A Versatile Load Leveling Method for Fuel cell-based Electric Drive for Vehicular Application

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Abstract: This paper presents a flexible power control strategy of a fuel cell (FC)- battery combined hybrid power source fed DC motor drive suitable to be used in electric vehicles which can be capable of working efficiently with an straightforward control method, operating the drive precisely in FC and hybrid modes during the entire drive operation. Although Fuel Cells are very widely accepted by the electric vehicle manufacturing industries, still the power control criterion can be improved to increase overall efficiency. The most appropriate Master Slave Control technique has been implemented to control the modes based on load power requirement and transient operations. The controller with the algorithm guarantees that total load is shared exactly between the two sources all through intense load and transients conditions. Such method inevitably facilitates the fuel cell to work in normal load region throughout transient and steady state by equally sharing the load current between the master and slave converters. The efficacy of the proposed scheme is verified through simulation which is carried out using MATLAB/Simulink software. Investigational tests are carried out using LabVIEW platform with PCI 6251 DAQ I/O interfacing card for viability of the system. FC can be considered as most vital electric power and component of an electric vehicle.

Keywords* : *Battery, converters, dc motor, electric vehicle, fuel cell, Power management.

I. INTRODUCTION

The prospective of Fuel cells proves to be useful in various applications broadly provide electric power to diversified utilities such as electric vehicles, computers, mobile phones and electric grid and especially in the application where usability of ac supply is quite impossible. Among various types of fuel cell, proton exchange membrane (PEMFC) emerges to be appropriate in electric vehicles [1]–[3] due to its high power density and allowable operating temperature range [4]. Control of fuel cell power flow is one of the challenging issues when it comes in electric drive application which has drawn more attention towards the researchers in recent years. DC systems have been used in various applications due to its easy interconnection of renewable sources, high reliability and high efficiency as compared to ac systems, but less attention has given to use of FC in dc drive system. In a single stage power conversion process a dc motor can be driven directly from FC by connecting a conventional dc-dc converter with static load characteristic. But with a varying load characteristic, FC as a single candidate is inefficient during transient period and high load period as it possesses slow dynamics with frequently varying load characteristic. Also Fuel cells have limited range of operating voltage and load following capability and are the main draw backs which can be eliminated by mixing a battery bank of adequate capacity. Therefore, an auxiliary power source is essential for effective operation of FC in such applications.

The control strategies of FC and battery directly reflect on hydrogen consumption. Many control methods have been evolved in recent years which aims first at optimizing the power sharing between the fuel cell and battery for a known driving cycle in second case control is based on real-time controllers such as fuzzy logic [8]–[10], neural network [11], or predictive control [12], [13]. On the other hand, a predefined driving cycle will definitely differ from realistic one. Predictive control objective will never match with the real control objective. This paper proposes a simple power sharing technique without any complicated control structure where the FC power can be used more efficiently while reducing the hydrogen consumption.

Recently many power management control strategies have been proposed for FC and battery hybrid systems which are mainly based on rule-based control strategy and optimization-based control strategy. In rule-based control strategy, the rules are designed based on heuristics, intuition and mathematical modeling and without prior knowledge of a predefined driving cycle. The main purpose of these control approaches is based on conception of load leveling which leads the operation of the drive close to some predetermined value during the vehicle operation. Master- slave control strategy works with some predefined conditions and very easy to implement which is the main focus of this paper.

II. CONVERTER STRUCTURE AND OPERATION

Power converters play a very vital role in such hybrid power systems and they can be used with proper control methods to stabilize FC which also needs to combine energy storage units. A hybrid power system combined with storage batteries shows fast dynamic response and high reliability by compensating excess power requirement from fuel cell. [1]–[8] Based on the electrical characteristic of FC mostly high current, low voltage, a conventional boost converter is designed which uses a single IGBT switch is more appropriate and operates in current control mode. The dc-dc boost converter for FC is shown in Fig.1, which converts the dc output voltage of FC from its

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rated voltage to desired dc link voltage. This DC-DC boost converter designed with high frequency Inductor L_1, DC link capacitor C also acts as filter, a diode and one main IGBT switch S_1. The bidirectional dc-dc converter operates in parallel with the FC converter consists of IGBT switches S_2, S_3 and diodes D_2, D_3 connects the battery with the load. Switch S_2 and diode D_3 serve as buck converter and during its operation batteries charges through regenerative braking action. During boost mode operation of bidirectional converter switch S_3 and diode D_2 operate that delivers the power from the battery to load.

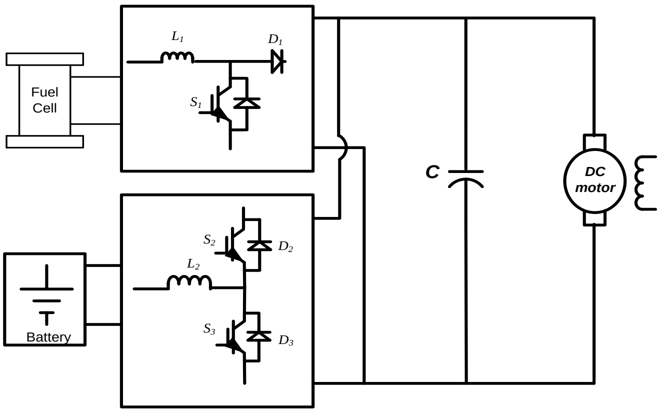
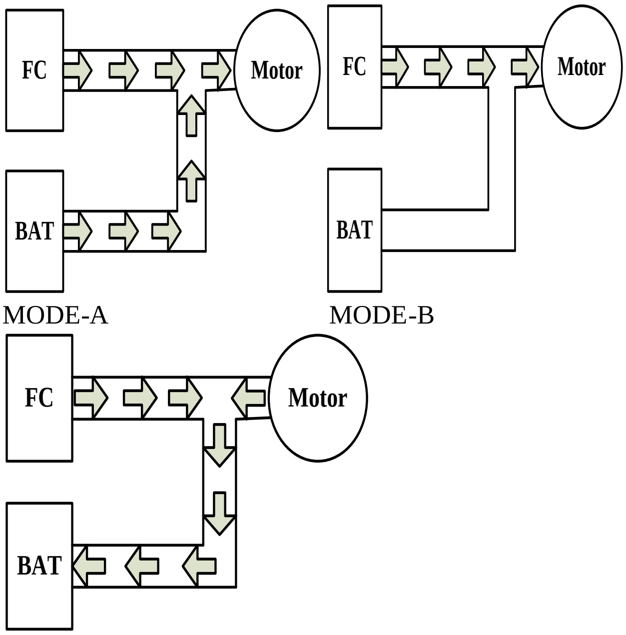


Fig. 1. Configuration of hybrid power source.

Due to the major advantages of parallel interleaved dc–dc converter providing adequate output current and reduced ripple content with high efficiency in output voltage makes suitable for hybrid power system [9]–[11]. To ensure even circulation of power under transient condition, the total current needs to be shared equally between the converters by using master-slave current sharing technique.

The operation of FC and battery converters is explained in Fig. 2. During starting and while load changing both the converters operate as shown in mode A. In steady state FC converter operates alone to supply the load demands which is shown in mode-B. During regenerative braking battery charges through bidirectional converter from regenerative power of motor and excess charge of fuel cell, this is shown in mode-C.



MODE-A

MODE-B

MODE-C

Fig.2. Hybrid mode operation during transient and high load period (mode-A), steady state operation and regenerative braking operation are shown in mode B and C respectively.

The mathematical modeling of dc-dc boost front end converter used for fuel cell and bidirectional dc-dc converter for battery using state space average method described in author's previous research paper [7].

Fuel Cell (PEMFC)

In PEMFC, many smaller molecules are combined to form proton composed of molecules with a high molecular weight. Hydrogen fuel and oxygen are used in PEMFC is acquired from the air as an input and produces water and electricity. PEM Fuel cell has high power density and can be operated at high temperature of 50° C to 100° C. It takes very little time to warm up and begins generating electricity quickly with an efficiency varies at a wide range of 25% to 58% and widely adopted its usefulness in transportation sector due to its longevity, efficiency and high power density. Hydrogen consumption can be brought under control by combining battery into drive system with suitable power control methods. In hybrid electric vehicle (HEV), FC has been used with batteries which lead to zero emission. In this work, a PEMFC model of 42 cells, 1.26kW, and 48V has been considered in simulation study.

The output voltage equation of fuel cell is represented as function of current and temperature E_{fc} (i,t) and present the potential variation due to chemical reactant disparity of fuel and oxidant delay. The fuel cell output voltage, E_{FC} is expressed as

$$E_{FC} = E_{oc} - E_{activation} - E_{ohmic} - E_{conc} \qquad (1)$$

$$E_{oc} = N.\left[E_o + \frac{rt}{2F} \ln\left(\frac{ph_2\sqrt{po_2}}{ph_2o\sqrt{po}} \right) \right] \qquad (2)$$

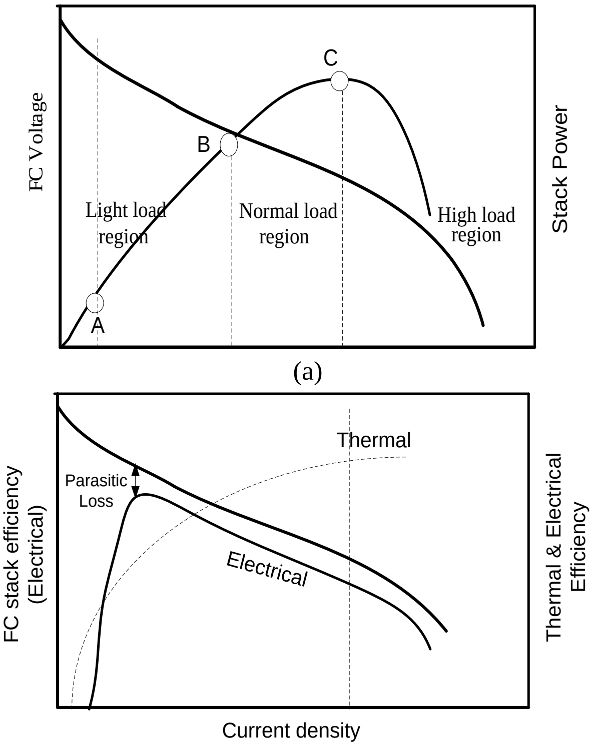
$$E_{ohmic} = N.I_{fc}.R_{FC} \qquad (3)$$

$$E_{actuation} = N.\frac{rt}{2\alpha F}.\ln\left(\frac{I_{fc} + I_n}{I_o} \right) \qquad (4)$$

$$E_{con} = N.m.\exp(n.I_{fc}) \qquad (5)$$

Where E_{oc} is the ideal voltage of FC, $E_{actuation}$ is the part of activation voltage drop, E_{ohm} is the natural ohmic voltage drop, E_{con} is the concentration over voltage. Also the output voltage is a function of Gibb's free energy, gas constant, cell temperature and partial pressure of reactance. In addition its output voltage decreases as output current demand increases as shown in Fig.3(a) also each operating point of a fuel cell represents different power outputs and different power conversion efficiency, hydrogen consumption, operating temperature [4]. From the voltage current characteristics of FC as shown in Fig.3 , it is evident that if the working of the FC in the region after point C it would lead to use of excess hydrogen. To achieve an effective power sharing during short time over loading and transients the following power equation is used.

$$P_{FC} = V_{FC}.I_{FC}$$



(a)

(b)

Fig. 3 (a) curves showing V-I and P-I characteristics of PEMFC, (b) Efficiency of PEMFC.

Battery

The most suitable batteries used in ground vehicles are Lithium-ion and Nickel-Metal hydride (NiMH) because of their superiority in terms of high energy density, compact size and consistency. Battery bank also can be recharged by the regenerative action of the motor which provides resistance at time of braking; thereby facilitate to reduce speed of the vehicle.

The advantages of lithium-ion batteries are high energy density, excellent performance at high temperature environment, and also it is eco-friendly. Other important features of the Li-ion batteries comprise less memory effect, high specific power, high specific energy and long battery life [15]. Due to these exceptional characteristics, lithium-ion battery is more suitable for replacing NiMH as next-generation batteries for vehicles. The Li-ion rechargeable battery is used as auxiliary energy source to supplement the power to the drive during acceleration, cruise and regenerative braking. The bidirectional converter which allows charging and discharging of the battery operates in two modes such as buck mode and boost mode. The detail components with their parameters and values of the proposed system are shown in the Table-1.

TABLE.1

Components	Parameters
Fuel cell	PEMFC, 1.26kW, 48Vdc
Battery	Lithium-Ion battery, 48V, 16A, SOC=88%.
Fuel cell converter	DC-DC Boost converter, L=1600µH, C=2000µF, V_{in} =45v. f_{SW} =20kHz
Battery converter	Bi-directional dc-dc converter, L_1 =1350 µH, C=2000 µF, ESR=10mΩ, f_{SW} =20kHz.
DC Motor	0.5HP, 220v, 1500rpm

III. ANALYSIS OF THE CONTROLLER

The proposed integrated control structure using master slave control [20] technique is suitable for control of hybrid electric source comprises fuel cell and battery fed dc drive is shown in Fig.4. Here FC converter treated as master converter and battery converter as slave converter thus both operated in parallel. Here, the master converter module is accountable for motor speed regulation and provides the reference current for the slave converter, while the slave converter is dedicated to track the output current of the master module.

Master module has two control loops one outer speed and another inner current control loop. The output of the speed control loop is the reference to current control loop which depends entirely on load. The battery converter receives the current reference from FC converter. The speed control loop gain affects the speed regulation of motor with load variations, input and control parameters. The output of the current control loop is compared with triangular signal carrier signal of 20 KHz frequency. The comparator output then passed through a suitably designed gate driver circuit to generate PWM signal to control the IGBTs of the power circuits. The reference current for the controller of the slave converter is generated by the speed control loop of the master module. This proves that the current circulation between the converters is even, thus reduced problems associated with unequal power sharing between the converter modules and hence relieves stress on the FC.

Fuel cell current, I_{fc} , battery current, I_{bat} and real speed of the motor are fed back to the controller to generate the proper switching signals for FC and battery converters to regulate the output load current and the output voltage of power converters. The difference of the reference and actual speed is fed into PI controller to generate reference current for the inner current control loop. Then the reference currents for the FC and battery are compared with the actual currents of FC and battery. The error signal is processed through different current controllers. Since during boost converter operation of both power converters, there is a constraint on flow of the inductor current which is unidirectional, the dynamics of current control loops has been decoupled from each other, and PI controllers are designed separately for each current control loop. Also with PI controller, steady-state error is eliminated which facilitates precise power sharing. Even during rapid speed change, the performance of PI controller is better to provide fast response without oscillations in the signals. Thus it can be summarized that the basic principle of the proposed control system is based on the required load power, FC and battery health condition. There are three loops associated with the control structure such as two inner current control loops and one common output voltage control loop. The output voltage loop generates the reference current based on the error in the output voltage at the DC link. To achieve fastest response of the current controller, large bandwidth is chosen.

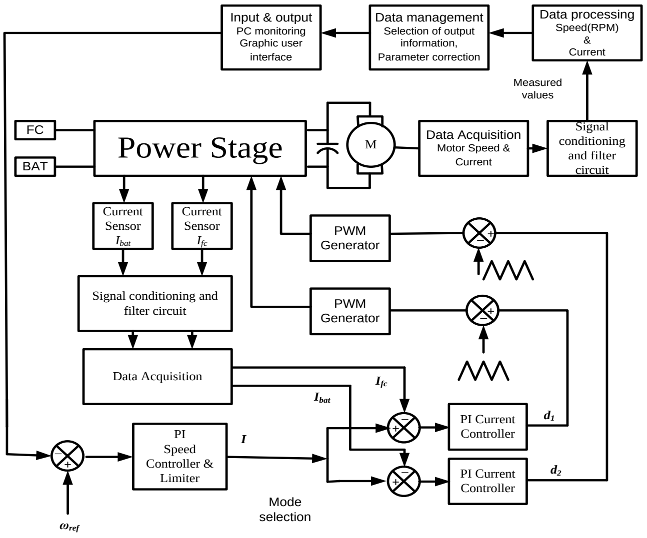


Fig.4 Control strategy of the converter system.

average inductor current in each module is controlled with the help of average signal, Fig. 4 depicts the control structure, which includes the current-sharing loop(CSL) and voltage control loop (VCL). Both power converters are operated parallel and use a common voltage control loop. Every power module has its individual current-sensing network and its current-sharing control loop. Absolutely negligible steady-state error is achieved with the inclusion of nn integrator in the main controller. Major advantages of series-parallel converters include:[21]

(a) Higher efficiency can be achieved by using low voltage IGBTs and due to standardization the cost and mechanized effort can be reduced

(b) Power processing capability can be increase and lower conversion ratios for individual converters can be achieved.

(c) Power density also increased due to interleaving technique and improved reliability due to even distribution of stresses.

The following driving equations [15-18] are implemented to validate the master-slave control strategy in the proposed dc drive system which is suitable for electric vehicle application. As the source voltages are different, both converters are controlled at different duty cycles to maintain a common dc link voltage. Therefore,

$$V_{fc}=V_{bat}=V_o=V_{dclink} \tag{14}$$

$$D_{fc\_con}.V_{s\_fc}=D_{bat-con}.V_{s\_bat}=V_0 \tag{15}$$

As the power drawn from the two sources are equal in hybrid mode,

$$V_{fc}.I_{fc}+V_{bat}.I_{bat}=V_0.I_0 \tag{16}$$

$$D_{fc}.I_{fc}=D_{bat}.I_{bat}=\frac{I_0}{2} \tag{17}$$

During hybrid mode the following Equation 18 describes the current sharing between master module and slave module. Thus the power can be shared equally among the two sources.

$$I_{ref}=\frac{1}{n}\sum_{m=1}^{n} i_m \tag{18}$$

Where i_m is the module currents; $m=1,2$;

In drive operation the converter is controlled in terms of its voltage and current to supply excess energy required during starting to load, change in load and facilitates regenerative braking also. The required rated voltage at the motor terminal as well as the charging/discharging of battery is maintained by appropriate control of the switching signal of the bidirectional converter.

FC and Battery Control

To control hydrogen flow rate of FC and to regulate power flow from FC, it has two independent and parallel controllers. Flow rate control of FC depends on fuel cell current. Second controller compares the FC current with the reference load current to generate control signal for dedicated FC power converter.

The function of the controller used for bidirectional converter regulates the duty cycle in order to maintain required DC link voltage at load terminal. The controller smoothly regulates the battery voltage and current to facilitate charging and discharging of the battery with the indication of SOC level. The switching signal with a dead time for the bidirectional converter is shown in Fig.5. The switching signal of S_1 *and* S_2 are shown which are complementary to each other.

The steady state error can be eliminated with the use of PI controller and precise load sharing is achieved. The proportional-integral (PI) controller is helps to eliminate the steady state error between the actual signal and the desired signal to be tracked. The transfer function of PI controller is given by equation 19.

$$G_C(s)=K_P+\frac{K_i}{s} \tag{19}$$

Where K_P and K_i are gains of proportional and integral controller.

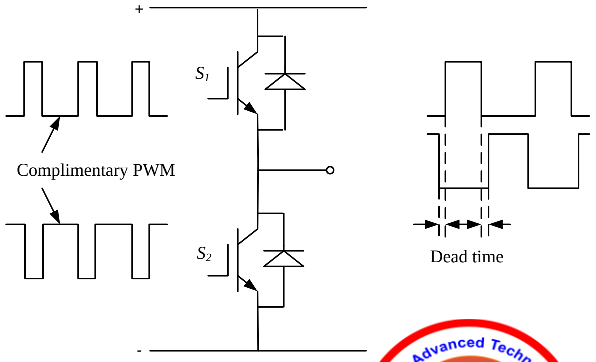
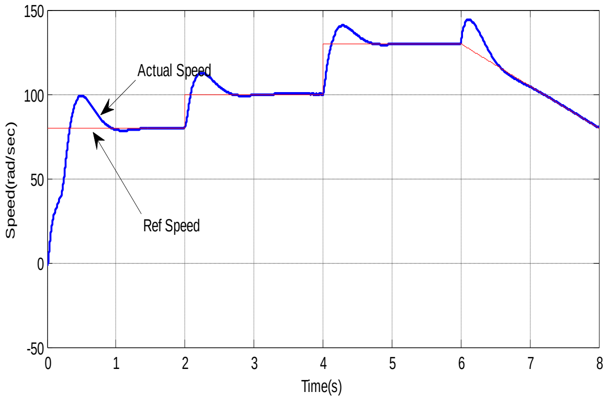


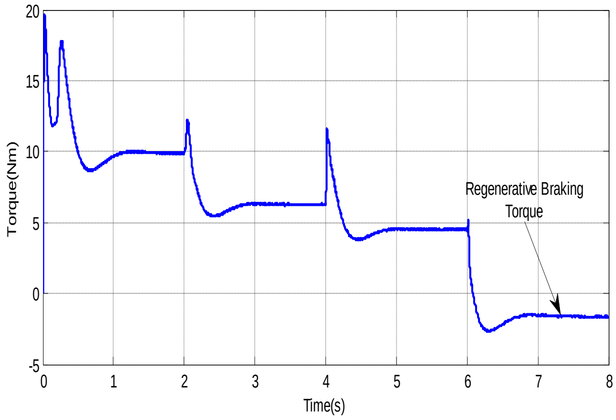
Fig.5 Complementary Switching signals for Bidirectional Dc-Dc converter with dead time.

IV. SIMULATION RESULTS

In this section, the simulation results of the hybrid power system fed dc motor drive with load current sharing using MSC method is presented. The parasitic resistance of the inductor L_2 is 10mΩ and the ESR of the capacitance is 30mΩ. It is imperative to note that the power management at different driving cycles is the main prerequisite of electric drive in means of transportation operating system. Fig. 6(a) shows the speed response of the dc drive system with a variable reference command (80rad/sec→100rad/sec→130rad/sec→80rad/sec). Speed reduction shown from 130rad/sec to 80rad/sec during regenerative braking. As shown in Fig.6 the controller effectively tracks the suggested speed command within a reasonable time period of one second. As FC possesses poor dynamics, during starting, the required power is drawn from the battery source. After FC reaches its proper chamber temperature, it shares equal power with battery to supply the load. In steady state operation of the drive, load current is shared equally among the two energy sources through the two DC-DC converters. Fig. 6(b) shows the developed motor torque in correspondence to the load torque. Fig. 7(a) & (b) show the battery current and SOC during starting and steady state operation of the drive. Due to higher bandwidth of battery current control loop, during starting battery channel is able to respond faster than FC, which relieve the stress on FC system. Battery current is high during starting. Fig.8(a) & (b) shows the fuel cell current and voltage respectively. FC current is insignificant at beginning due to its sluggish behavior at starting. Fig.9 shows the actual load power and both sources power throughout complete operation.

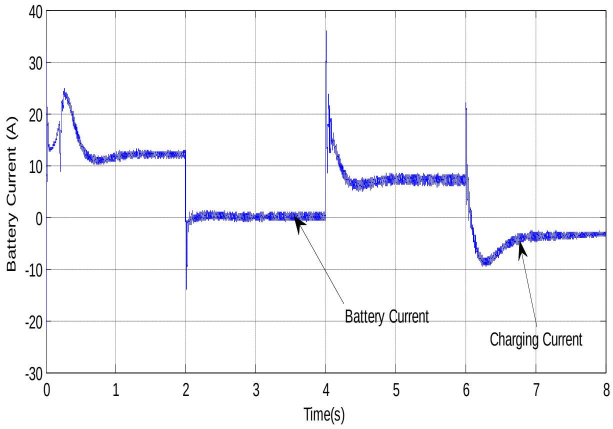


6(a).



6(b)

Fig.6 (a) Motor speed (b) Torque.



7 (a)

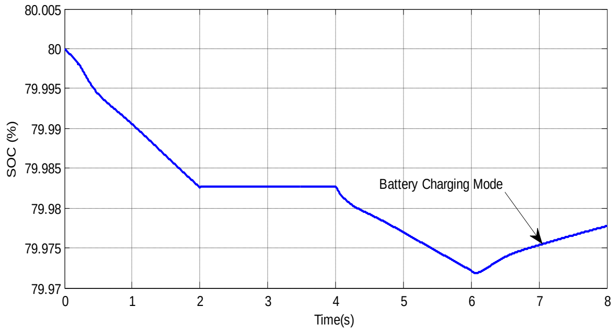
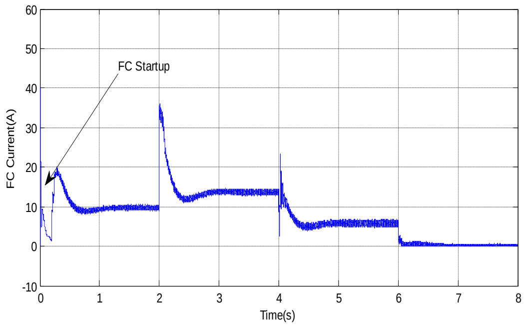
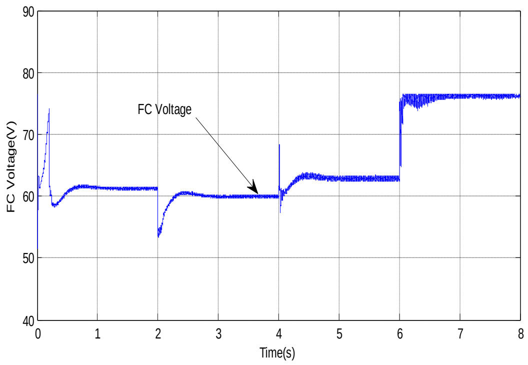


Fig. 7 Battery characteristic (a) Current (b) SOC.



8 (a)



8 (b)

Fig.8 Fuel cell current (a) and voltage (b).

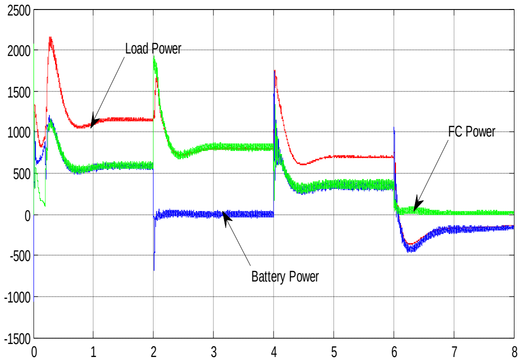


Fig.9 Motor power, Battery power and Fuel cell power.

V. EXPERIMENTAL VALIDATION AND RESULTS.

The proposed hybrid source fed drive system was developed and tested completely in the laboratory. In this section experimental validation of the simulated results under transient and steady state are presented. The proposed load current sharing using MSC technique scheme is tested by using a 0.5HP DC motor. Transient and steady state system behavior is carried out. The dc motor is fed from a rectifier and battery bank of 48V, 42Ah. Mitsubishi IGBT modules (CM50DU-12H) have been used in implementation of bidirectional and unidirectional dc-dc converters. The motor speed sensor circuit is developed using an IR LED and one L14F1photo transistor. The current transducers (part no-LA 55-P) are used to sense the converter output currents. These variables are used for generation of reference current and for PI- current controllers. The master-slave digital controllers were implemented in LabVIEW environment which is shown in Fig.10. The hardware consists of PCI 6251 DAQ input/output interface card with a connector block. Fig.11 shows the generated gate signals for the IGBT switches S_1 and S_2 of the bidirectional dc-dc converter. The gating signal of S_2 is complementary of the gating signal of S_1 with a dead time of 5μs.

During forward motoring mode of the dc drive, the bidirectional converter operates in boost mode. In MSC scheme both FC converter and battery converter share equal amount of the load current. A driver circuit (IC- M57962L) of 20 KHz switching frequency is set to achieve the balance among converters output current ripple level, reasonable switching loss and switching stress. Fig.12 shows the dynamic speed response while demanded reference speed changes from 500rpm to 600rpm. The controller performance in Fig. 13 shows the speed response of the drive with a reference speed of 600rpm. Fig.14. (a) and (b) shows the current sharing phenomena of FC and battery converter. The mean values of the two converter currents are close and thus establishing equal current sharing between the master and slave modules. The total load current of 0.4A is shared equally by both the converters (0.2A each). The converter current of slave module tracks the corresponding master module current signal well as expected. In order to impose electrical load to the drive system, a generator was mechanically connected to the motor and current sharing phenomena achieved when load resistance changes from 100Ω to 60Ω as shown in Fig.15 while motor runs at a speed of 600 RPM. Fig. 16 shows the current sharing among FC and battery when load changes from 60Ω to 100Ω respectively at a motor speed of 500RPM.

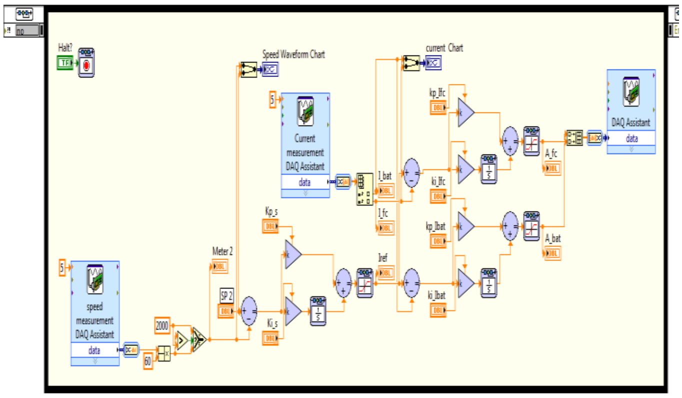
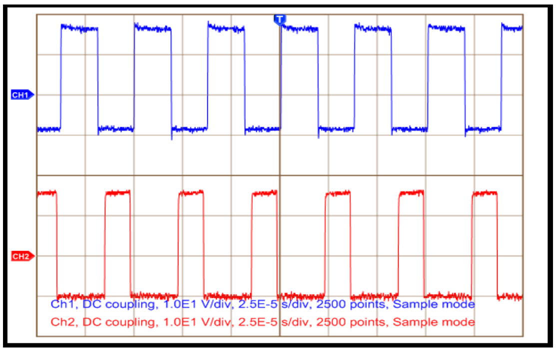


Fig. 10. Master-slave digital controller implemented in LabVIEW.



Ch1, DC coupling, 1.0E1 V/div, 2.5E-5 s/div, 2500 points, Sample mode
Ch2, DC coupling, 1.0E1 V/div, 2.5E-5 s/div, 2500 points, Sample mode

Fig. 11. Gate signals of Bidirectional dc-dc converter With delay time of 5ms.switch S_1 (Blue), switch S_2 (red).

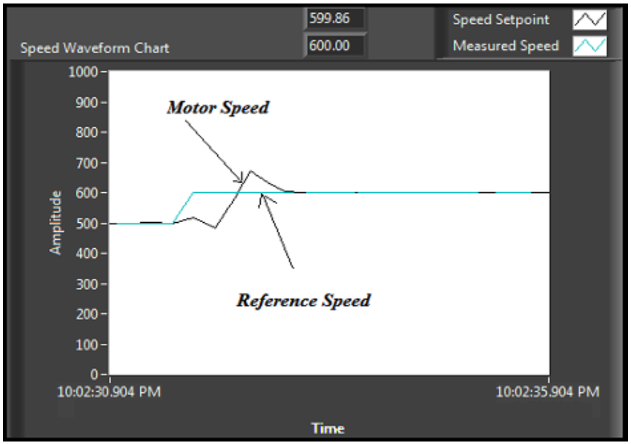
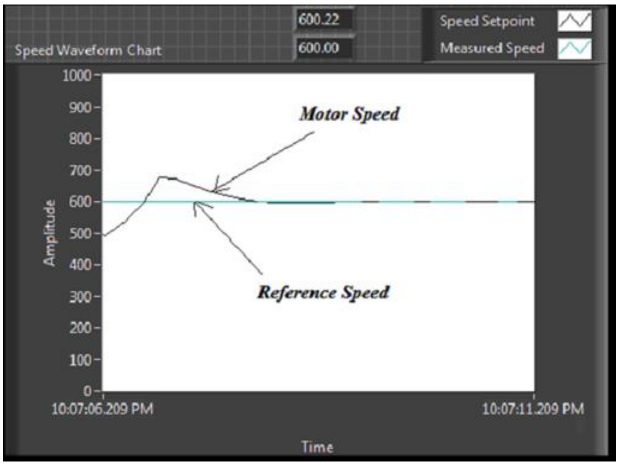


Fig. 12 Closed loop speed response during speed change from 500rpm to 600rpm.



14 (a)

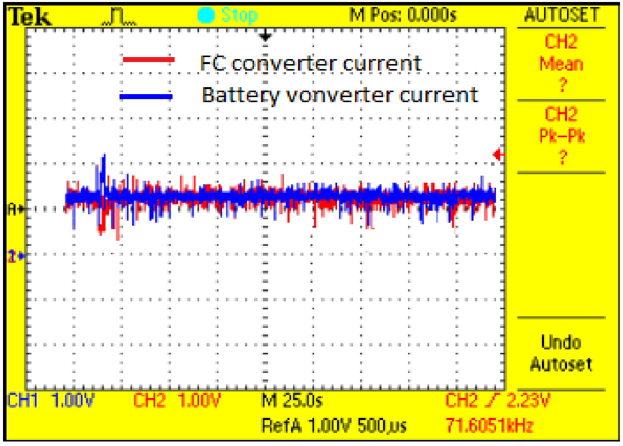


Fig. 14. Equal current sharing among FC and battery converters using MSC technique.
(a) LabVIEW front panel result (b) result on DSO.

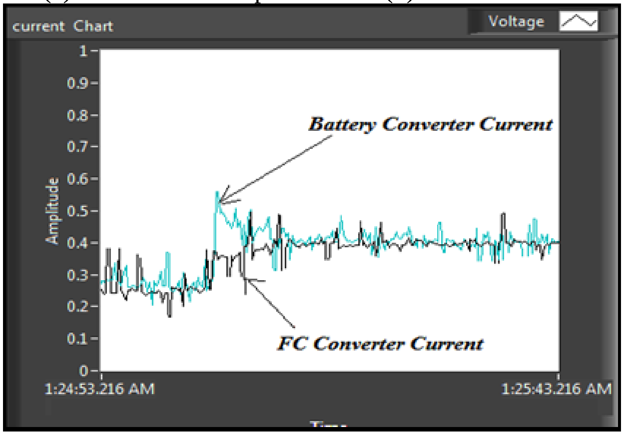


Fig. 15. FC and Battery converter currents during load change from 60Ω to 100Ω at speed 600rpm

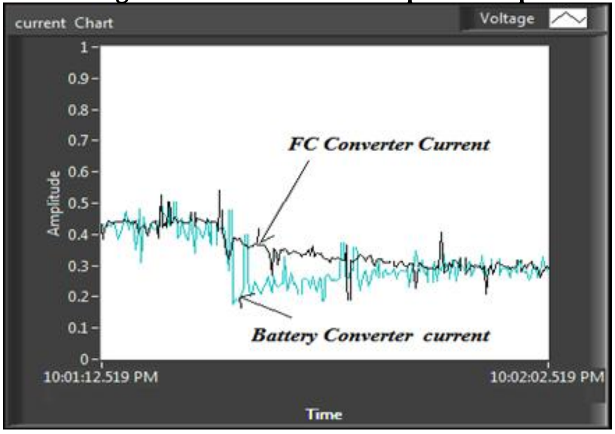


Fig. 16. FC and Battery converter currents during load change from 100Ω to 60Ω at 500rpm.

VI. CONCLUSION

This paper demonstrates the effectiveness of master-slave current sharing method in FC-battery hybrid power system under transient and steady state condition. This current sharing method has been tested with two different power converters connected to different voltages of fuel cell and battery respectively. The proposed technique of load current sharing has been implemented for efficient power management in hybrid power system is analyzed and verified through simulation and experimental results. Load current sharing and source management control system is designed with power management control. This load current sharing method will enhance the system reliability with longer life span of FC and battery.

REFERENCES

1. S.M. Mohiuddin, M.A. Mahmud, A.M.O. Haruni, H.R. Pota“ Design and implementation of partial feedback linearizing controller for grid-connected fuel cell systems,” International Journal of Electrical Power & Energy Systems, Volume 93, Pages 414-425, December 2017.
2. S.M. Rakhtala, E. Shafiee Roudbar, “Fuzzy PID control of a stand-alone system based on PEM fuel cell, ” International Journal of Electrical Power & Energy Systems ,Volume 78, Pages 576-590, June 2016.
3. Yinliang Xu, Hongbin Sun, Houde Liu, Qing F, “Distributed solution to DC optimal power flow with congestion management,” International Journal of Electrical Power & Energy Systems, Volume 95, Pages 73-82, February 2018.
4. Mohammad Mohammadi, Roghayeh Ghasempour, Fatemeh Razi Astaraei, Esmail Ahmadi, Ashkan Toopshekan, “Optimal planning of renewable energy resource for a residential house considering economic and reliability criteria” International Journal of Electrical Power & Energy Systems ,Volume 96, Pages 261-273, March 2018.
5. Da Huo, Simon Le Blond, Chenghong Gu, Wei Wei, Dongmin Yu, “ Optimal operation of interconnected energy hubs by using decomposed hybrid particle swarm and interior-point approach,” International Journal of Electrical Power Energy Systems, Volume 95, Pages 36-46 February 2018.
6. Rupendra Kumar Pachauri, Yogesh K. Chauhan, “**Various** control schemes of power management for phosphoric acid fuel cell system,” International Journal of Electrical Power & Energy Systems, Volume 74, Pages 49-57, January 2016.
7. Premananda Pany, R. K. Singh, R.K. Tripathi. "Performance analysis of fuel cell and battery fed PMSM drive for electric vehicle application", 2012 2nd International Conference on Power, Control and Embedded Systems, 2012
8. Jennifer Bauman, Mehrdad Kazerani, “A Comparative study of Fuel Cell Battery, Fuel Cell Ultracapacitor, and Fuel Cell Battery Ultracapacitor vehicles,” IEEE Transaction on vehicular technology, vol 57, no 2, pp. 760-769, March. 2008.
9. Wei Jiang, Babak Fahimi, “Active Current Sharing and Source management in Fuel Cell–Battery Hybrid Power System,” IEEE Transaction on Industrial Electronics, vol 57, no 2, pp. 752-761, Feb. 2010.
10. J. Wang, F. Z. Peng, J. Anderson, A. Joseph, and R. Buffenbarger, “Low cost fuel cell converter system for residential power generation,” *IEEE Trans. Power Electron.*, vol. 19, no. 5, pp. 1315–1322, Sep. 2004.
11. L. Solero, A. Lidozzi, and J. A. Pomilio, “Design of multiple-input power converter to hybrid vehicles,” *IEEE Trans. Power Electron.*, vol. 20, no. 5,pp. 1007–1016, Sep. 2005.

a. Khaligh, A. M. Rahimi, Y.-J. Lee, J. Cao, A. Emadi, S. D. Andrews, C. Robinson, and C. Finnerty, “Digital control of an isolated *active hybrid fuel cell/Li-ion battery power supply," IEEE Trans. Veh. Technol., vol. 56, no. 6, pp. 3709–3721, Nov. 2007.*

12. H. Tao, J. L. Durate, and M A.M. Hendrix, "Line-interactive UPS using a fuel cell as the primary source," *IEEE Trans. Ind. Electron.*, vol. 55, no. 8, pp. 3012–3021, Aug. 2008.
13. K. Jin, X. Ruan, M. Yang, and M. Xu, "A hybrid fuel cell power system," *IEEE Trans. Ind. Electron.*, vol. 56, no. 4, pp. 1212–1222, Apr. 2009.
14. Emadi, A.; Lee, Y.J.; Rajashekara, K.: *Power electronics and motor drives in electric, hybrid electric, and plug-in hybrid electric vehicles*. IEEE Transactions on Industrial Electron, vol. 55, no. 6, pp. 2237-2245, June. 2008.
15. C.L. Wang, C.L. Yin, T. Zhang and L. Zhu, "Powertrain Design and Experiment Research of a Parallel Hybrid Electric Vehicle," international journal of Automotive Technology, vol.10, no.5, pp. 589-596, 2009
16. Vincenzo Di Dio, Diego La Cascia, Rosario Liga, Rosario Miceli, "Vehicles PEM Fuel Cells Power System Mathematical Model for Integrated Design" ecologic vehicles renewable energies, 2009.
17. D. Zumoffen, M. Basualdo, "Advanced control for fuel cells connected to a DC/DC converter and an electric motor," Elsevier, 2010, pp.643-655.
18. Kirubakaran, Shailendra Jain, R.K. Nema, "The PEM Fuel Cell System with DC/DC Boost Converter: Design, Modeling and Simulation," International Journal of Recent Trends in Engineering, vol 1, no. 3, pp.157-161, May 2009.
19. Pablo Garcia, Luis M. Fernandez, Carlos Andres Garcia, Francisco Jurado, "Energy management system of Fuel cell-Battery Hybrid tramway. IEEE Transaction on Industrial Electronics, vol 57, no 12, pp. 4013-4023, Dec 2010.
20. Sudip K. Mazumder, Muhammad Tahir, Kaustuva Acharya, "Master-Slave Current-sharing Control of a Parallel DC-DC Converter System Over an RF Communication Interface, " IEEE Transaction on Industrial Electronics, vol. 55, no. 1, pp. 59-66 January 2008.

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