*Journal of Science and Technology (JST)*
*Volume 3, Issue 4, July - August 2018, PP 20-31*
*www.jst.org.in* *ISSN: 2456 - 5660*

# Effective Power Utilization Strategy of Fuel Cell System Using FSTP Sepic Inverter

**A. Arun Vikram*[1], R. Ram Kumar[*2] , R. Navaneeth[*3], G. Gokulakrishnan[*4]**

*[1], Department of EEE, K. Ramakrishnan College of Technology, Tiruchirapalli, Tamil Nadu, India
arunavikram@gmail.com
*[2], Department of EEE, K. Ramakrishnan College of Technology, Tiruchirapalli, Tamil Nadu, India
ramkumarr.eee@krct.ac.in
[*3]. Department of EEE, K. Ramakrishnan College of Technology, Tiruchirapalli, Tamil Nadu, India
navaneethr111097@gmail.com
[*4]. Department of EEE, K. Ramakrishnan College of Technology, Tiruchirapalli, Tamil Nadu, India
gokulakrishnan1997surya@gmail.com

***Abstract :*** *Four-Switch mode Three-Phase (FSTP) inverter is considered as an advanced inverter structure to diminish the price, complication, dimension and losses during its switching. The traditional FSTP inverter usually achieves merely buck DC- AC type conversion and highest voltage of the FSTP structured inverter is same as V/2√3. Therefore, the output side line voltage cannot go beyond this rate. To improve the VUF( voltage utilization factor) and reliability of the conventional FSTP inverter, the FSTP SEPIC inverter is considered in this research work, in which both the buck and boost DC-AC conversion is achieved. The double integral Sliding-Mode Control (SMC) is utilized to optimize its dynamics and also it is utilized to confirm whether strength of the whole system at various operating situations is upto the limit. Parameter design, element ranges, and the working of the FSTP-SEPIC based inverter are also offered. The MATLAB Simulink model is used to validate the concept of power utilization of Fuel Cell (FC) by the FSTP-SEPIC inverter. Simulation result shows the efficiency of the inverter , both the buck and boost operation with FC input. The inverter efficiency and other outputs of buck and boost inverter operation with FC input is exhibited using Simulation.*

***Keywords -*** *Fuel Cells, FSTP Inverter, SEPIC Converter, Double integral SMC.*

## I. INTRODUCTION

Present-day, maximum vitality challenge in the globe depend on relic oils like petroleum, coal and gas which exhaust at very fast rate and also leads to global warming and ozone depletion. The value of FC has increased in the last decade because of zero toxic emissions. A FC is an apparatus which converts the chemical vitality in the FC to electrical vitality. A classic FC yields a voltage of 0.6-0.7V during fully rated condition and 60% electrical efficiency. In the literature, many researchers has been proposed many modeling techniques for FC to improve the vitality efficiency and reliability. Abdin.Z et. al. [1], has presented an improved design of a PEM electrolyzer cell depends on (LMMM) linked modular mathematical models of the anode terminal, cathode terminal, membrane and fuel cell voltage. In [2], the model was designed with an objective to ease the simulation of FC power systems by utilizing only less variables from constructor datasheets. A novel non-linear state-space model with dynamic non-isothermal Polymer Electrolyte Membrane Fuel Cell (PEMFC) model has been improved by Faysal et. al. [3]. The mathematical design was improved depending on mass and vitality equation. In this manuscript, the writers proposed a mixture of various dynamic equations to study the consequence of sudden deviation of few working parameters like resistance, pressure and temperature input. The outcomes are related to those of an isothermal design.

A mathematical design of 750W PEMFC is developed by Seyezhai e.t al. [4]. This design describes the behavior of PEMFC beneath steady-state and transient conditions. Karim Belmokhtar et. al. [5] has defined the modeling and process control of PEMFC. An active controller of $H_2$ and oxygen streams to increase the PEMFC efficacy is also proposed. The dynamic design of the PEMFC scheme and the regulator of the DC/DC converter utilizing Proportional Integral (PI) were offered.

So, the power generated from the modeled FC system can be used for driving loads in industries. FSTP inverter has been considered in this work because of its advantages over other inverters. Many researchers have studied and proposed the performance of FSTP inverter using the laboratory prototypes and software. A Simulink model and execution of FSTP inverter fed type induction motor drive is presented by Nalin Kant Mohanty et. al. [6]. In this methodology, the investigation is supported by Spartan-III processor with Xilinx. [7]-[8] has investigated the performance of a cost effective FSTP fed type induction motor drive scheme for high presentation industrial drive scheme. Wen Wang et. al. [9] has proposed a space vector based Pulse-Width Modulation (PWM) technique and a DC link voltage mode control strategy for FSTP shunt active power filters.
M.K. Metwally [10] has proposed the model set reference adaptive scheme based speed and stator resistance calculators of drives served by FSTP inverter in the dangerously small and zip speed area of working.
FSTP inverter has so many advantages but it is not widely used because of unreliable performance for the long run of the motors and it achieves only buck mode DC-AC conversion i.e. high voltage is reduced to $V/2\sqrt{3}$. The voltage utilization factor of the produced FC voltage is improved when it is given as input supply to circuit containing FSTP-SEPIC inverter and also reliability will be more and performs both the buck and boost DC-AC conversion.

In the following chapters, modeling of FC and its advantages, design, principle behind the working of the FSTP SEPIC inverter are offered. Apart from this, the double integral type sliding-mode controller is utilized with the FSTP-SEPIC inverter to improve its dynamics and to guarantee toughness of the scheme at the period of various working conditions.

## II. MODELING OF FUEL CELL

### *A. Theoretical Background*

A FC is an electro-chemical apparatus and it utilizes hydrogen as its source fuel to harvest protons, electrons, heat and a water. This knowledge is usually established on modest chemical reactions between hydrogen and atmospheric air which are given below:

at Anode side,

$$H_2+O^{2-} = H_2O+2e^- \qquad (1)$$

at cathode side,

$$\tfrac{1}{2} O_2+ 2e^- = O^{2-} \qquad (2)$$

Overall Cell reaction,

$$2H_2 + \tfrac{1}{2} O_2 = 2H_2O \qquad (3)$$

These chemical reactions between $H_2$ and $O_2$ along with electrons which could offer electricity through a modest connected circuit provided with a load. The strategy is created on the modest procedure of dual electrodes located contradictory to the electrolyte as shown in Fig 1.

### *B. Dynamic scheme of a FC system*

Many models are presented to pretend the FC in the literature. This dynamic system is constructed by using the connection amongst the delivery voltage and possible pressure of $H_2$, oxygen and water.

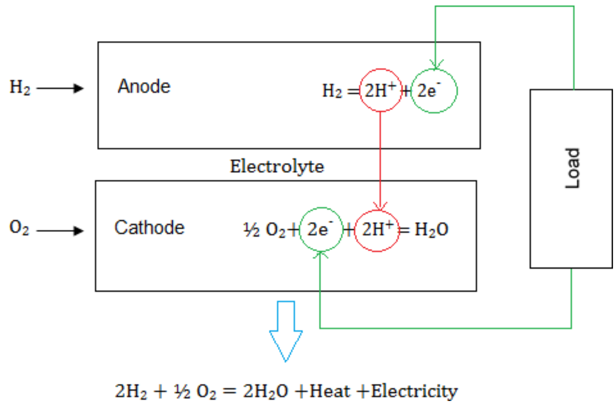


Fig.1 Cross-sectional view of FC Structure

The FC scheme uses hydrogen gained from the on-board great pressure hydrogen tanks rendering to the power mandate. From the derived equations and parameters considered, the active modeling of the FC is obtained as shown in Fig.2.

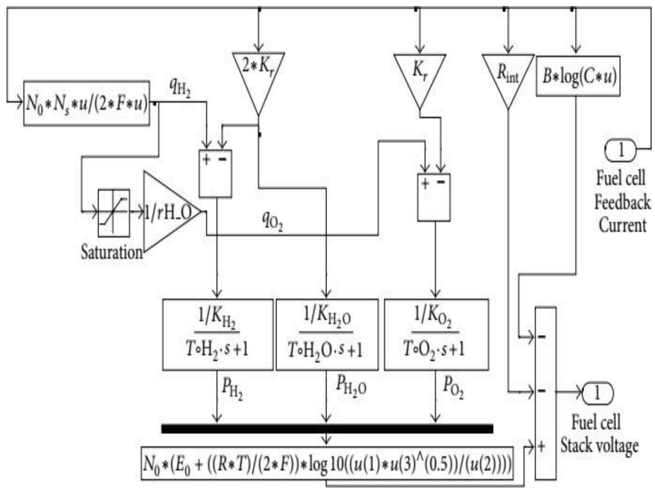


Fig.2 Dynamic Model of the FC

A feedback control scheme is utilized to control $H_2$ stream rate rendering to the output power of the FC system. This feedback control is attained where FC current is engaged back into the input while transforming the $H_2$ into molar form. The FC stack output voltage is taken and utilized for driving loads. The FC voltage will be increased if the number of stacks and cells are increased. In this work, power generated by the modeled FC system is given as an input to the FSTP-SEPIC Inverter.

## III. FSTP-SEPIC BASED INVERTER

### A. *Principle of operation*

The FSTP-SEPIC mode inverter contains of dual SEPIC type converters and attains DC–AC transmission by joining dual phases of the 3Φ load to the delivery side of dual DC–DC SEPIC converters which modulates sinusoidal in nature, although the third phase is straightly associated to the input side DC source. Collected SEPIC and DC-DC converters make a DC-biased AC output, consequently that every converter harvests a unipolar voltage. To produce3Φ stable load voltages, the sinusoidal alteration of every converter is 120° moved to get DC-bias corresponding to the DC source voltage. Meanwhile the load is related variously across the dual converters and the DC source, thus, while a DC bias looks at every termination of the load, the variance DC voltage through the load is zero and the voltage produced through the load is bipolar voltage, which requires the DC–DC SEPIC type converters to be current bi-directional. The bi-directional SEPIC DC–

DC type converter is presented in Fig.3, and the complete arrangement of the FSTP-SEPIC type DC-AC inverter is displayed in Fig.4.

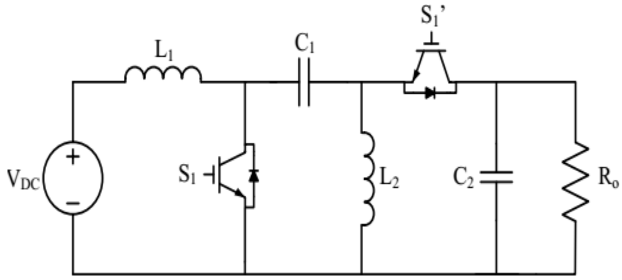


Fig.3 Bi-directional SEPIC Converter

As shown in Fig.3, the bi-directional mode SEPIC type converter contains DC input voltage $V_{DC}$, input inductor $L_1$, two opposite bi-directional switches $S_1$,$S_1$', coupling capacitor $C_1$, output inductor $L_2$ and output capacitor $C_2$ nourishing a load resistance $R_O$. SEPIC working core indicates charging the inductors $L_1$and $L_2$ for the period of the ON condition enchanting the vitality correspondingly from the input source and from the capacitive coupling $C_1$ and discharging them concurrently into the load via the bi-directional switch $S_1$' at the switching time the OFF condition. The delivery voltage of the SEPIC type DC-DC converter might be fewer or added depending on the duty cycle period of the input voltage.

In Fig.4, the output line voltages across the load are given by,

$$V_{AB}(t) = V_{DC} - [V_{DC} - V_{m_{L-L}} \sin \tag{11}$$

$$V_{BC}(t) = V_{DC} - V_{m_{L-L}} \sin(\omega t) = \tag{12}$$

$$V_{CA}(t) = V_{DC} + V_{m_{L-L}} \sin(\omega t + 2\Pi/3) - V_{DC} = V \tag{13}$$

Though the FSTP-SEPIC type inverter can provide an output stream line voltage up to a value is same as the voltage of the input voltage range, however, it is recommended to define lower than the range of the input DC voltage value to avoid working at zero value of the duty cycle. Accurate range selection of passive type components of SEPIC mode Converter is required for proper DC-AC type conversion.

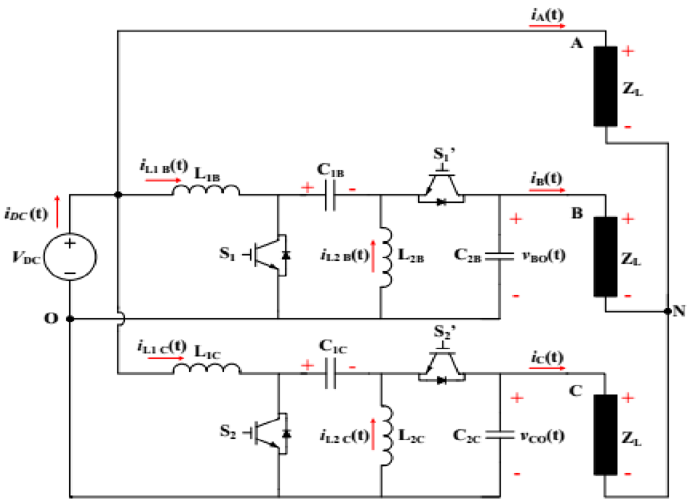


Fig.4 FSTP-SEPIC type Inverter

From Eq. (16&17), it is perfect that the total charge of dual input inductor currents value are identical only when cosφ is unity, due to this situation both SEPIC type converters will exchange the similar quantity of power to the load side. Otherwise the average currents are not identical i.e. SEPIC converters will exchange various quantity of power to the load sideways. Also from Fig.4, the DC source input current of the inverter mode topology is equivalent to the total load current drained by phase A which shows that the DC supply current drawn by the inverter is continuous.

Table.1 shows the overall difference between the predictable FSTP Inverter and FSTP-SEPIC Inverter which are discussed in the above passages.

**Table.1 Comparison between Conventional FSTP and FSTP-SEPIC Inverter**

| **Conventional FSTP Inverter** | **FSTP SEPIC Inverter** |
|---|---|
| Does only buck conversion | Performs both buck and boost conversion |
| The peak voltage Vdc is reduced to Vdc/2√3 | The peak voltage Vdc is reduced to Vdc/2 |
| High input ripple current content | Low input ripple current content |
| Reliability and performance are low | Reliability and performance are high |
| Switching Losses are more | Switching Losses are less |

## IV. CONTROL STRATEGY

A strong control approach is essential since any irregularity in the produced voltage of the dual SEPIC DC-DC type converters from the preferred DC-biased source sine wave reference hints to a substantial destabilize in the 3Φ output stream voltage. The finest appropriate scientific design for the submission of sliding-mode type control technique to the SEPIC [9] is used a non-linear state space illustration. The converter is measured over two opposite switches, which has the control signal as same as its duty cycle and is expected to work in unceasing operation. Henceforth, there are couple state space illustrations at the time of ON and OFF conditions of the switch.

### *A. Double-Integral SMC*

To maximize the efficiency of the primary sliding-mode type control, a supplementary double-integral period of the state variables fault could be accessible in the sliding superficial. Hence it is called as Double-Integral SMC. Thus, the DISM control technique has the subsequent sliding surface as,

$s= \alpha_1 e_1 + \alpha_2 e_2 + \alpha_3 e_3 + \alpha_4 e_4$ (22)

where $\alpha_1$, $\alpha_2$, $\alpha_3$ and $\alpha_4$ are the desired control parameters denoted sliding coefficients and $e_1$, $e_2$, $e_3$ and $e_4$ are the state errors.

The block diagram of the DISMC is given in Fig.5.

At an infinitely high switching frequency the SMC will ensure that both input inductive current and output capacitive voltage are regulated to track precisely their instantaneous references. Though, in the situation of finite frequency or static frequency SMC's, the controller is imperfect where steady-state faults occur in two sides of inductive current and output capacitive voltage. A good technique for overwhelming these faults is to present an extra integral time of the state variables into the sliding surface. So, an integral time of this fault is presented into the SMC as an additional measured state-variable to decrease these steady-state faults. But to increase the efficiency of the integral SMC, a supplementary double-integral period of the state variables faults could be introduced in the sliding mode surface as shown in Fig.5

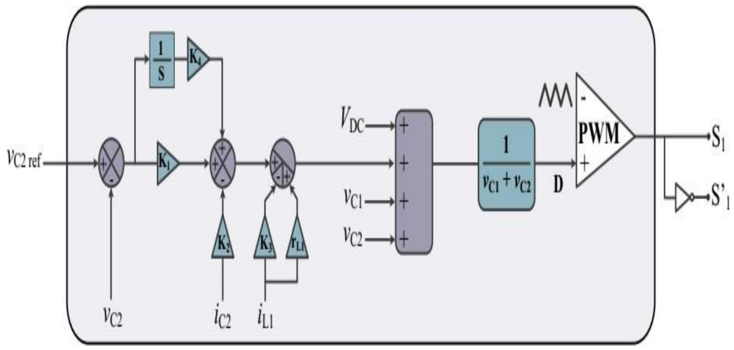


Fig.5 Block diagram of Double-Integral SMC for SEPIC Converter

## V. SIMULATION RESULTS AND ANALYSIS

The comprehensive simulations of the power produced by the modeled FC system are presented in this section. Also, the FSTP-SEPIC type inverter is modeled, simulated, analyzed and compared with the performance of the conventional FSTP inverter to authenticate its general performance. The models are being done using Simulink to legalize the analytical results and to demonstrate the robustness of the recommended DISM control approach when realistic on the proposed inverter topography through various simulation readings.

The output voltage known as phase value of voltage in the inverter is fixed to a top value of 100 VAC for Buck and 300 VAC for Boost DC-AC Conversion though the input source voltage was set around 200 VDC. The parameters of the FSTP-SEPIC type inverter for models are abridged in the final section of this chapter.

### *A. Performance of Dynamic Model of FC*

The FC output voltage is obtained from the sum of three effect namely, the Nernst potential, the cathode and anode activation over voltage and the resistive over voltage due to internal resistance are given in equation 8 & 9. The FC system constraints utilized in this simulation are given in the Table.2. The voltage produced from the modeled FC system is expected to be around 200 VDC. So, in order to attain the desired goal number of Cells and Stacks are also fixed.

Table.2 Fuel Cell system Model Parameters

| **Parameters** | **Values** |
|---|---|
| Activation voltage constant B (active voltage B-constant) | 0.04777 [$A^{-1}$] |
| Activation voltage constant C (active voltage B-constant) | 0.0136 |
| Conversion factor (CV)(transmission factor) | 2 |
| Faraday's constant | 96484600 [C/kmol] |
| Hydrogen time constant( ) | 3.37 [s] |

| | |
|---|---|
| Hydrogen valve constant ( ) | 4.22* $10^{-5}$ [kmol/(atms)] |
| Hydrogen- oxygen flow rate | 1.168 |
| Number of cells and stacks | 20 & 1 |
| Utilization gas constant R | 8314.47 [ J $K^{-1}$ $kmol^{-1}$] |
| Water time constant | 18.418 |
| Water valve constant | 7.716*$10^{-6}$ [kmol/(atms)] |

The voltage and current of the modeled FC system when the number of cells is taken as 20 and number of stack is unity are shown in Fig.6 and Fig.7. So, the voltage generated by the FC system model is more (i.e. 197 $V_{DC}$) when the number of cells are also more. The current obtained for the above considered cells and stacks is 1.97 A. The power generated by the same model is shown in Fig.8. This produced power is sufficient to drive a load. Hence, the presented results admit that the modeled FC is efficient to generate the required amount of voltage, current and power as far as the number of cells and stacks are concerned.

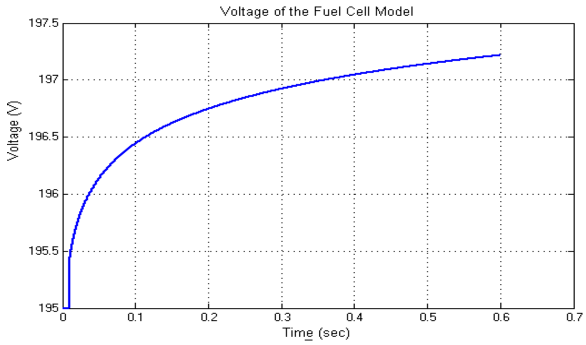


Fig.6 Voltage of Fuel Cell Model for =20 and =1

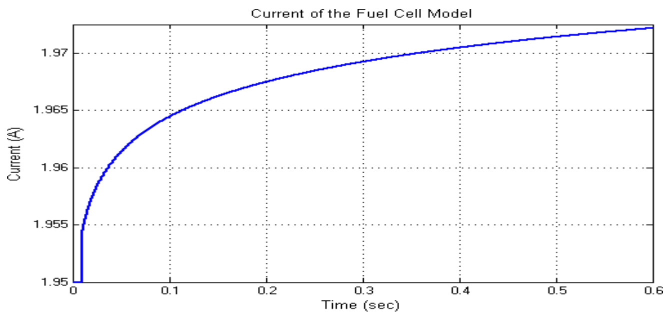


Fig.7 Current of Fuel Cell Model

*A. Performance of Conventional FSTP Inverter*

From the modeled FC, obtained voltage is 197 V. The voltage utilization factor of the produced FC voltage is improved when it is given as an input supply to circuit containing FSTP inverter. But some of the disadvantages of conventional FSTP inverter are: 1) only Buck DC-AC Conversion, 2) output voltage is reduced to Vdc/2√3 and 3) High input ripple current content.

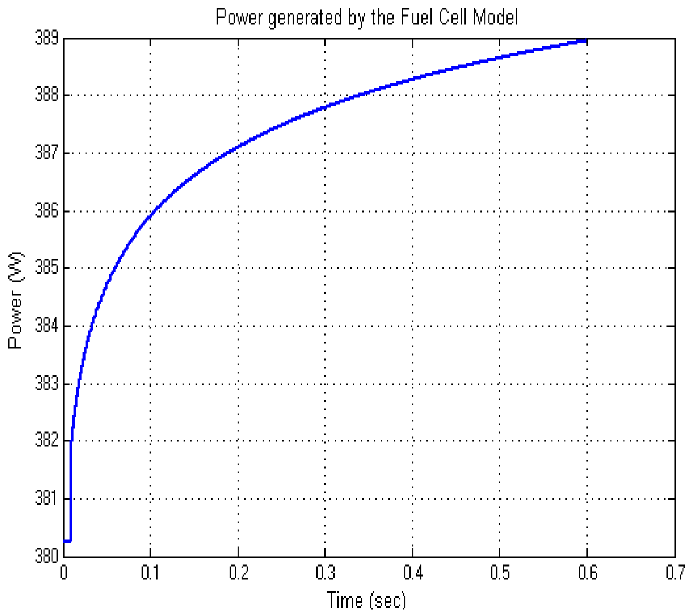


Fig.8 Power generated by the FC Model

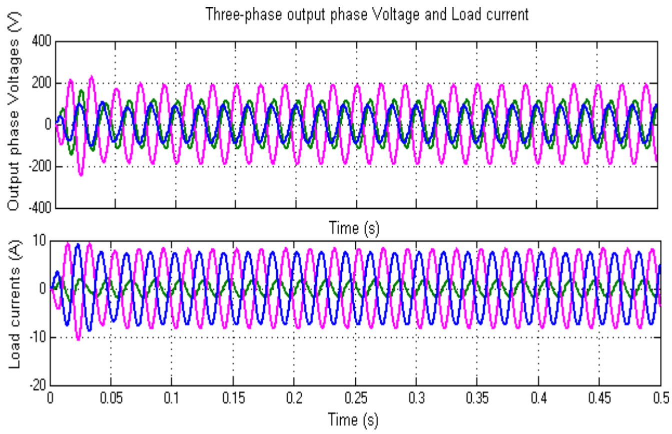


Fig.9 Three phase mode output phase Voltage and Load current of the conventional FSTP Inverter

In the conventional FSTP inverter, one of the phase voltage output will be less when compared to the other two phase voltages as shown in Fig.9 which occurs due to the improper switching of capacitors. Also, it shows the Buck DC-AC Conversion of the FSTP Inverter. This type of AC Signal will affect the performance and reliability of the motors in the long run.

*A. Performance of FSTP SEPIC based Inverterl*

The Fig.10 shows the output phase voltage source and load current belonging to FSTP- SEPIC type inverter. Input DC supply is given as $197V_{DC}$ and the three phase AC output peak-to-peak voltage is obtained as 100VAC which is an example of buck DC-AC conversion. Also, input supply current is given as 1.97 A whereas the load current obtained is 4 A. The magnitude of the output AC Voltage is maintained with the help of a controller action. In Fig.11, 3Φ AC output peak-to-peak voltage is measured as 300VAC, for the given input DC supply of 197 VDC. In the boost DC-AC Conversion, the load current of the FSTP-SEPIC inverter is measured to be 10A for the same input supply current and input DC voltage which is shown in Fig.12.

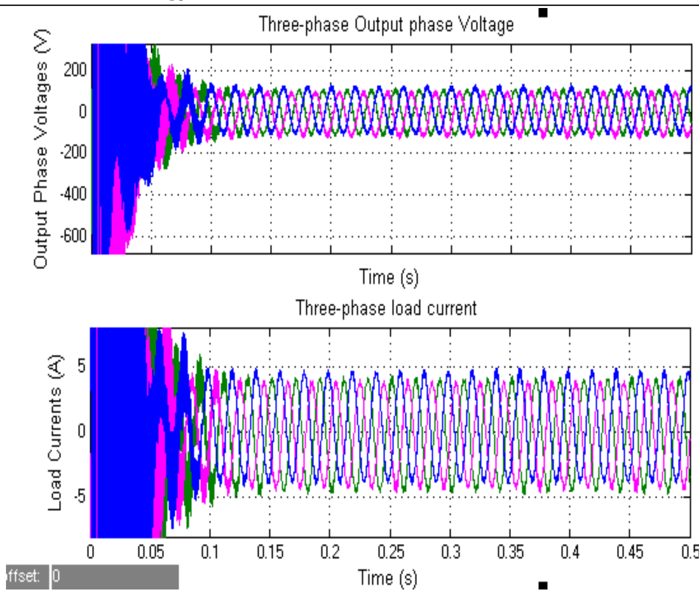


Fig.10 Three phase output phase voltage and load current of FSTP-SEPIC inverter for Buck operation

More attention should be given for the selection of capacitances and inductances values because the system behavior is completely determined by these values. Ripples in the three phase output phase voltage and load current can be reduced by the proper selection of inductances and capacitances values

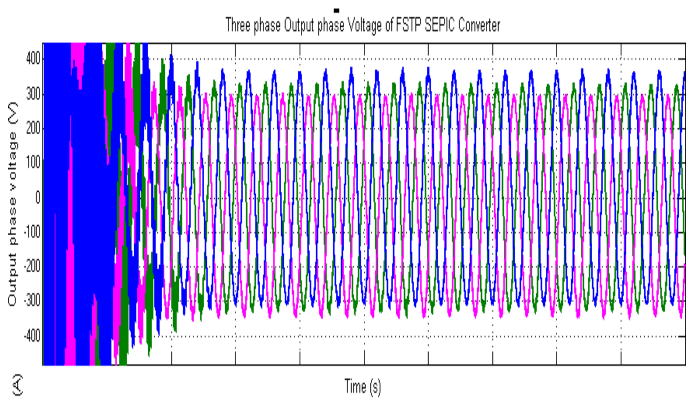


Fig.11 Three phase voltage of FSTP-SEPIC inverter for boost operation

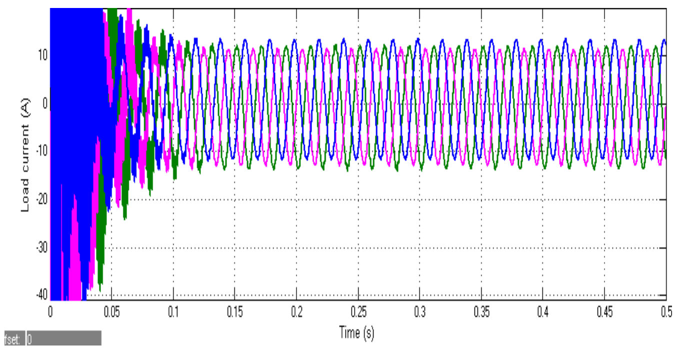


Fig.12 Three phase current of FSTP-SEPIC inverter for boost operation

The effectiveness of the SEPIC converters during normal functional circumstances are offered in the below sections. Fig.13a displays that the simulated waveforms of the current passing in an input inductive element of dual SEPIC converters are steady and Fig.13b illustrates that the current passing in an output inductive element has the similar waveform output of the equivalent load current rating with overlaid switching ripples. The voltages across the output side capacitor of all converters are displayed in Fig.14. These capacitance and inductance have provided a pure sinusoidal output voltage so there is no need for output filter to remove the ripples. The model conditions of the FSTP-SEPIC based inverter that are employed in the above simulations are shown in the Table.3.

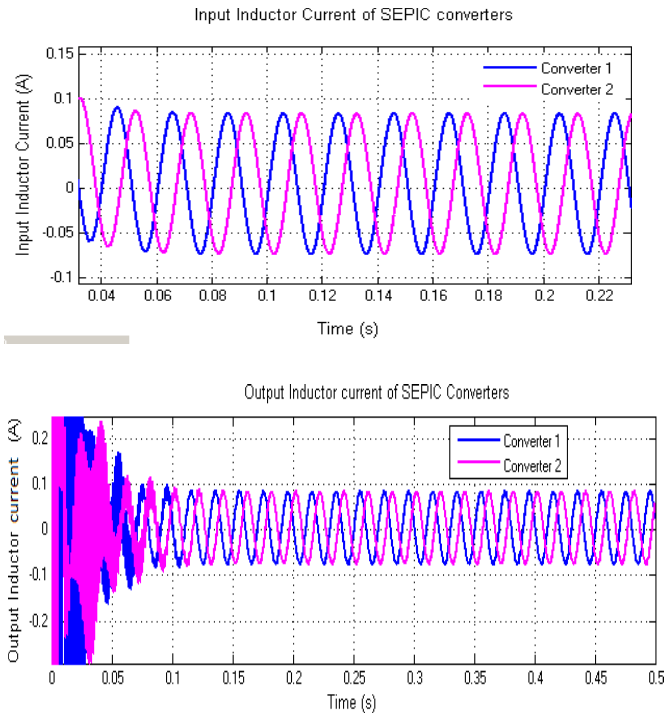


Fig.13 depicts the enactment of the proposed SEPIC type inverter underneath normal functional conditions (a) Input inductor current of SEPIC type converters (b) Output inductor current of SEPIC type converters

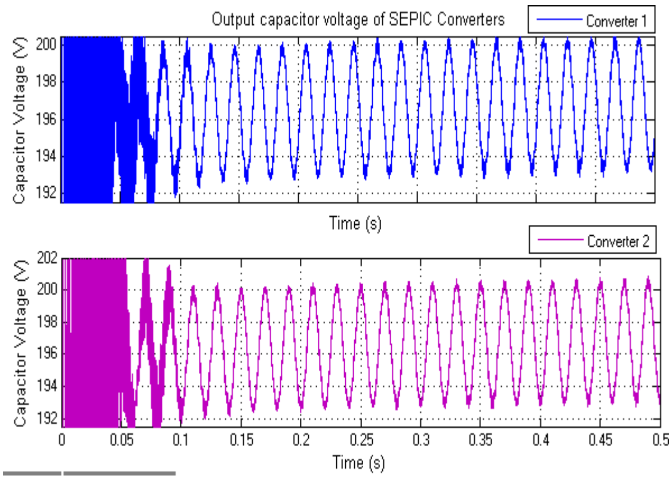


Fig.14 Output capacitor voltage of proposed converters

Table.3 Specifications - FSTP SEPIC based inverter

| Parameters | Values |
|---|---|
| Input DC voltage | 197 V |
| Switching frequency | 25 kHz |
| Rated current | 4A |
| Inductors values in mH | $L_{1B}$ = 6.77 , $L_{2B}$ = 2.26 ,$L_{1C}$ = 7, $L_{2C}$ = 2.36 |
| Capacitors values in μF | $C_{1B}$ = 10.6, $C_{2B}$ = 2.8 , $C_{1C}$ = 10.3 , $C_{2C}$ = 2.8 |
| DISMC coefficients | $K_1$ = 2, $K_2$ = 10, $K_3$ = 1, $K_4$ = 100 |

## VI. CONCLUSION

In this paper, power utilization strategy of the FC system by FSTP-SEPIC based inverter was carried out and presented along with necessary simulation results. Firstly, the steps involved in the FC modelling and equations involved are presented. Since voltage and power generated from the FC system has to be given as input to the drive, required voltage is fixed as 200 $V_{DC}$. So, Number of cells are fixed at twenty with single stack and voltage around 197 $V_{DC}$ has been generated. Secondly, comparison chart provided between the conventional FSTP inverter and FSTP-SEPIC inverter utilizes the power attained from FC system. It is also provided in detail along with proper equations, design and parameter values. DISM controller has been designed to optimize and to ensure the dynamic condition and robustness of the system during various operating conditions. Finally, the simulation results of the modeled FC system, performance and comparison of predictable FSTP and FSTP-SEPIC type inverter was presented by utilizing MATLAB/Simulink to certify the analytical outcomes and to show the healthiness of the recommended DISM control approach adopted in an inverter topology through simulation studies. Thus, the effective power utilization of the FC system was done using the considered inverter topology.

## REFERENCES


[1] *Abdin.Z, Webb.C.J and MacAGray.E, "Modelling and Simulation of a Proton Exchange Membrane (PEM) Electrolyser Cell," International Journal on Hydrogen Energy, vol. 40, no.5, pp.13243-13257, September 2015. http://dx.doi.org/10.1016/j.ijhydene.2015.07.129.*

[2] *Ali, A. Nazar. "Ride through Strategy for a Three-Level Dual Z-Source Inverter Using TRIAC." Scientific Research publication 7.ISSN Online: 2153-1293 (2016): 3911-3921.*

[3] *Ramkumar, R., and N. Tejaswini. "A novel low cost three arm Ac automatic voltage regulator." Advances in Natural and Applied Sciences 10, no. 3 (2016): 142-152.*

[4] *Seyezhai.R and Mathur.B.L, "Mathematical Modeling of Proton Exchange Membrane Fuel Cell," International Journal of Computer Applications, vol.20, no.5, pp.816-825, April 2011.*

[5] *Ramkumar,R., et al." A Novel Low Cost Three Arm Ac Automatic Voltage Regulator" Advances in Natural and Applied Sciences ISSN: 1995-0772 AENSI Publication EISSN: 1998-1090. 2016 March 10(3): pages 142-151.*

[6] *R.Ramkumar "High current and High Voltage Gain Soft Switched Multiphase Multilevel Modular DC-DC Converter." International Journal of Applied Engineering Research 10, no. 0973-4562 (2015): 7686-7689.*

[7] *Radwan.T.S, and Rahman.M.A, "Performance Analysis of a Cost Effective 4-Switch 3-Phase Inverter Fed IM Drive," Iranian Journal of Electrical and Computer Engineering, vol.5, no.2, pp.97-102, June 2006.*

[8] *Ganesh, Rajendran Jai, et al. "Fault Identification and Islanding in DC Grid Connected PV System." Scientific Research Publishing 7.Circuits and Systems, 7, 2904-2915. (2016): 2904-2915.*

[9] *Wen Wang, An Luo and Xianyong, "Space vector pulse-width modulation algorithm and DC-side voltage control strategy of three-phase four-switch active power filters," Power Electronics, IET , vol.6, no.1, pp.125-135, January 2013. doi: 10.1049/iet-pel.2012.0391*

[10] *Ali, A. Nazar. "Performance Enhancement of Hybrid Wind/Photo Voltaic System Using Z Source Inverter with Cuk-sepic Fused Converter." Research Journal of Applied Sciences, Engineering and Technology 7.ISSN: 2040-7459; (2014):3964-3970.*

[11] *Kalavalli,C., et al. "Single Phase Bidirectional PWM Converter for Microgrid System." International Journal of Engineering and Technology (IJET) ISSN : 0975-4024 Vol 5 No 3 Jun-Jul 2013.*

[12]

## BIBLIOGRAPHY OF AUTHORS

| | |
|---|---|
|  | *Mr.A.Arunvikram completed his BE in PSNA College of Engineering and Technology,,Dindigul.He Completed his M.E in PSNA College of Engineering and Technology,,Dindigul.And he is having 4years experience on teaching field. Currently he is pursuing his Ph.D degree in Anna University, Chennai. His area of interest is power Converters,Renewable Energy* |
|  | *Mr.R.Ramkumar completed his BE in K.L.N.College of Information Technology,,Madurai.He Completed his M.E in Sethu Institute of Technology,Madurai.And he is having 5years experience on teaching field. Currently he is pursuing his Ph.D degree in Anna University, Chennai. His area of interest is power Converters,Micro Grid.* |