Pollution Free Operation of Rail Vehicle with Diesel Engine using Fuel Cell

Naseam Haider Jafri, Sushma Gupta

Abstract: Presently, energy used in rail transportation is fossil in nature, in case of electric vehicle, electricity which is generated mostly from coal/gas while in diesel engine driven vehicle oil /gas. Fossil energy sources inherently suffers from disadvantages such as limited in nature, damage to environment due to exhaust of greenhouse gases, noise pollution etc. Fuel cell not only overcome above demerits of diesel engine but offer other advantages such as energy recovery during braking, better dynamic response. A feasibility study of use fuel cell in place of diesel engine is presented in this paper. It briefly discuss fuel cell operation, its suitability for transient energy requirement of transportation application, necessity of energy storage system, simulation of potential of recovery of energy during braking. Present status of technology of drives, power conditioning is reviewed and a circuit topology for conversion of existing diesel engine based vehicle into fuel cell system is presented. Advantages of fuel cell hybrid electric vehicle (FCHEV) over conventional transportation vehicle is also discussed.

Keywords : Fuel cell; diesel engine; transportation; energy storage system; supper capacitor; lithium-ion batteries; energy recover; converter9; diesel engine

I. INTRODUCTION

This is an With change in style of life and ever growing industrialization is resulting in increased demand of energy at alarming rate, whereas reserve of conventional energy source such as coal, oil, gas are depleting very high rate beside damage to environment by air and noise pollution in. Hence there is immediate need for development alternative energy sources to overcome above concerns. A lot of development has taken place in this direction and some such sources. Renewable energy sources identified with good potential are, solar with batteries/ grid synchronized, wind generator, tidal energy of sea, biomass etc. Fuel cell from biomass family has potential to meet requirement of transportation application, such as compactness, availability 24x7x365 time frame and suitable to work on move.

Indian Railways trains utilize energy either from 25 KV overhead catenary or from diesel engines. Since electricity is generated far away from the train hence, it does not create air and noise pollution at its site of use, therefore is not a health hazard to society. Furthermore, nonpolluting sources of energy such as water, nuclear, solar etc. are being explored for electricity generation besides development of modern technology for better emission control is being employed to limit air pollution. Hence electric transportation is not an immediate concern. Whereas diesel engine driven vehicles pass thru cities and town cause health hazard to the society and shall be addressed on priority. Fuel cell offers reliable and practical solution for use in transportation application, as it not only provides sustained renewable source of energy but also almost eliminate generation of greenhouse gases (Sox/Nox) hence no pollution to environment, produces almost no noise being combustion free system, no wear and tear of components so requiring less maintenance.

In technical advance countries, fuel cell technology in car/busses/two-wheelers is being used commercially [1-4] though in limited numbers in comparison to conventional vehicles. (for details please refer www.fuelcells.org /uploads/fcbuses-world1.pdf) mainly due to higher cost, limited infrastructure for fuel supply and maintenance but fast spreading world over. It expected that as number increases cost will automatically come down and infrastructure will improve. Fuel Cell Hybrid Electrical Vehicle (FCHEV) buses/cars biggest advantage is zero emission from source to wheel and compare well in terms of efficiency with Electric or Hybrid Electric Vehicle while in terms of emission is way ahead, as later create considerable emission (for details please refer icrepq.com/ icrepq07/228-moghbelli.pdf). Indian government is pursuing introduction of FCHEV on large scale in mission mood from 2022 onwards. However, fuel cell technology in rail transport is in infancy stage and getting matured slowly. Few experimental prototype rail vehicles have been developed in recent [5-7]. Recently, Germany and UK has introduced intercity fuel cell based trains name Hydrail (http://www.railwaytechnology.com/features/ feature 122016 /) and Hydroflex (spectrum.ieee.org, AUG 2019, pp 06-07). China has also announce commercial operation of such trains. In a comparative study conducted for electric and fuel cell based hybrid system in terms of overall cost, emission and performance & capital cost revealed that considering infrastructure cost of electric system of electric vehicle, fuel cell based hybrid rail system cost is less, (for detail (pl see docs.trb.org/prp/13-1394.pdf and www.scirp.org/ journal/ PaperDownload.aspx).

Revised Manuscript Received on December 15, 2019.

***** Correspondence Author

Naseam H. Jafri, Sr. Member IEEE, Member IEI, Head of Centre for Transportation & System Design, Bharat Heavy Electricals Limited Bhopal 462022, MP, India nhjafri@bhel.in1; jaf12@rediffmail.com1
16-digit ORCID of the author(s); 0000-0002-1107-8618

Dr. Sushma Gupta, Professor, Department of Electrical Engineering Maulana Azad National Institute of Technology, Bhopal 462003, MP India sush_gupta@yahoo.com2,

II. DIESEL ENGINE BASED RAIL VEHICLE

Normally diesel engine based trains are operated either on long distance for goods movement for example in USA, Siberia etc (as large investment needed for electrification of tracks becomes economically unjustified) or in third world country due to constrain of capital investment. Roughly 40% routes in India are still non-electrified. However government has taken electrification of route in mission mode to avoid dependency for oil on foreign countries beside pollution caused by diesel engine operated trains. In India, DEMUs (Diesel electric Multiple Units) is used for passenger transport service on intercity routes, where distance between station stops is small 2 to 15 kilometer and total route is order 100-500 KM. DEMU is consists of minimum two basics unit on either end to facilitate movement of train in either direction. No of basic unit in a trains could be selected on passenger volume. Basic unit diagram is shown in figure 1, it consists of a Driving a Power Car (DPC) and no of passenger cars based on power capacity of DPC.

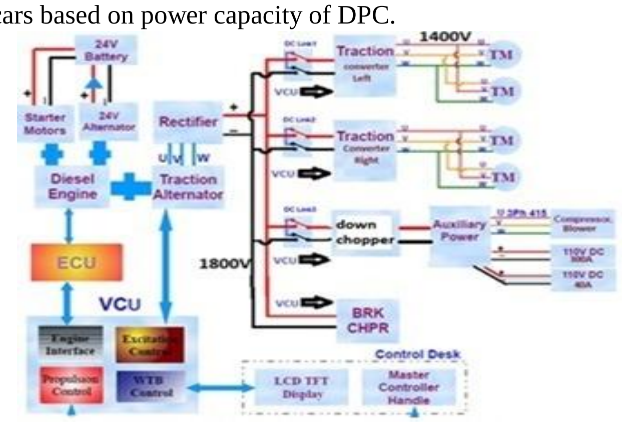

Figure 1 Typical block diagram of diesel power car

DPC has a diesel engine-alternator set, which supply DC power to two DC/AC converters connected in parallel, each of them fed 3phase Variable Voltage Variable Frequency (VVVF) supply to two motors connected in parallel mounted on each axle of bogie. DPC usually has two bogies. Normally power rating of diesel engine and DC link voltage of DEMU in range of 1400- 2200 HP and 1500-2000 volt respectively. A digital controller ensures proper operation of complete train. Diesel engine based transportation vehicle inherently has following limitations/ disadvantages;

a) Exhaust of greenhouse gases (Sox/Nox) causing air pollution thereby creating health hazard
b) Generates a lot of noise thereby sound pollution
c) One of the major disadvantage is inability to recover energy during braking (as neither any load nor energy storage system is available)
d) Being an internal combustion engine require high maintenance due to wear and tear of rotating parts
e) Poor efficiency from fuel to wheel
f) Being mechanical system poor dynamic response resulting in poor acceleration of train
g) Carrying fuel stock as dead load there by reduced hauling capacity

III. FUEL CELLS BASED HYBRID SYSTEM

A typical block diagram of Fuel Cell Hybrid Vehicle (FCHEV) is depicted in figure 2. It consists of mainly following sub systems.

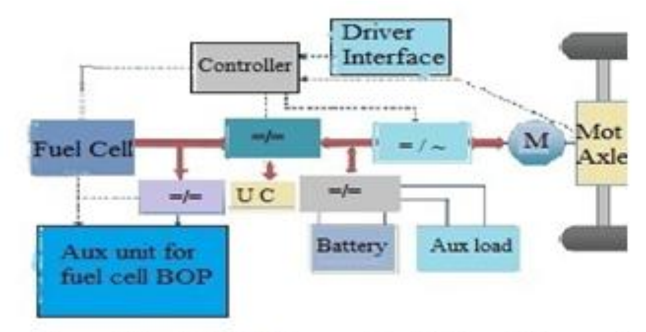

Figure 2 Typical block diagram of Fuel Cell based Transports drive

A. Fuel Cell and Balance of Plant (BOP)

A simplified fuel cell is shown in figure 3 [8]. The fuel cell consists of two electrodes on either side of an electrolyte layer. The hydrogen fuel is fed to the cathode & oxygen from air is fed to anode continuously.

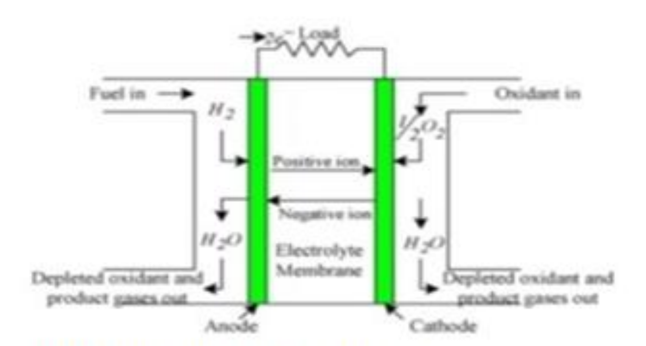

Figure 3 Typical block diagram of Fuel Cell

The hydrogen fuel is decomposed into positive ions and negative ions. The intermediate electrolyte membrane, permits only the positive ions to flow from anode to cathode side and acts as an insulator for electrons, the free electrons moved to the cathode side through an external electrical circuit thereby produce electricity. Hydrogen positive ion react with oxygen at cathode to form pure water. The chemical reactions involved in the anode and cathode are given as

Anode reaction:

$2H_2$ $4H^+ + 4e^-$ (1)

Cathode reaction

$4H^+ + O_2$ $2 H_2O$ (2)

Characteristic and performance of fuel cell greatly depends on type of electrolytes used. Various type of electrolytes have been developed such as Polymer Electrolyte Membrane (PEM), Alkaline (AFC), Phosphoric Acid (PAFC), Molten Carbonate (MCFC), and Solid Oxide (SOFC). The Polymer Electrolyte Membrane Fuel Cell (PEMFC) best suits to transportation application being robust design, offers better resistance to shock and vibration by using solid electrolyte, low operating temperature, high power density and quick start. Maximum voltage of a fuel cell at open circuit is order of 1.0 volt, which drops to around 0.7 volts at efficient loading point.

Retrieval Number: C8347019320/2020©BEIESP
DOI: 10.35940/ijitee.C8347.019320

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Fuel cell being an energy source exhibit dropping characteristic of constant power except at both higher voltage and current due to polarization effect as shown in figure 4 [8,9]. Several fuel cells are stacked together connected in series and parallel combinations to produce required voltage & current. Fuel cell stacks for its operation requires many other equipment like compressor, regulator, diffusor etc. known as Balance of Plant (BOP) [3].

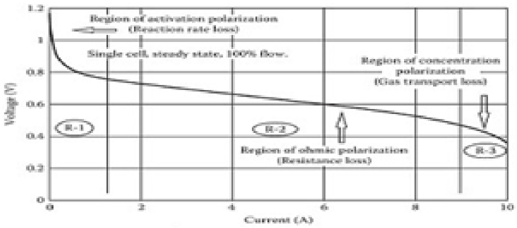

Figure 4 Typical block diagram of Fuel Cell

B. Energy storage system (ESS)

Rail transportation vehicle operates in three distinct modes as shown in figure 5.

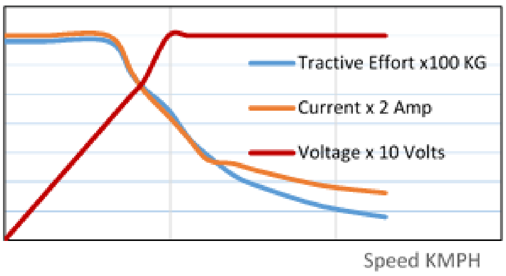

Figure 5 Typical characteristic of traction drive

i. At constant torque to pull the train to desired level of acceleration
ii. Then at constant power to gain speed till rated voltage of motor is reached
iii. Finally at weak field to reach maximum speed

As evident from the above characteristic, none of power current or voltage are constant over the operation. Thus transient power, torque and current is required for successful operation. The requirement of tractive effort and current for specified performance depends upon mode of operation & load requirements e.g. in conventional local trains with DC traction motor, current drawn in constant torque operation typically goes as high as 2.5 times of rated current and reduces with increase in speed, whereas voltage increases with speed till it reaches rated value and remains constant thereafter. In typical sub urban route simulated time domain variation of current for 180 Amp rated motor for a complete route is shown in figure 6. Since fuel cells energy source has slow time domain characteristic, hence could not supply transient requirement of transportation application of energy, current or torque.

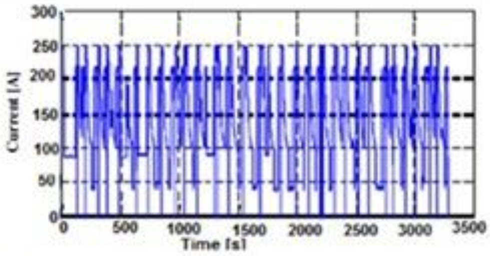

Figure 6 Variation of motor current with time

Therefore, fuel system has to be supplemented by some energy source, which is able to deliver energy as well as store available energy at required rate at desired moment. The supplementary system is called Energy Storage System (ESS) and Fuel Cell System along with ESS is called Fuel Cell Hybrid System (FCHS) [10, 11]. Various ESS having specific energy delivery and storage have been discussed in literature [12] with various combination [13, 14]. Lithium-ion battery pack with super capacitor combination is one of the best combination and has been used in most of the development in this area. Fuel cell is operated at near optimal level to meet average load requirement whereas battery and ultra-capacitor delivery energy in medium and short duration respectively. However, type of service being performed by the vehicle decide quantum of benefit and complexity of implementation [10]. Energy recovered and performance improvement is remarkably high in sub urban application for mass movement and in hilly region but low enough in plane and long distance trains.

C. Traction Drive

The purpose of power conditioning unit is to convert input power into a desired fashion at output. In this case input power is DC voltage supply combination of fuel cell and ESS, which is converted into 3 phase variable voltage variable frequency (VVVF) supply at terminals of motor. Besides, it has to ensure operation of ESS and fuel cell in safe operational region and optimal fashion. Several topologies are reported in literature [10, 13]. FCS is connected to ESS which may be battery or combination with Ultra Capacitors (UC) via bidirectional converter to have independent control on charging and discharging rates and supply power to DC link at predefined voltages. DC link voltage could be converted to VVVF supply using 3 phase converter either directly or via step up converter figure 7a, or Z- source inverter using less no of switches and providing protection

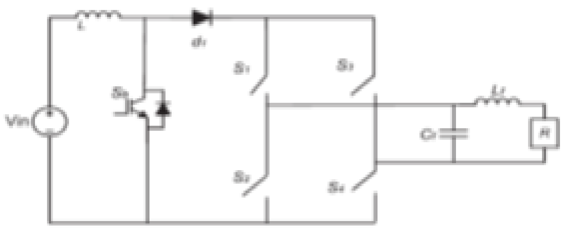

Figure 7a Switched boast inverter

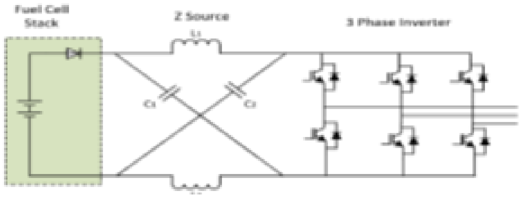

Figure 7b Z- Source inverter [10]

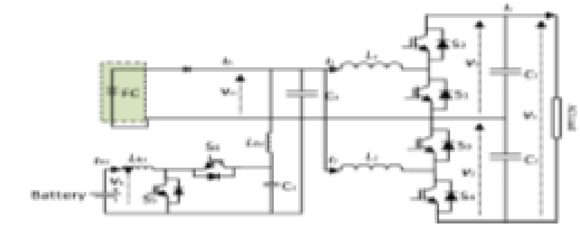

Figure 7c Boast Inverter with Multi input [10]

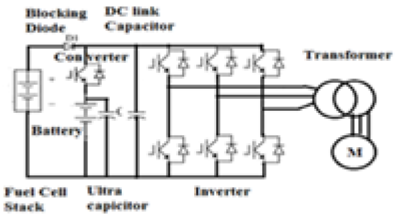

Figure 7d Power frequency inverter

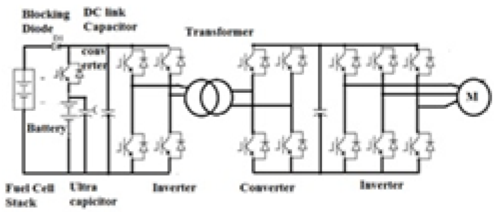

Figure 7e High frequency link multistage inverter

against shoot through [14] figure 7b, or boast inverter with multi sources figure 7c, or power frequency transformer figure 7d or high frequency link figure 7e depending upon terminal voltage rating of motor. Though various type of motors, Permanent Magnet AC Motors BLDCM (brushless DC motor), Switched Reluctance Motors (SRMs), Synchronous Permanent Magnet Outer Rotor (In Wheel) Motor, Induction Motors (IMs) have been discussed [5, 14]. Induction motor with sensor /sensor less vector control is preferred in industry to take advantage of robust designed and matured controls. Various type of optimization of power from FCS and ESS with focus on fuel consumption, performance have been discussed [15, 16].

D. Proposed Drive

Modern diesel engine driven vehicles are normally provided with IGBT based converter with VFFF vector control and induction motor. One of the important issue to be addressed for conversion of exiting diesel engine based transportation drive is, to utilize existing equipment to extent possible for economic feasibility and assets utilization. In order to utilize existing drive having DC link voltage in range of 1500-1800 Volts DC, topology presented in figure 8, could be employed. Wherein fuel cell stack is connected to DC link bus through a block diode to prevent reverse flow of current into fuel cell. Two independent bidirectional converters are connected each with batteries and ultra-capacitor to have independent controls of charging and discharging. Voltage of this DC link is boasted to desired voltages level by single phase converter pair with high frequency link or normal transformer replacing diesel engine-alternator cum rectifier. It will also provide isolation between high and low voltage circuit as desired feature in traction drives. A bogie control may be adopted, where in motors of on bogie are connected in parallel with one power converter. However for new vehicle axel control, wherein each motor is fed with independent converter could be employed. Further isolation transformer may be avoided by selecting a motor to match prevalent rating of fuel cell provided design permit. This arrangement will also offer flexibility in mounting of equipment on vehicle and weight balance.

IV. SIMULATION OF ENERGY RECOVERY POTENTIAL IN BRAKING OPERATION

Typical operation cycle of a transportation drive consist of acceleration to increase speed to reach quickly to destination and deceleration to reduce the speed in order stop or to meet the speed limitation of route. Rate of acceleration and deceleration depends upon application and varies in suburban, intercity, long distance/good trains. In trains having DC motors, during braking dynamic energy of train is either dissipated through frictional brake resulting in high wear and tear of brake shoes or in load resistor dissipating as heat. With invent of high rating power devices like GTO, IGBT, Induction motor with VFFF drives were developed, which are not only robust requiring less maintenance in absence of brushes and commutator but also facilitate recovery of energy during braking provided energy could be stored or used with other loads. This feature could be implemented in electric driven vehicle due to presence of strong grid of power supply capable of absorbing energy but not in diesel engine driven vehicles as neither storage nor utilization of energy in other loads is possible. Which is a big drawback of diesel engine driven vehicle. However, in Fuel Cell Hybrid Electric Vehicle (FCHEV) this limitation doesn’t occur due to presence of ESS. Recovered energy in braking operation is quite considerable.

In order to have an idea of potential of recoverable energy during braking, an actual operation of suburban train for round trip Church gate-Andheri- Church gate) route in Mumbai (India) for which all data such as route profile, track resistance and train schedule were readily available has been simulated for energy consumed in motoring and regenerated during braking operation with operation restrictions such as speed limit, stops etc

Energy consumption in total route has been worked by calculating required tractive effort to overcome resistance of train movement and to achieve desired performance defined in equation 1.

Tre = Tr + Tacc (1)
q

Where;

Treq is required tractive effort

Tr is tractive effort to overcome resistance to train movement

Tacc is tractive effort needed for acceleration or deceleration of vehicle

Track resistance is given as

$$Ttrack = A+BV+CV2 \quad (2)$$

where A, B & C are constant and depends on track design, resistance due to curvatures gradation of route and air due to movement of train respectively [7]

V is train speed.

Tractive effort required for movement of vehicle given by equation 3

$$Tacc = m*a \quad (3)$$

Where;

m is total mass of train with passenger load

a acceleration or deceleration of vehicle

Once required tractive effort over to and fro route is known required energy could calculate as per equation 4

$$Energy = 1/T \int_0^T Treq\, dt \quad (4)$$

Where

T is total travel time

Required tractive effort is calculated over the complete route with increment in speed. Energy is calculated for motoring and regenerative braking operations and thereby net energy.

V. RESULTS

Simulation results for energy consumed during motoring, regenerated in braking and thereby net energy is given in table 1.

Table1. Simulated result of energy consumption over the route

Station Name	Energy(KWhr) per Motor car		
	Motoring	Regenerative	Net
Church Gate	0.00	0.00	0.00
Marine Lines	10.80	-1.70	9.10
Chami Road	14.70	-5.60	9.10
Grant Road	20.20	-6.90	13.30
Mumbai Central	17.40	-6.90	10.50
Mahalaxmi	19.70	-7.30	12.40
Lower Parel	22.00	-7.20	14.80
Elphinstone Road	5.70	-1.20	4.50
Dadar	20.20	-6.90	13.30
Mantunga Road	21.30	-7.90	13.40
Mahim	18.80	-7.00	11.80
Bandra	22.80	-7.70	15.10
Kher road	21.10	-7.30	13.80
Santracurz	24.80	-7.90	16.90
Vile Parle	23.70	-7.70	16.00
Andheri	25.50	-7.70	17.80
Vile Parle	28.60	-10.50	18.10
Santracurz	21.60	-7.90	13.70
Kher road	22.30	-8.00	14.30
Bandra	20.20	-8.00	12.20
Mahim	22.60	-8.10	14.50
Mantunga Road	18.70	-7.30	11.40
Dadar	22.40	-7.90	14.50
Elphinstone Road	19.50	-7.70	11.80
Lower Parel	22.30	-7.00	15.30
Mahalaxmi	14.30	-5.70	8.60
Mumbai Central	20.70	-7.10	13.60
Grant Road	17.60	-6.70	10.90
Chami Road	21.10	-6.80	14.30
Marine Lines	14.60	-5.60	9.00
Church gate	19.50	-6.60	12.90
Total	**594.70**	**-207.80**	**386.90**

Energy consumption as function of travel time is plotted in figure 9 & as function of travel distance is plotted in figure 10 respectively.

It may be noted that about 35% energy could be recovered using regenerative braking system, which goes unrecovered in diesel engine based vehicles. However energy recovery to above level is not always possible and depends on track geometry and application.

VI. DISCUSSION

The Electric & diesel engine (internal combustion) driven vehicles are being commonly used in Indian railways on electrified and non-electrified routes respectively. A comparison of above with proposed fuel cell based vehicle for various parameters is presented in table 2.

Table 2 Advantages of fuel cell hybrid over conventional vehicle

Parameter	**Electric driven vehicle**	**Diesel Engine driven**	**Fuel Cell hybrid**
Infrastructure Cost	High Justified only on high passenger density route	Negligible (ignoring refineries & transport cost of fuel).	Negligible (ignoring Hydrogen generation and supply)
Fuel type	Fossil Electricity is generated from coal, gas, nuclear, etc.	Fossil (Diesel is hence limited in nature, & imported	Renewable Fuel
Air Pollution	High at source (coal based)	High along route even in residential area	Virtually Nil
Noise pollution	Medium	High	Silent operation
Regenerative braking	Possible (with AC drives)	Not possible	Possible
Maintenance	Medium	High	Low

It is evident from above table that Fuel Cell Hybrid Electric Vehicle (FCHEV) is winner with flying colors considering its features of pollution free operation, use of renewable green fuel and regeneration of energy during braking operation.

VII. CONCLUSIONS

The use of Fuel Cell System supplemented with Electrical Energy Storage System has good potential in transportation applications especially as alternative to diesel engine based vehicle for obvious advantage of almost nil air & sound pollution besides ability to regenerate power during braking. Combination of Li-Ion batteries with super capacitors is found to be most technically appropriate solution for ESS.

The induction motor being most reliable, robust & being widely used in transportation is obvious choice. Isolated topology using converter –transformer combination is a good choice for rail vehicle, which has inherent advantage of isolation between fuel cell stack and motor circuit. Optimum energy consumption from FCS and ESS could be achieved by appropriate control management system.

However technology of Hybrid Fuel Cell based transportation system is yet to be matured, at present is in infancy, requiring further development in all related areas such as availability of hydrogen and its supply network, fuel cell stack including balance of plant for presenting a realistic, commercially viable challenge to diesel engine based rail transportation vehicles. Further, fuel cell and ESS accommodation in the space vacated by diesel engine system and weight balance is to be evaluated along with commercial viability.

REFERENCES

1. Naseam H Jafri M'2007 and Dr Sushma Gupta, "An overview of Fuel Cells Application in Transportation", ITEC-AP (2016) https://doi.org / 10.1109/ITEC-AP.2016.7512935
2. Naseam H Jafri M'2007 and Dr Sushma Guptal, "Technical viability study of fuel cell as an alternative to Diesel in Diesel Electric Multiple Units (DEMUs) for suburban rail transportation", ICSPC (2017) https://doi.org / 10.1109/CSPC.2017.8305834
3. Brian D. James Jennie M. Moton Whitney G. Colella, "Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2013" Update ,January 2014 ,Prepared By:, Strategic Analysis Inc supported by the Department of Energy USA
4. ThanhHua, Rajesh Ahluwalia, Leslie Eudy, Gregg Singer, Boris Jermer, NickAsselin-Miller, Silvia Wessel, Timothy Patterson and Jason Marcinkoski, , "Status of hydrogen fuel cell electric buses worldwide", Journal of Power Sources 269 (2014) ,975-993
5. WeiRong Chen • FeiPeng • Zhixiang Liu •,Qi Li & Chaohua Dai; "System integration of China's first PEMFC locomotive", J. Mod. Transport. (2013) 21(3):163–168
6. Miller, A.R.Hess, K.S. ; Erickson, T.L.& Dippo, "Fuel cell-Hybrid Shunt Locomotive: Largest Fuel cell Land Vehicle" Railway Traction Systems (RTS 2010), IET Conference ,April 2010
7. Andreas Hoffrichter, Peter Fisher, Jonathan Tutcher, Stuart Hillmansen& Clive Roberts, "Performance evaluation of the hydrogen-powered prototype locomotive 'Hydrogen Pioneer'", Journal of Power Sources 250 (2014), 120–127
8. A. Kirubakaran, Shailendra Jain & R.K. Nema, "Renewable and Sustainable Energy Reviews", Renewable and Sustainable Energy Reviews 13 (2009) 2430–2440
9. Arnold R. Miller&John Peters, "Fuelcell Hybrid Locomotives: Applications and Benefits", Proceedings of JRC2006 Joint Rail Conference, (2006), 287-293
10. Himadry Shekhar Das, Chee Wei Tan, A.H.M. Yatim, "Fuel Cell Hybrid Electric Vehicles: A Review on Power Conditioning Units and Topologies", Renewable and Sustainable Energy Reviews 76 (2017) 268–291
11. MatějPácha&JiříŠtěpánek," Energy Savings and Performance Optimizations of Shunting Hybrid Locomotives" "ELECTRO, IEEE (2012), 225-231
12. ChangjunXie A, XinyiXu, PiotrBujlo B, Di Shen B, HengbingZhao&ShuhaiQuan, "A Fuel cell and lithium iron phosphate battery hybrid powertrain with an ultra- capacitor bank using direct parallel structure", , Journal of Power Sources 279 (2015) 487–494
13. LipingGuo, KarthikYedavalli&Donald Zinger, , "Design and modeling of power system for a fuel cell hybrid switcher locomotive", Energy Conversion and Management 52 (2011) 1406–1413
14. Anton Rassõlkin, Thesis for Ph.D, Tallinn University of Technology(2014), 23-28
15. Fang Zheng Peng & Miaosen Shen, , "Application of Z-Source Inverter for Traction Drive of Fuel Cell—Battery Hybrid Electric Vehicles", , IEEE trans Power Electronics, VOL. 22, NO. 3 (2007) 1054-1061
16. Daoud Rezzak , Nasserdine Boudjerda, Management and control strategy of a hybrid energy source fuel cell/supercapacitor in electric vehicles,Wiley, Int Trans Electr Energ Syst (2016), 1–17
17. Mauro G. Carignano a, *, Ramon Costa-Castello b, Vicente Roda c, Norberto M. Nigro d, Sergio Junco e, Diego Feroldi, Energy management strategy for fuel cell-supercapacitor hybrid vehicles based on prediction of energy demand, Journal of Power Sources 360 (2017) 419-433

AUTHORS PROFILE

Naseam H. Jafri (SM'2007) received B.Sc. Engg from AMU Aligarh '85 in Electrical Engineering and M. Tech. from IIT Kanpur'87 in Electrical Engineering with specialization in Power Electronics and Industrial Drives. Since 1991, he is working in BHEL Bhopal in traction system & control design, presently as head of Transportation System Group and Center of Electrical Transportation responsible for development of new systems and validation. His areas of interest are renewable energy sources, AC drives, Traction System, Simulation & digital controls. He has 3 patents to his credits.He is also pursuing Ph.D. from MANIT Bhopal.

Dr Sushma Gupta-Sushma Gupta was born in Lalitpur, U P., India, in 1971. She received the B.E., M.E. degrees from Barakatullah University, Bhopal, India, in 1993, 1999 respectively and PhD from Indian Institute of Technology, Delhi, in 2005.She was a Lecturer with the Electronic Engineering Department, Government Engineering College, Rewa M. P., India, UIT- RGPV Bhopal. She is currently Professor with the Department of Electrical Engineering, MANIT Bhopal. Her research interests include Power Electronics, Machines, Digital Electronics, Microprocessors, and Self-Excited Induction Generators.