cross coupling between the input variable parameters can be mitigated. The proposed system was simulated and the steady state transient performance of the closed loop analyzed .The results validated with the hardware setp.The efficiency, voltage regulation and dynamic response was improved.

Index Terms— Hybrid Electric Vehicle, MISO converter, decoupler.

I. INTRODUCTION

There is a growing push for the adoption of green technology to combat pollution and promote the integration of various renewable energy sources. Electric vehicles (EVs) have become increasingly popular due to their environmentally friendly characteristics. According to the International Energy Agency (IEA) report, the profit projected for the EV market will reach \$457.60 billion by 2023. Additionally, the consumer base is expected to increase to 16.21 million users by 2027 [4].The existing Electric Vehicles (EVs) have the problem of using fossil fuel and producing non-zero carbon emissions. To solve this issue, researchers are focusing on the development of Hybrid Renewable Energy Vehicles (HREVs). These types of vehicles utilize a hybrid combination of solar cells, fuel cells, biomass, and other renewable energy sources. As a result, zero carbon emissions can be achieved. Renewable sources of energy are known for their intermittent nature. To ensure a smooth and continuous power supply to loads, energy storage elements are required in stand-alone renewable power systems. Traditionally, multi stage DC-DC converters are used in these applications [1], [2]. However, this approach may suffer from drawbacks of high cost and low efficiency.

In recent times, Multi Port Converters (MPCs) have gained significant research interest as they offer a more promising solution. MPCs have the capability to interface and control multiple power terminals synergistically. They possess several merits, including low cost, high power density, high efficiency, and a compact structure [3]-[21]. By utilizing MPCs, it becomes possible to interface and manage various renewable power sources simultaneously, such as multichannel PV panels, hybrid PV systems, and wind turbines[8-11].

With the integration of MPCs into renewable energy systems, the issues of high cost and low efficiency associated with conventional multiple-stage conversion approaches can be addressed [11-12]. This advancement can lead to more efficient and cost-effective renewable power systems, helping to foster the widespread adoption of renewable energy sources and promoting a sustainable energy future.

Major problem faced by the multiport converter implementation is a proper control strategy. Since the system has to deal with the more than one source the chance for coupling of various parameters are high. As result the performance of the system will be descend. Multivariable control strategy will be a promising solution to this issue. The available multivariable control strategies are Model Predictive Control (MPC), decentralized control, decoupler control etc. In this decoupler control is the populated one due the simplicity and accuracy. The decoupler control is of static model and dynamic model are available. When a practical scenario is considered dynamic decoupler is preferred. In the realm of dynamic decouplers, there are three main types available: the ideal decoupler, the simplified decoupler, and the inverted decoupler. In their study [15], the researchers extensively discussed ideal and simplified decoupling techniques, ultimately concluding that the simplified technique outperforms the ideal method, offering better performance. Additionally, in a separate study [16], the author detailed that the inverted decoupler surpasses the simplified decoupler in terms of efficiency. The inverted decoupler was found to produce more accurate results in control applications. Notably, a growing number of researchers [12-20] have shown a recent interest in the application of inverted decoupler techniques in their work, indicating a trend toward its adoption in various research projects.

This paper proposes an inverted decoupler control for a three input port MPC. This MPC has a solar PV source ,fuel cell and battery. The converter is mathematically modelled and transfer function determined. The proposed inverted decoupler control technique enhances the dynamic performance of the MPC converter by reducing cross-coupling effects among inductor current, source current, and load voltage. Furthermore, the converter is highly efficient in minimizing current ripples.

II. PROPOSED CONVERTER TOPOLOGY

The new converter is integrated with three input sources, including a fuel cell ,PV cell, a, and a battery. The operation mode of the converter is determined by the battery performance. To incorporate nonlinear elements, an inductor and an internal resistance are connected to the source.

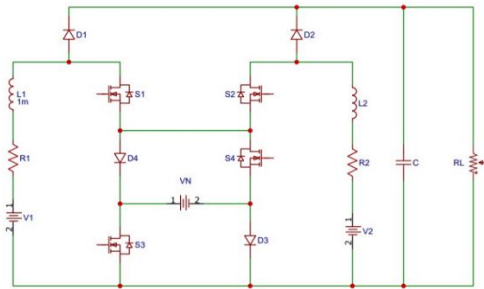


Fig.1 Circuit diagram of three input multiport boost converter

The converter operates in three distinct operating modes, each characterized by specific switching periods. The duration of these switching intervals is determined by the duty ratio of the semiconductor switches. To maximize power extraction, this model incorporates Maximum Power Point Tracking (MPPT). The regulation of power extraction is influenced by the duty ratio of the switches.

$$D_1 + D_2 + D_3 + D_4 + D_5 = 1 \quad (1)$$

$$V_o = \frac{V_{PV} + D_4 V_{Bat}}{1 - D_1 - D_4} \quad (2)$$

$$V_o = \frac{V_{FC} - D_3 V_{bat}}{1 - D_2 - D_3} \quad (3)$$

$$P_{Bat} = D_3 I_{FC} V_{Bat} - D_4 I_{PV} V_{Bat} \quad (4)$$

Where,

D_1 -Duty ratio of switch 1: D_2 -Duty ratio of switch 2: D_3 -Duty ratio of switch 3: D_4 -Duty ratio of switch 4:

V_O -Regulated output voltage of converter: V_{BAT} -Battery voltage: V_{FC} -Fuel cell voltage : P_{Bat} -Battery power level:

I_{FC} -Fuel cell current : I_{pv} -Solar cell current:

The eqn. (1-4) define the working of the duty ratio working for the regulation of the converter, Eqn. (2-4) explain the relationship of battery voltage , fuel cell current and duty ratios. From equation (2) it can be understood that the PV power can be controlled by adjusting D_1 . D_3 controls the Battery charging performance.

$$v_{L_1} = d_4 T (v_1 - r_1 i_{L_1} + v_B) + (d_1 - d_4) T (v_1 - r_1 i_{L_1}) + T(1 - d_1) (v_1 - r_1 i_{L_1} + v_0) \quad (5)$$

$$v_{L_2} = d_4 T (v_2 - r_2 i_{L_2} + v_B) + (d_2 - d_4) T (v_2 - r_2 i_{L_2}) + T(1 - d_2) (v_2 - r_2 i_{L_2} + v_0) \quad (6)$$

Where,

d_1, d_2, d_3, d_4 -Duty ratio of switches 1,2,3 and 4 small signal model is considered:

v_{L_1}, v_{L_2} – voltage across inductors L_1 and L_2 : I_{L_1}, I_{L_2} – current through inductors L_1 and L_2 :

Eqn. 5 and 6 represent mathematical equations describing the behaviour of the inductor voltage. The gating pulses are generated from the saw tooth pulses produced by the inverted decoupler. The overall operation is determined by the control of duty ratios during the five switching intervals.

III SIMULATION-RESULTS

MATLAB simulations analyse the converter model functioning in n using the proposed inverted decoupler control strategy. Different modes of operation in simulation are specified by varying the PV power and load conditions. The hybrid model includes the maximum power of 1 kW and 0.85 kW of average power is given to the load side. The rating of the input sources are set to $P_{pv}^{max} = 1.5kW$, $P_{FC}^{max} = 1kW$, and $P_{battery}^{max} = +1.5kW$. The regulated voltage for the closed loop MPC is 220V. The ripple content is measured for the input source current.

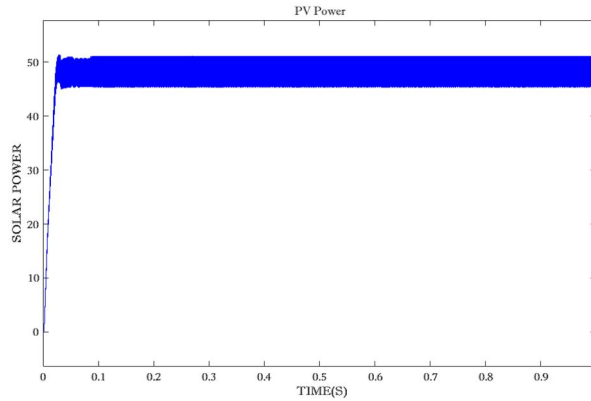


Fig.2 The waveform shows the solar power extraction using the MPPT control

Fig.2 shows the solar power extracted from the panel. The main source for the converter is solar power. Due to the irradiance variation the power will be varying in nature .A perturbation and observation MPPT algorithm is used to obtain the maximum power from the source.

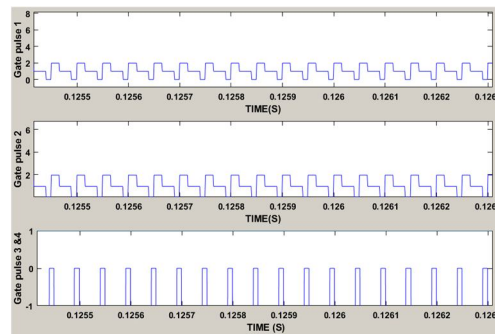


Fig.3 Gate pulses applied for the semiconductor switches

Fig. 3 illustrates the switching pulses provided to the four switches in the proposed converter. The duty ratio varies across different switching periods. Table I presents a comparison of the closed-loop performance of the proposed converter. The converter was simulated using an existing PID controller, but for this MPC converter, three PID controller loops are required.

TABLE I -COMPARISON OF CLOSED LOOP PERFORMANCE OF THE PID CONTROL AND INVERTED DECOUPLER CONTROL

Feedback Controller type	Rating	Percentage Overshoot(%)	Settling time (ms)
Three loop PID controller	220V,1kW	4.3	80
Decoupled control converter	220V,1kW	0.92	45

The simulation results demonstrate a robust dynamic response for the double boost MPC with an inverted-decoupler controller, even in the presence of input disturbances. The closed-loop performance has been significantly improved when compared to the existing feedback controller, as evidenced by the reduced peak overshoot and settling time.

IV. HARDWARE IMPLEMENTATION

To validate the efficacy of the proposed converter, a laboratory prototype was constructed, as illustrated in Figure 4. The prototype of the proposed converter is designed with the following specifications: a rated power of 30 W, input source voltage 20-40 V, and a 120V regulated output voltage. The switching frequency is configured to operate at 70 kHz



Fig.4 Experimental setup for the proposed converter

Figure 5 illustrates the impact of the inverted decoupler control, which was activated at 1 second. The response clearly indicates that the input current waveform becomes distorted when using PID controllers. The glitches observed are a result of the interaction between the inductor current and load current. However, with the implementation of the decoupler, the current response becomes smooth, and the closed-loop performance improves, achieving a settling time of 40 ms.

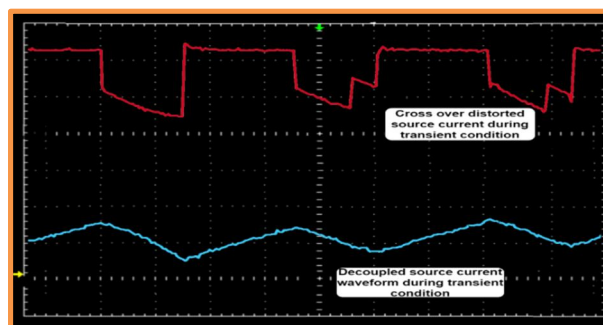


Fig.5 Waveform of the distorted source current and the decoupled output

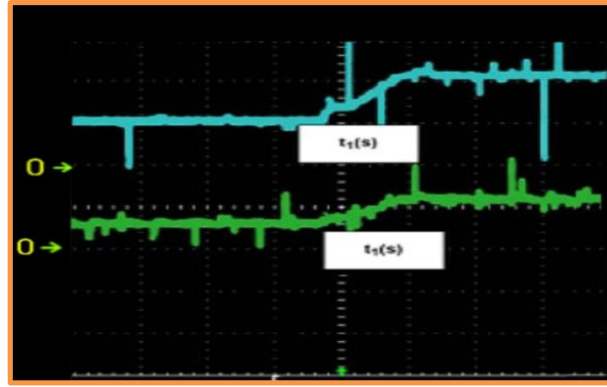


Fig.6 load voltage and current response for the proposed converter

Figure 6 displays the responses of the load voltage and current for the converter. The load voltage response reaches the steady-state value within a 40 ms interval, while the load current takes 55 ms to reach its steady-state value. The improvement in closed-loop performance can be clearly observed from these waveforms.

TABLE II-COMPARISON OF THE PID CONTROLLER AND DECOUPLER CONTROLLER FOR THE NEW CONVERTER PERFORMANCE

	Control strategy	Change for the reference value	Settling time for regulated voltage	Efficiency
simulation	PID Controller[27]	33%	2s	78.25%
	Inverted decoupler	5.2%	35ms	91.2%
Hardware	Inverted decoupler	9.8%	40ms	85.04%

V. CONCLUSION

In this paper, an inverted decoupler control strategy for non-isolated double boost MISO converters is proposed. The MPC is a hybrid model incorporating three different renewable energy sources: a PV cell, a Fuel cell, and a Battery. A power control algorithm, known as perturbation and observation, is employed to achieve maximum power extraction. This algorithm ensures the balanced delivery of energy from the sources to the load. The converter utilizes four independent switches and four duty ratios to manage power flow between the two input sources and the load. Analysis demonstrates that the MPC with the proposed control strategy yields stable closed-loop responses even in the face of reference parameter variations. This method offers several advantages:

- The decoupled system is entirely free from coupling elements, as evidenced by the analysis of the diagonal elements of the decoupler matrix, which consistently equals one.
- The controller effectively mitigates cross-coupling between variables, reducing power source current ripples to 2.6% within IEEE standard limits.
- It regulates the output voltage to 220V while remaining immune to disturbances.
- The control strategy enhances closed loop dynamic response with a regulated voltage settling time of 40ms, an overshoot of only 0.96%, and a rise time of 50ms.

This novel control approach minimizes interactions among different control loops and demonstrates strong dynamic performance.

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