Misan Journal of Engineering Sciences ISSN: 2957-4242
Vol. 5, No. 1, 28 June 2026 ISSN-E: 2957-4250

Analysis of Low Cost Inverter (Three Phase – Four Switch) under Abnormal Conditions

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(Received 12 Nov 2025, Revised 29 Nov 2025, Accepted 12 June 2026)

Abstract: This revision explores the principle operation and control of a low-cost four-switch three-phase inverter (FSTPI). Dissimilar the traditional three limb six-switch inverter, the FSTPI topology uses four switches and two DC-link capacitors, thus decreasing circuit components then overall cost. Offering economic advantage, this topology simplifies control difficulty. The inverter's performance was examined under both balanced and unbalanced load environment via MATLAB simulations. Specific attention was agreed to the consequence of changing load impedances on total harmonic distortion (THD), current and voltage waveforms, and overall efficiency. The results validate that variations in load impedance create only minor variations in THD, which in turn slightly distort the current and voltage signals. Specifically, under the first and second load states, the THD was measured at 2.87% and 5.21. Also, the study reveals an inverse relationship between THD and efficiency: when THD increased from 2.87 the efficiency decreased to 94.6%, whereas at a lower THD value of 5.21 % efficiency improved to 96.6%. Under unbalanced load conditions, the inverter exhibited only a slight increase in distortion of the AC current, while efficiency remained nearly constant compared to balanced operation. These findings confirm the suitability of the FSTPI topology for engineering applications requiring reliable performance under both balanced and unbalanced load conditions..

Keywords: Blast loads; Blast-resistant structures; Structural analysis; Blast design criteria

1. Introduction

In power electronics fields, inverter considered the key for converting direct current to Alternating current, these inverters can be seen in different applications comprise a.c drive system , u.p.s , and the modern systems used renewable energy .Traditional type of three -phase inverter employs six power electronic switches , this kind of inverter may suffers from increasing cost , complexity in control . A new category of inverters was created to address the mentioned challenges; it is composed of four switches instead of six, with two capacitors serving as the d.c. link. Different study has been implemented to analyze and evaluate FSTP inverters to present the principle operation and construction of them, they studied with different load conditions as well as controlled situation to achieve suitable method to run the drivers .[1][2]. using triggering method (Space Vector Pulse Width Modulation) SVPWM researcher compare between both three phase rectifiers (four switch and six switch) , where TPFSI bids an advantages in cost , size as well as switching losses reduction . The last comes from the fewer number of power device. They also advance a mathematical model for (SVPWM) for inverter depending on.. Clarke's transformation, dividing the αβ-plane into four sectors instead of the six used for the TPSSI. By using the mentioned methods, the circuit gives a balance output voltage signal and current at resistive load state. The search finally identified that the capacitor in (TPFSI) may cause a circulating current leads to unbalance in output voltage so it needs to especial method for control compared to three-phase six-switch inverter (TPSSI) especially in drive system [3]. A new topology of TPFSI) presented integrated by boosting capability. The new circuit aimed to enhance the gain limitation of low voltage witch in traditional four switch inverter, this happened

DOI: https://doi.org/10.61263/mjes.v5i1.234

by modifying circuit as a split source network (capacitor, inductor and, diodes) with an inverter bridge to realize higher voltage conversion. Author developed scalar space vector PWM (SVPWM) scheme for driving inverter to avoid complex sector and make circuit effective even states of capacitor voltage oscillation. Giving better choice for inverter with cost effective and fault tolerance for renewable energy applications where energy conversion and stepping up voltage needed from single stage converter. [4]. Model predictive direct torque controller (MPDTC) was implanted on (TPFSI) driving three phase induction motor. In spite of this kind of inverter has low cost it suffer from asymmetrical voltage vectors as well as zero voltage vector, which create ripple in flux and torque with conventional DTC . The proposed control method implemented to overcome the mentioned problem by interchanging the hysteresis comparators and switching table of DTC by a predictive model. It estimate both (stator flux, torque) for all voltage vectors through a prediction horizon, choosing the vector that optimize the defined objective purpose. Then giving high performance operation for drive system and this approach inherently compensates for computational delays in digital implementation by reducing ripple and fault tolerance [5][6]. In power system, application the needs for devices used to control the power flow in transmission system will increase. Unified power flow controller (UPFC) was one of these devices, it delivers active and reactive power compensation, phase shifting, damping oscillation as well as voltage regulation, and all of these purposes lead to increase system stability. Inverter considered the backbone of UPFC, designing a four switches three- phase inverter in micro grid system. Researchers used PWM technique to implement to configure the power flow achieved using the new types of inverters, figure (1) illustrate the construction of using FSTPI in UPFC [7]

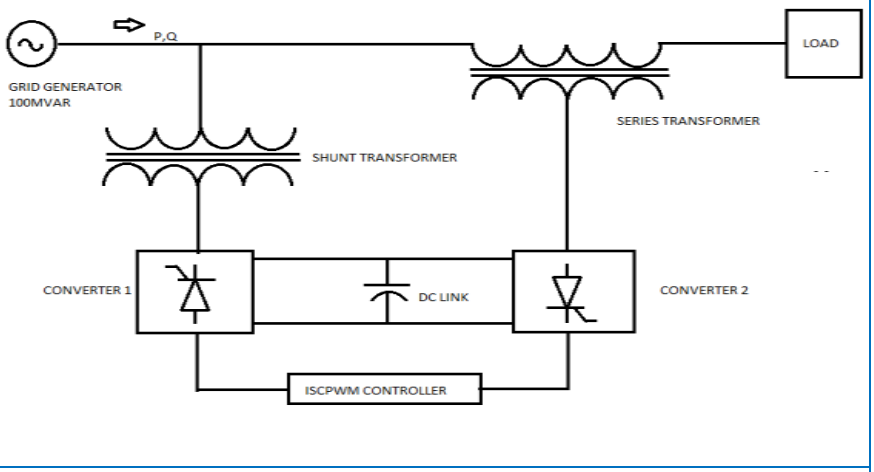


Fig. 1 Construction of UPFC used FSTPI in grids

Using MATLAB software FSTPI implemented as power supply fed three-phase induction motor. DC link of inverter is supplied from diode bridge rectifier, then it convert d.c power to a.c form researchers realized the circuit in practical experiment using FPGA and Spartan 3controller, as shown in figure(2)

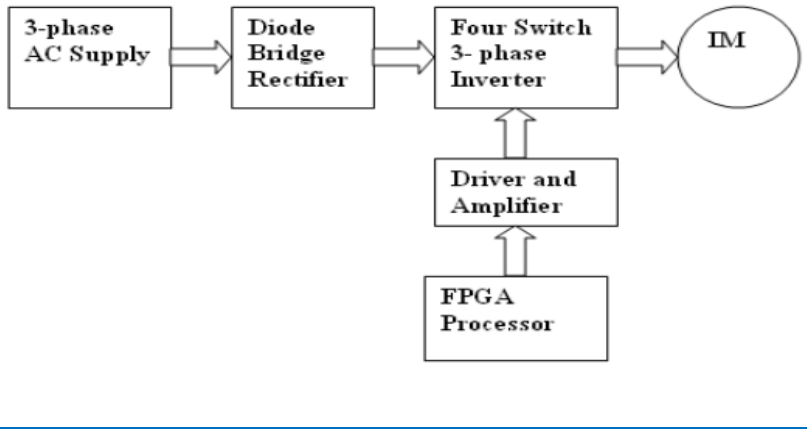


Fig. 2 The whole structure of a.c drive using FSTPI

Where the controller is responsible for generating pulse width modulation (PWM) feeding inverter switches. [8][9][10]

Driving three phase induction executing by four switches three-phase inverter (FSTPI). Due to difficulty of speed control in induction motor, a cage type used as variable a.c drive. Researchers depends on V/F strategy as a common strategy used to regulate motor speed, it states that the ratio of voltage to frequency is constant. To obtain the ratio, different manners of modulation approach to control the switching of power electronics device. Researchers listed three main ways as written

1. Single Pulse Width Modulation
2. Multiple Pulse Width Modulation
3. Sinusoidal Pulse Width Modulation

Among this strategy, the third point considered frequently way for speed control of 3-phase induction motor. Researchers implemented two strategies sinusoidal pulse width modulation (SPWM) and space vector modulation (SVM) to drive induction motor. by comparing two methods they show the effects for each one on circuit performance especially total harmonics distortion as presented in table1 [11]

Table 1. Effect of strategies on circuit performance

Circuit	Method Used	THD Result
Four Switch Three Phase Inverter	SVM Technique	THD reduced to 3.96%
Four Switch Three Phase Inverter	SPWM Technique	THD reduced to 2.58%

Power electronics converter played a prominent role in modern power system. By integration, them with renewable energy in micro grid system it can obtain efficient power conversion topologies. Four switch three phase inverter well choice to complete the mentioned purpose, it improves the system reliability, reduce the complexity in control strategy and decrease the cost. Researchers used a sinusoidal pulse width modulation (SPWM) technique to switch semiconductor device. Due to use current control the results gained show inverter ability to provide accurate active and reactive power as well as controlling the total harmonics distortion (THD) [12].

2. Three phase voltage source inverter (conventional type)

Multi-phase inverter is a basic power electronics converter in modern industrial and power system application. Commercial or three-phase type convert d.c power gained from supply or renewable sources

to a.c having three distinct phases. these form of inverter usually consist of d.c- link (capacitor) with three limbs each one comprise two semiconductor switches . This device finally generate a symmetrical three-phase voltage signal separate by 120o between them, and pure sinusoidal current waveform. Using this output waveform it can , guaranteeing a stable transfer of power. leading to the reliable operation of machine and other high-demand applications, with high efficiency and better performance in different technological fields[13][14].

3.Four Switch Three Phase Inverter (FSTPI)

Four Switch Three Phase Inverter (4S3PI or FSTPI) is a new topology of multi-phase inverters. It uses two legs with four switches instead of those three legs six switches. Figure (3) introduce the construction of 4S3PI circuit

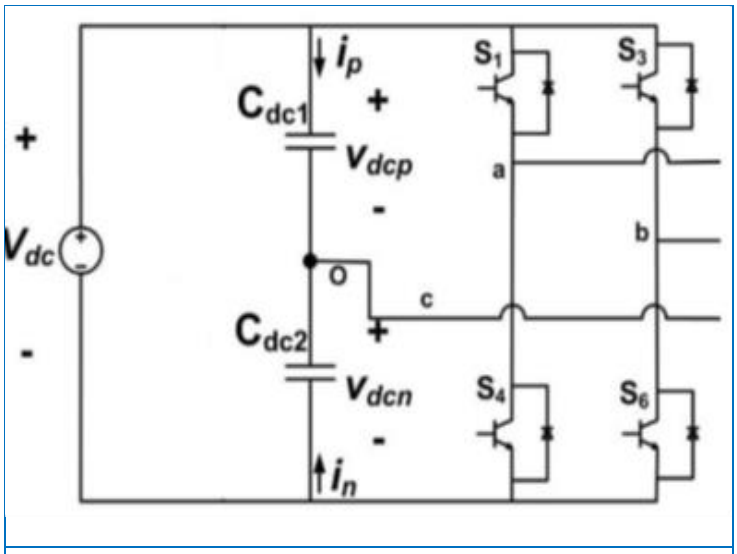


Fig. 3 Construction of 4S3PI circuit

In the circuit shown above besides the four switches (S1, S2, S3, S4) there are two capacitors (cd1, cd2) as d.c link. Whole circuit is feeding power from d.c source that may be battery or renewable energy sources. The output voltage waveforms are separated three, two are obtained from two main legs (phases) a and b while the third gained from the center of dc link

To understand the inverter operation, it can be treating the on-off switching of switches as 1-0 symbol. Where it refers to the state of them.

The output Voltage of inverter then expressed as equation written below [13][14]

Van = Vc/3 (4S3- 2S1 – 1) ... (1)

Vbn = Vc/3 (-2S3+4S1 – 1) ... (2)

Vcn = Vc/3 (-2S3- 2S1 +2) ... (3)

Table 2 introduces a comparison between the conventional and four switches three-phase inverter related to their construction, operation , control , application as well as reliability [15][16]

Table 2. Comparisons between conational and FSTP inverter

Feature	**conventional six switches**	**FSTP**
Switch Count	6 switches	4 switches
DC Link	dc link one capacitor	Two capacitors in series (split DC link)
Cost	Higher related to FSTP	Lower
Control Complexity	More complex complicated	Reduced complexity

Performance	Better voltage utilization, lower distortion	Slightly higher distortion, limited voltage vectors
Reliability	More redundancy, robust under unbalanced loads	Acceptable but capacitor balancing is critical
Applications	Widely used in drives, renewable integration, UPS	Cost-sensitive applications, small drives, low-power converters

4. Control strategy (Space vector pulse width modulation) SVPWM

SVPWM strategy is the better types of modulation methods in power electronics converters. While offering many advantages for circuit. It improves efficiency, decrease the total harmonic distortion. Different application can be seen the modulation strategy used with them such as [17]:

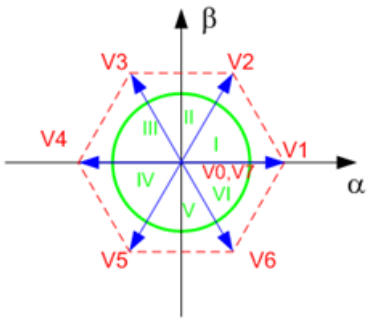
1 Electric and hybrid car
2 systems containing renewable energy sources
3 mill and industrial motor control scheme

5.Mathematical Analysis of SVPWM

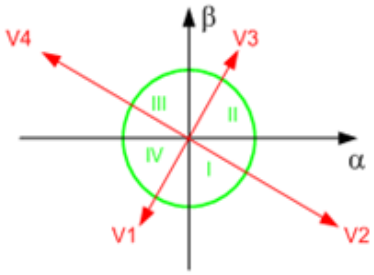
Analysis of the SVPWM depends on Clark s equation applied on traditional inverter (B6) that has six sectors then forming Vref. Hinge on the same criteria the theory can applied on the proposed 4S3P (B4). Using this modification V1and V3 added to another effective vectors (V23, V34, V41, V12) which written as below.

V23M = 0.5 (V2+V3) = (Vdc/3) ej0. V34M = 0.5(V3+V4) = (Vdc/3) ej2*pi/3 ... (4)
V41M = 0.5 (V4+V1) = (Vdc/3) ejpi. V12M = 0.5(V1+V2) = (Vdc/3) e -jpi/3 ... (5)
V0M=0.5(V1+V3)=0.5(V2+V4) ... (6)

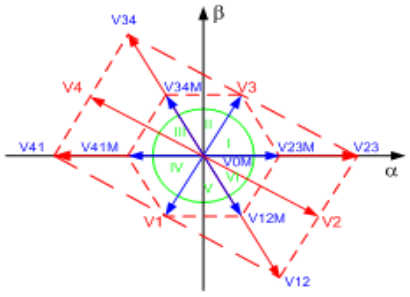
Figure (4) illustrate using sectors scheme for both B4 and B6 , (a) svpwm for commercial inverter (B6) , (b) SVPWM for B4 .(c) SVPWM method used for B4 depends on principle of B6. [17][18]



(a) svpwm for commercial inverter (B6)



(b) SVPWM for B4.



(c) SVPWM method used for B4 depends on principle of B6

Fig. 4 Illustrate using sectors scheme for both B4 and B6

6. Circuit model and Simulation Results

In this part of work a simulation of four switch three phase inverter (FSTPI) presented in block diagram as shown in figure (5) , where it connected to (R-L) loads , the specific load vary to include different

states of operation

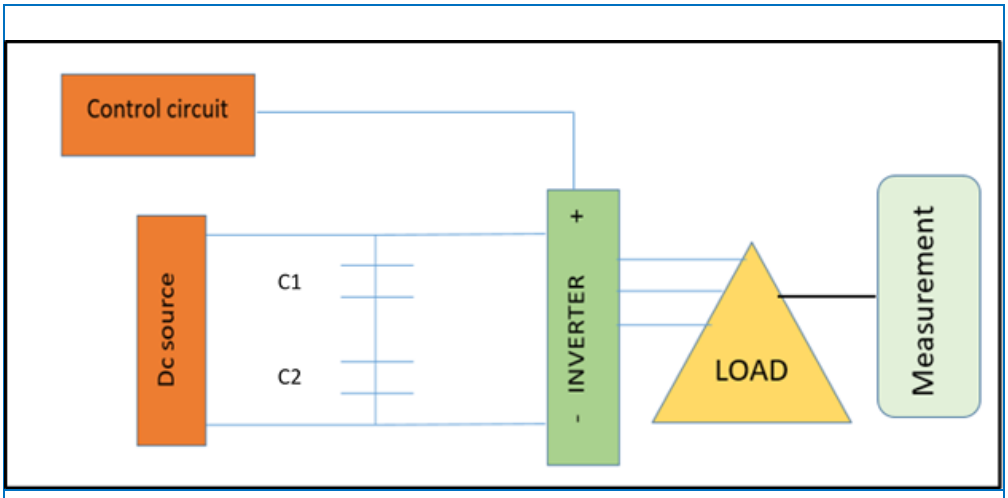


Fig. 5 Illustrate Full scheme of FSTPI with R-L Load

Figure (6) show 3-phase output load current nearly sinusoidal waves form fed balance load

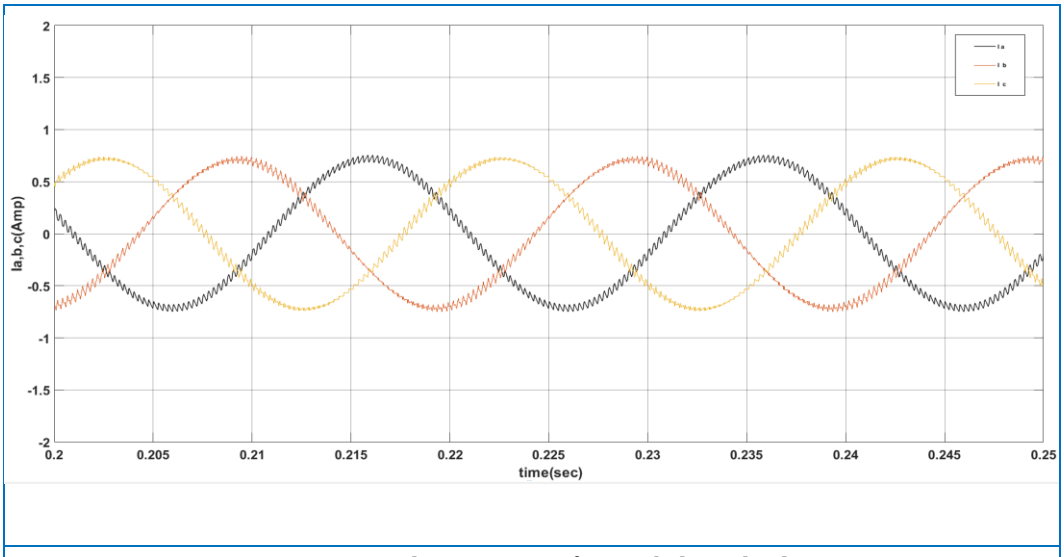


Fig. 6 Load current wave form at balance load

Figure (7) describe the voltage waveforms on loads

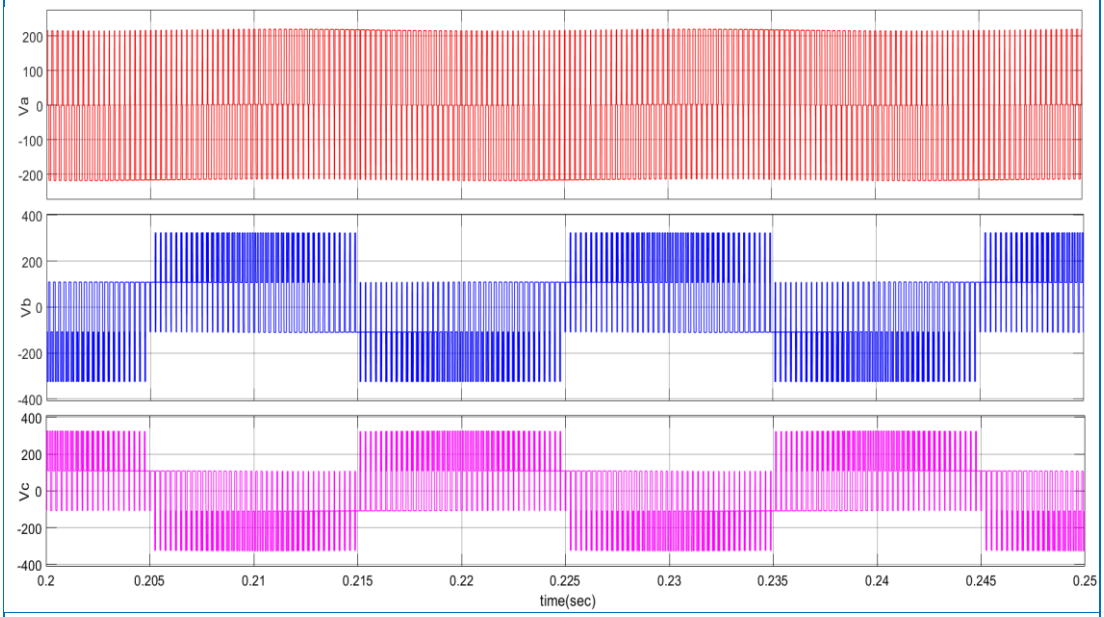


Fig. 7 Load voltage wave form at balance load

When connected output unbalance load on phase (a) and symmetric load on phase (b & c) once ,then changing load resistance on phase (a) in steps ,finally connected unbalance load in phase (a,b,& c) . The load currents is presented in figure (8). Where it can show asymmetry and consistency of current waves

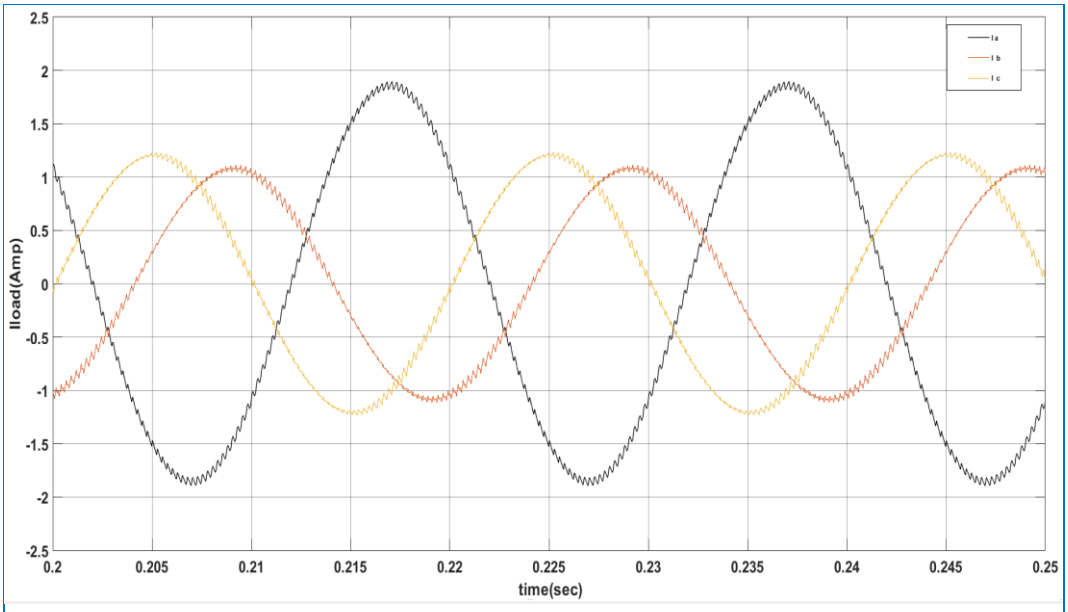


Fig. 8 Load current waves form at unbalance load

Figure (9) describe the voltage waveforms on three phase loads

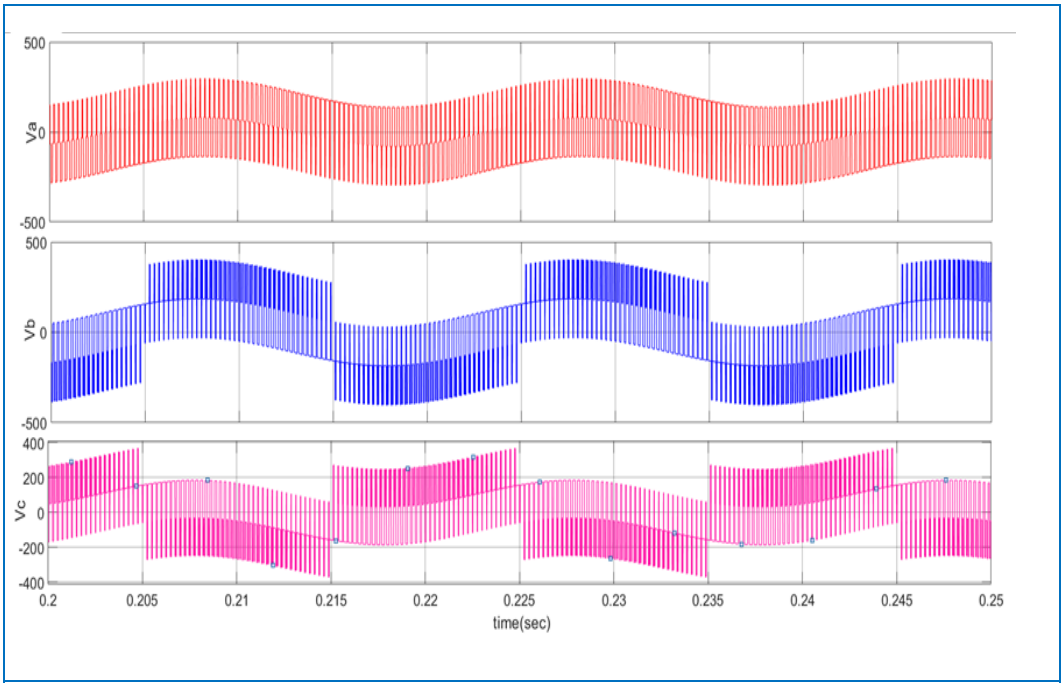


Fig. 9 Load voltage waves form at unbalance load

The Total Harmonic Distortion (THD) factor considered as one of the important parameter describe the quality of electrical signal generated by power electronic circuit. THD measures the distortion existing in a waveforms by relating the amount of the powers of all harmonic components to the power of the fundamental frequency.in this work the measured value of current THD taken for two case study balance and unbalance load condition as shown in figure(10) and (11)

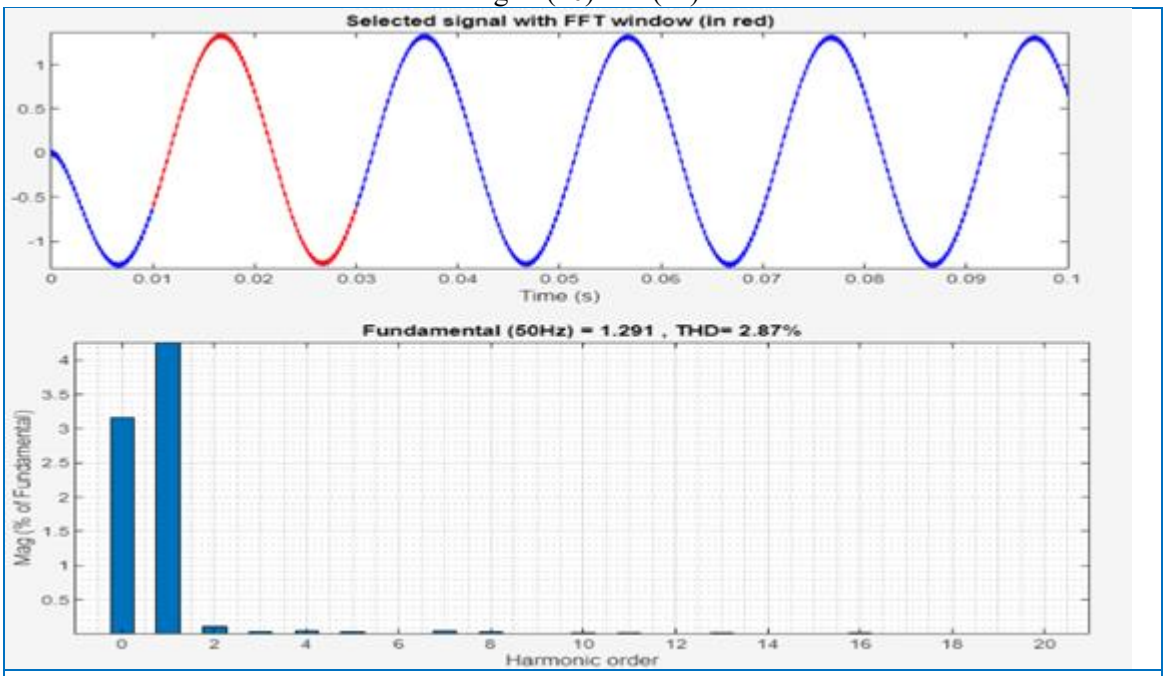


Fig. 10 Current waveform and THD value for current in phase a at balance load condition (200Ω, 200mH)

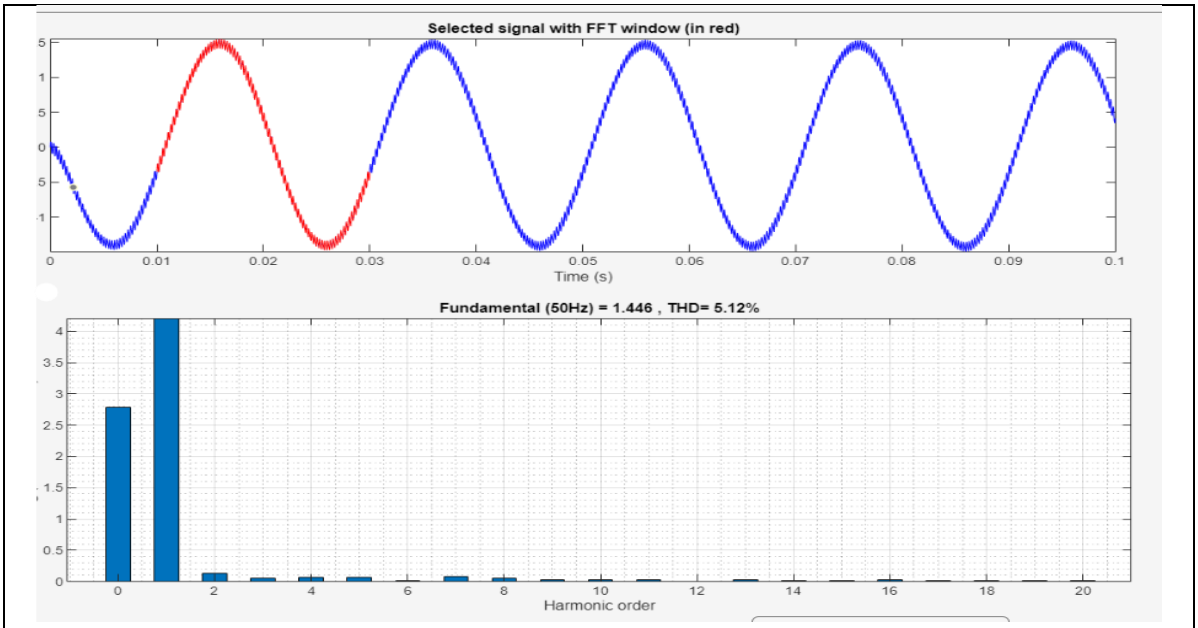


Fig. 11 Current waveform and THD value for current in phase a at unbalance load (25,200,100Ω,200mH)

7.THD effect on circuit efficiency

Figure (12) explain the impact of load changes on the relation between (THD) and efficiency of circuit. the figure demonstrate that raise load resistance leads to small change of THD in circuit which in turn results in a reduction in system efficiency.

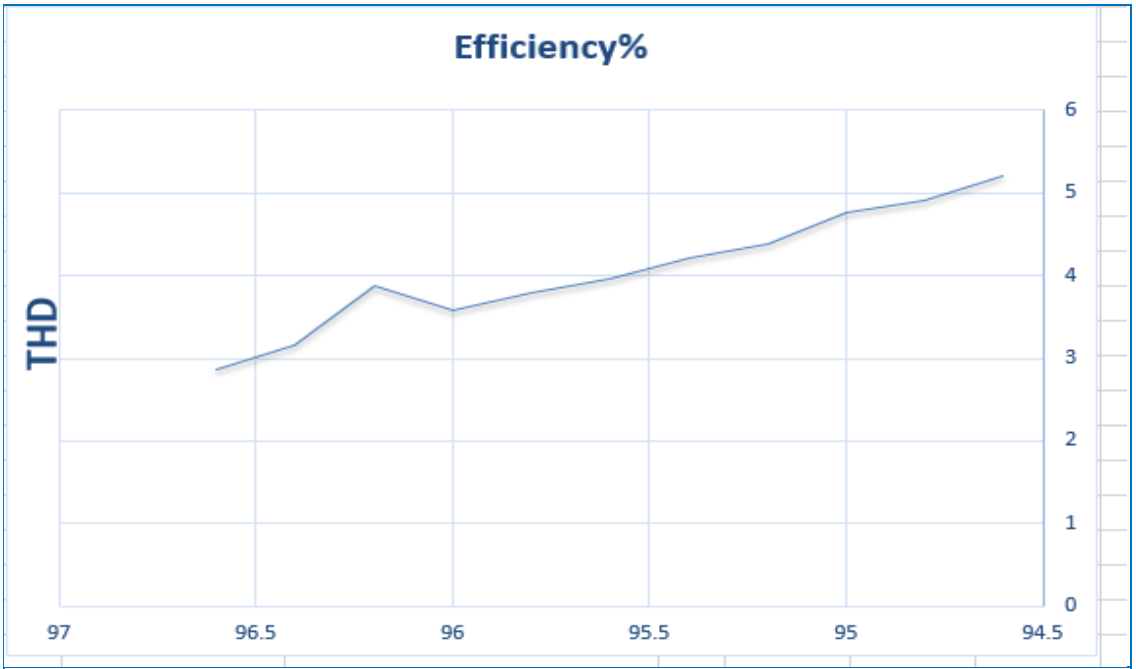


Fig. 12 Load change effect on relation between (THD – Efficiency)

8. Discussion

When the load on a 4-switch, 3-phase inverter changes, the Total Harmonic Distortion (THD) and efficiency of the system change slightly. However, the voltage and current waveforms display noticeable variation. This can be attributed to the following causes:

*The FSTPI usages a lesser number of switches compared to the conventional 6-switch inverter
*Different loads have varying impedance and power factor characteristics
*The efficiency of the inverter is affected by the switching losses and conduction losses

9. Conclusions

The examine of the four-switch three-phase inverter (FSTPI) under unbalanced loading conditions showed that differences in load impedances offered just a slight raise in total harmonic distortion (THD), that did not meaningfully disturb voltage or current waveform feature, so remaining closely fixed efficiency. This highlights the importance of balanced loading to reduce distortion and enhances performance, while unconventional control approaches can additional advance stability reliability as well as efficiency of inverter under loading leading FSTPI appropriate for engineering power conversion requests. Though, under real-world environments, many of limitations necessity be considered: unbalanced loads may lead to unbalance DC-link capacitor. Where imbalanced discharge leads to voltage oscillations and slanted output waveforms, and directly raise total harmonics distortion creating torque ripple in motor drives. The other limitation of this circuit is that the switches suffer from raising temperature due to Lessing the switches count . Stress on switches also considered as one of the limitation of this ciruit for the same reason of count switched .Finally fault tolerance is the important point that affect on circuit operation , it is mean that a one switch or capacitor failure can cruelly harm operation associated to conventional topologies., control limitations associated to fix capacitor value and balancing in appropriate value to stabilize voltage under abnormal loads, The results of the drive studied validate that changing in load impedance affected slightly on THD, that marginally diturb the current and voltage waveform. Definitely, under limited variants of load values the THD was stately at 2.87 % and 5.21 % Also, the study reveals an inverse relationship between THD and efficiency: when THD increased to 5.21%, the efficiency decreased to 94.6%, whereas at a lower THD value of 2.87% efficiency improved to 96.6%. Under unbalanced load conditions, the inverter exhibited only a slight increase in distortion of the AC current, while efficiency remained nearly constant compared to balanced operation

Acknowledgements
The researcher would like to thank and express the deepest gratitude grateful to every one help us to achieve this work

Parameter Values of model :

Vdc= 650 volt , output frequency = 50 Hz , switching frequency = 4 KHz
load : R= 100 ohm , L=200 mH ,

Author Contributions: The authors contributed to all parts of the current study.
Funding: This study received no external funding.
Conflicts of Interest: The authors declare no conflict of interest

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