NINE SWITCH CONVERTER BASED SOLAR HYBRID ELECTRIC VEHICLE

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ABSTRACT

Hybrid electric vehicle system with nine switch converters using permanent magnet synchronous machine as a motor and as a generator has been discussed in many papers. A series hybrid electric vehicle system with three phase induction motor connected as load to the Nine switch converter powered by a spark ignited internal combustion engine, along with solar panel to charge the battery based on its state of charge has been analyzed in this paper. Nine switch converter technique reduce voltage stress, power loss, number of switches required and the cost of the system.

Keywords: Nine Switch Converter, Series Hybrid Electric Vehicle, permanent magnet synchronous machine, Three phase induction motor.

INTRODUCTION

Air pollution is increasing at a rapid rate due to industrialisation and increasing rate of vehicles using internal combustion engines as their only power source. The World Health Organisation (WHO) guideline values for particulate matter are 20 μg/m^3 for PM10, and 10μg/m^3 for PM2.5 respectively. Particulate matter (PM) is a mixture of solid and liquid particles of sulphur dioxide, ammonia and nitrous oxides suspended in air due to burning of fossil fuels. This particulate matter causes hazardous effects in living organisms both in a direct and indirect manner [1]. To reduce the pollution caused by the vehicles and to improve the efficiency of the fuel used, Electric and hybrid vehicles are a promising replacement. However pure electric vehicles available in the low cost do not offer a high mileage on a single charge, whereas Electric vehicles that give more mileage on single charge are costly.

A Hybrid electric vehicle is powered by two energy sources such as an internal combustion engine or fuel cell and an energy storage device such as battery or ultra- capacitor. Vehicles based on fuel cell need more improvement on the areas of accessibility and safety of storage of hydrogen, so the practically feasible solution at economic cost is the Hybrid electric vehicles [2]. A series hybrid Electric vehicle system consists of an internal combustion engine, Generator, Motor, rectifier and inverter. The internal combustion engine run by fuel is used to give mechanical input to generator (PM SG). Three phase AC output of the generator is rectified and stored in the battery. The power from the battery is inverted to drive Permanent Magnet AC synchronous motor. In a Series Hybrid Electric Vehicle there is no mechanical contact between the engine and the wheels in a Series Hybrid Electric Vehicle.

Most of the Hybrid Electric Vehicles like Chevrolet Volt, Toyota Prius prime, Audi A3 sport back E-tron uses Permanent Magnet AC Synchronous machine as a generator and motor, along with Lithium-ion battery packs in kilo watt hour rating [4]. The Engine type of these vehicles is DOCH 16-valve Atkinson cycle with 1-1.8 liter inline-4 engines. Some Hybrid Electric Vehicles like Lexus CT uses1.3kWh nickel metal hydride battery pack. The proposed system uses Nine-switch Converter to control the generator (PMSG) powered by spark ignited internal combustion engine and three phase induction motor instead of a twelve-switch arrangement of separate rectifier and inverter arrangement present in the Hybrid Electric vehicle [5]. Since it has been proven that a Nine-switch Converter can control two three phase loads independently [3], and Nine-switch Converter connected to an induction motor drive can independently control the amplitude and frequency [6], PMSG and three phase induction motor has been used. Type of hybrid electric vehicle includes Series Hybrid Electric Vehicle, Parallel Hyb-rid Electric Vehicle, Power Split hybrid or Series Parallel Hybrid Electric Vehicle.

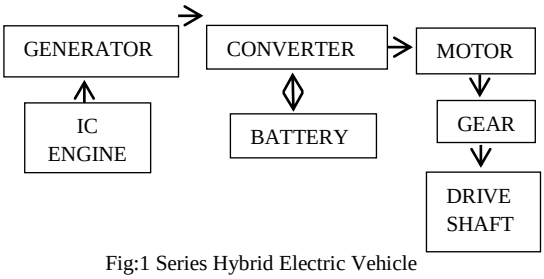

Fig:1 Series Hybrid Electric Vehicle

Advantage of using series hybrid over other Hybrid vehicle configuration is that the engine can continuously operate at maximum efficiency and can drive the generator to run at maximum performance. Transmission is negligible in some series hybrid configuration [7]. The engine never comes to idle state, so vehicle emission due to frequent acceleration is avoided. Series hybrid vehicle configuration is suitable for city driving conditions, as the power from battery alone is sufficient to drive the vehicle. A Series Hybrid Electric Vehicle can run in the following modes based on the user requirements, the driver can control in which mode the vehicle should operate.

Low power Mode: In this mode, the vehicle will be powered by the battery alone and the nine-switch converter will act only as inverter [8]. This mode is chosen during city driving where low power is sufficient to drive the vehicle.

Medium power mode: In this mode, the vehicle will be powered by the electrical generator through engine and the vehicle battery can also be charged at the same time based on its state of charge. The nine switch converters upper six switches will act as rectifier and the lower switches act as rectifier. High power mode: This mode is used during uphill driving and

when high power is needed during acceleration. In this mode, the vehicle will be powered by both battery and engine. However, a series hybrid vehicle uses a separate inverter and rectifier arrangement for powering the motor and charging the battery respectively. This twelve switch arrangement of inverter and rectifier has high volt-age stress on individual switches, power losses due to switching is high, losses due to heating are high. To over-come these problems nine switch converters can be used.

NINE SWITCH CONVERTER

The Nine Switch converter has three leg arrangement of nine Insulated Gate Bipolar Junction Transistor (IGBT) for handling three phase AC. This can operate as two separate converters; the upper converter includes upper three and middle three switches and lower converter includes lower three and middle three switches. The middle three switches are common for both the converters. Based on the gate pulses provided to the switching devices the converters can operate as inverter and rectifier. The main advantage of using a nine-switch converter is reduce voltage stress on individual switches, power losses due to switching, losses due to heating, number of switches required for inverter converter arrangement is reduced from 12 to 9.

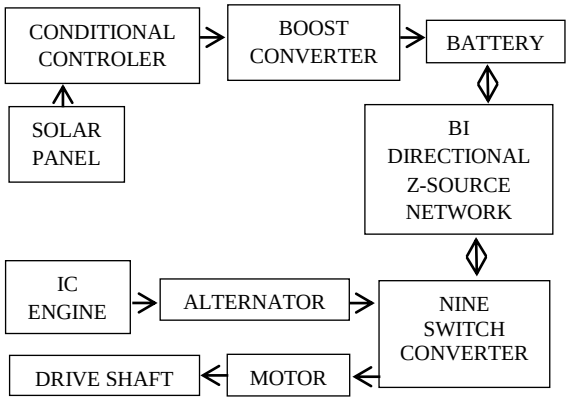

Fig:2 Proposed Series hybrid electric vehicle based on nine switch converters

The gate pulses for the IGBTs are generated by using sinusoidal Pulse Width Modulation technique. A triangular carrier wave of high frequency is compared with sinusoidal reference waves of required frequency. Separate sinusoidal reference wave is used for generating gating signals for upper and lower three switches of the nine-switch converter. The EXOR values of these two outputs form the gating signal for the middle three switches [6]. The triggering of the switches by gate pulse determines the operation of the converter as rectifier and inverter.

The combination of upper three switches and middle three switches connected to the generator act as a rectifier. Middle three switches and lower three switches connected to the motor act as an inverter. The middle three switches are common for both inverter and rectifier operation. The battery of the Hybrid Electric Vehicle is also powered by a solar panel based on the state of charge of the battery. This is controlled by using the controller circuit. The is simulation done by using MATLAB SIMULINK [9].

Battery can be charged by using the Solar Panel whenever the power from the solar panel is enough to charge the battery it will be detected by the conditional controller and it will allow the solar panel to charge the battery based on its state of charge. Selecting the charging source for battery between the solar panel and generator will be controlled by using the conditional controller based on the availability of the solar energy and state of charge of battery. To avoid the frequent charging of battery when panel voltage is at a sufficient range for a short time period and to improve the life span of the battery, the controller will allow the solar panel to charge the battery when the panel voltage is sufficient for a specific period of time to charge the battery in a linear manner [10]. This is accomplished by keeping track of the solar irradiation input to the panel. The panel will be turned on only when the solar irradiation input to the panel is a more than 800 watts/m^2 and the vehicle is not in motion, identified by the rpm of the motor attached to the drive shaft [11].

SIMULATION FOR NINE SWITCH CONVERTERS CONNECTED TO HYBRID ELECTRIC VEHICLE

The nine-switch converter is connected to the generator, motor, bidirectional z-source network powered by the battery. The generator is powered by an Internal Combustion engine. The output of the generator is rectified by the switches in upper and middle and the voltage is stepped down by using bidirectional Z source network which will act as a buck converter and it is used for charging the battery [12,13]. It also acts as boost convertor to increase the voltage when battery is powe-ring the motor this is accomplished by providing proper gate pulse to the IGBT in it. The Z source network consists of an IGBT, inductors and capacitors. The boosted DC voltage is converted into three phase AC by the middle and lower switches, it is used to power the motor of the Hybrid electric vehicle [14,15]. Introduction of bi-directional z source network to the system necessitates the use of the shoot through signal [16,17].

Reference signals are given by the equation

$$V_{1ref}=M_{1max}\, V_{refcx1} + M_{2max} \quad (1)$$

$$V_{2ref}=M_{2max}\, V_{refcx2} - M_{1max} \quad (2)$$

Where,

$V_{refcx1,}\, V_{refcx2}$ are control signals, x=a, b, c

$M_{1max,}\, M_{2max}$ are maximum modulation indexes

Shoot through is defined by the formula given below

$$ST=0.5(1/B+1) \quad (3)$$

$$B=Vin/Vo$$

Where, B - boost factor

V_{in}-voltage of the DC link

V_o - voltage of the battery

The sum of maximum modulation indexes are limited by: $M_{1max} + M_{2max} < ST$

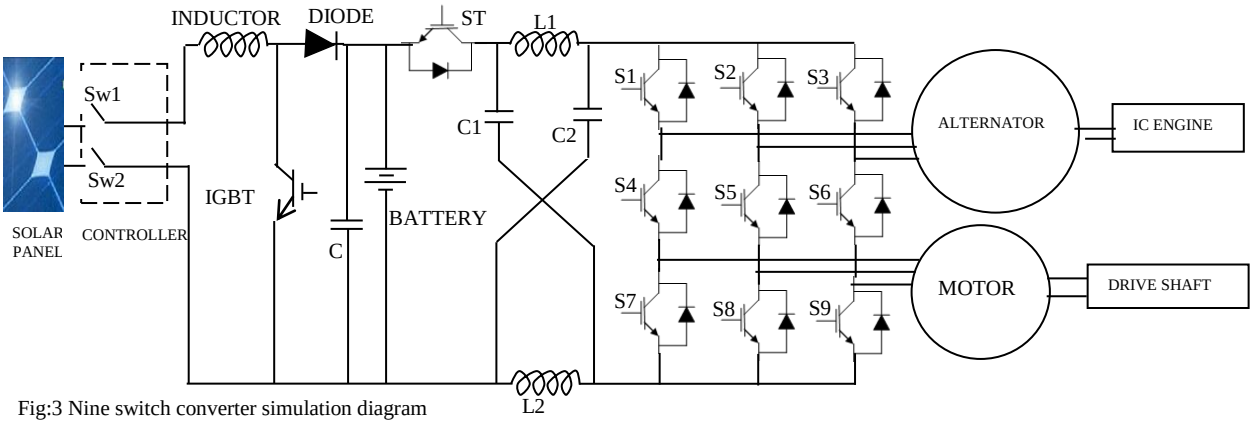

Fig:3 Nine switch converter simulation diagram

a) *Engine:* The engine used in the proposed system is a spark ignition type Generic engine. The throttle of the engine accepts values from 0 to 1. The engine can generate a maximum power of 5KW at a speed of 5500rpm. Fuel consumption of the engine is set as 'Brake specific fuel consumption by speed and brake mean effective pressure'. Engines initial velocity is kept at zero rpm and its inertia is 10 kg*^2. Output from the engine will be physical signals these are converted to Simulink signals by using 'PS-Simulink converter'. The Engine rpm is detected by using 'Ideal rotational motion sensor'.

b) *Generator:* The shaft of the engine is connected to the shaft of the generator by converting the speed of the engine into reference speed for the generator. The output of the generator is smoothed by using LC filters and the generated three phase AC output is given to the upper converter of the nine-switch converter [18]. This AC output is rectified by the upper converter and is used to recharge the battery based on its state of charge.

c) *Motor:* The motor of the series hybrid electric vehicle is powered from the battery. The Bidirectional Z-source network will act as a boost converter when powering the motor. The boosted output from the Z-source network is inverted by the lower inverter of nine switch converters, LC filters are used to smoothen its output and it is used to power the three-phase induction motor. High torque is applied to the motor during starting to ensure the motor produces enough power to move the vehicle from idle state [19]. The output torque of the motor is given to the vehicles wheels, since the motor shaft will be connected to the drive shaft to run the vehicle [20].

d) *Vehicle Body:* The vehicle body represents a two-axle vehicle body in longitudinal motion. The block accounts for body mass 1200 kg, aerodynamic drag, and road incline of zero and weight distribution between axles due to acceleration and road profile. The vehicle does not pitch or move vertically relative to the ground. Initial velocity of the vehicle is kept at 1m/s. The left and right tires connected to vehicle body represent the longitudinal behavior of a highway tire characterized by the tire Magic Formula specified in MATLAB. Road inclination and wind velocity are set to zero. The output speed will be in meters per second this is converted to kilometer per hour by multiplying with 3.6.

e) *Solar Panel:* Solar panel of rating 250W, Voc= 44.5V, Isc=7.58A, Vmp=35.55V, Imp=7.04A is used. The output voltage 35V from the solar panel will be boosted to 96V by using boost converter and it will be used to charge the battery.

Table 1: SIMULATION PARAMETERS

Element	Parameter	Value
Lithium-Ion Battery	Nominal voltage	400V
	Rated capacity	6.5 Ah
	Internal Resistance	0.01 Ω
z-source Network	Capacitor	400μF
	Inductor	1mH
IGBT	Internal Resistance	1mΩ
	Snubber resistance	0.1MΩ
Generator	Nominal power	750VA
	Line to line voltage	415V
	Frequency	50Hz
	Pair of poles	3
	Internal resistance	0.1Ω
	Inductance	0.215mH
	Active Power	4kW
Filter	Resistor	0.001Ω
	Inductor	1mH
	Capacitor	0.1mF
Motor	Nominal power	3.7kW
	Line to line voltage	415rms
	Frequency	50Hz
	Pair of poles	2
	Stator Resistance	0.0822Ω
	Stator Inductance	0.724mH
	Mutual Inductance	0.0271H
Generic Engine	Maximum Power	5kW
	Maximum power speed	5500rpm
	Maximum speed	7000rpm
	Inertia	kg*m^2
	Displaced volume	4000cm^2
Vehicle Body	Mass	1500kg
	Drag coefficient	0.4
	Vehicle initial velocity	1m/s
	CG height above ground	200mm

RESULTS FOR NINE SWITCH CONVERTERS CONNECTED TO HYBRID ELECTRIC VEHICLE

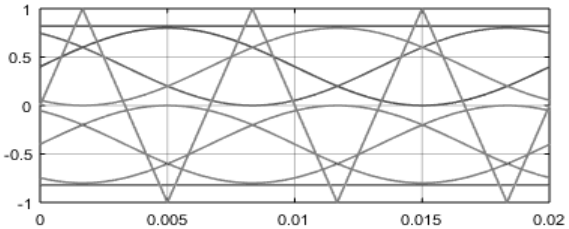

Fig:4 Input reference waveforms for nine switch converters with shoot through signal for bidirectional Z- source network

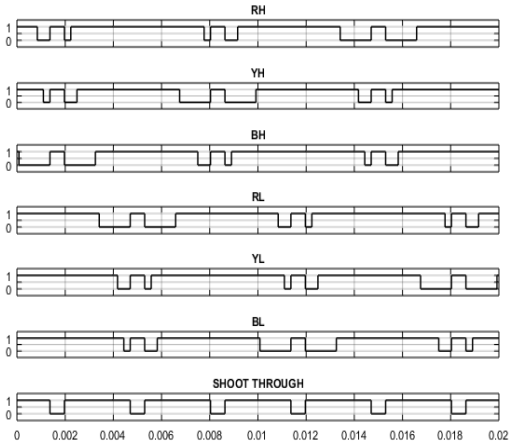

Fig:5 Waveforms for Gate pulse for upper and lower switches for nine switch converters with shoot through signal for bidirectional Z- source network

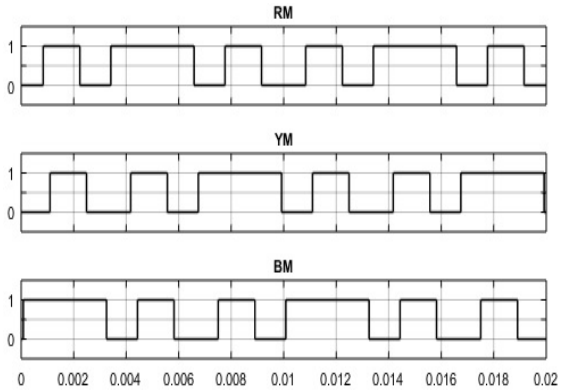

Fig:6 Waveforms for Gate pulse for middle switches of nine switch converter

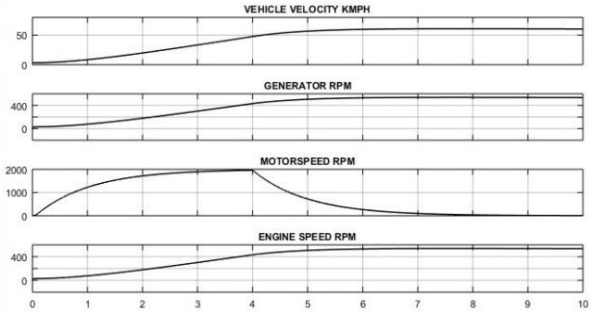

Fig:7 Waveforms for output of vehicle speed in kilometer per hour, Generator speed in rpm, motor speed in rpm, engine speed in rpm.

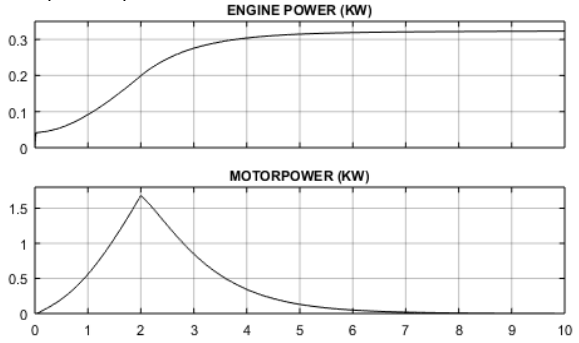

Fig:8 Waveforms for output for engine power in kilowatts and motor power in kilowatts

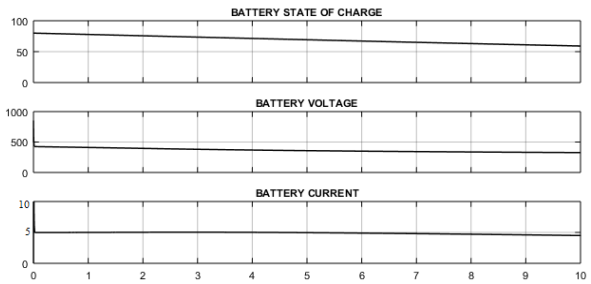

Fig.- 9: Output waveforms for battery state of charge in percentage, battery voltage in volt, battery current in amps

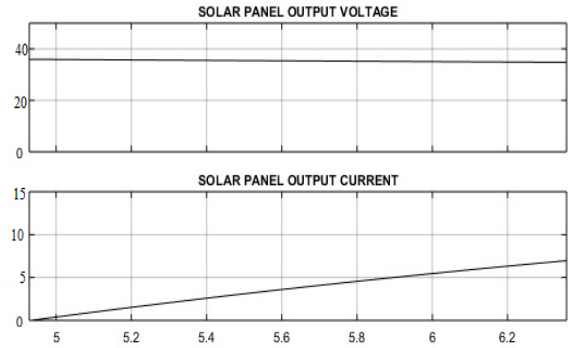

Fig:10 Output waveforms for solar panel voltage in volt, solar panel current in ampere

CONCLUSION

Nine switch converter using carrier based sinusoidal pulse width modulation with Bidirectional Z-source network is used for control of three phase induction motor and permanent magnet synchronous generator of the series hybrid electric vehicle eliminating the need for separate inverter and converter arrangement present in the existing method. The speed of the vehicle is controlled directly by varying the speed of the induction motor. Overall efficiency of the system is improved by the proposed method.

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