REVIEW AND SIMULATION OF UPS SYSTEM USING FLYWHEEL WITH THD ANALYSIS

[1]Rutul Patel, [2]Pushpak B. Patel
[1] PG Scholar, [2] Assistant Professor
[1] Electrical Department,
[1]LDRP-ITR, Gandhinagar, India

Abstract : In the current historiography the picture of consistent is that the uninterrupted as well as quality power supply. Flywheel energy storage has become one of the attractions in the field of uninterruptable power supplies. Nowadays static UPS systems are preferred for low-power applications, although rotary UPS systems offer some interesting advantages. A rotary UPS uses the inertia of a high-mass spinning flywheel (flywheel energy storage) to provide short-term ride-through the time of power loss. The flywheel also act as a buffer against power spikes and sags, since such short-term power events are not able to appreciably affect the rotational speed of the high-mass flywheel. UPS batteries are sized to provide backup power for periods measured in minutes. The period ranges from about 5 minutes up to around 1 hour, but is commonly about 15 minutes. A period of 15 minutes, more or less, is generally presumed adequate to allow an orderly shutdown of equipment. Flywheels, on the other hand, provide backup power for periods measured in seconds. The backup period for flywheels is commonly about 15 seconds. However, a flywheel alone will not provide backup power for a period long enough to allow an orderly process shutdown in most cases. In such critical conditions use of generator comes into context where a D.G set can entirely provide and can run orderly process plant for at least 12 hours of operation and after some breathing time it can be operated again, time which is sufficient for SEB power to restore. However due to technological advancements and according to some literatures battery backups are said to have a reliable and better option so we need to simulate UPS system with both flywheel as well as battery backup and their impact on power quality.

I. INTRODUCTION

Energy usage and consumption in the world today is considered to be a growing problem. This problem is caused by a combination of human population growth currently at 6.7 billion (2008) is the technological advances of society demanding more energy to improve quality of life. With increased energy demand, engineers of the world are finding innovative, new methods to create and deliver energy. The challenge is to generate and distribute that energy in ways which will not negatively impact the environment. One of the largest means of energy generation and distribution today is via electricity. Electricity is easily generated from a number of sources, most of which involve turning an electric generator to produce power. Chemical means such as batteries provide a stored source of electricity. Both of these methods generally rely on non-renewable sources for electricity generation. In the United States electricity is generated in a variety of methods such as coal at 49%, natural gas at 20%, nuclear at 19%, petroleum at 2%, and renewable at 10%.

Power sources such as chemical batteries will eventually wear out and can potentially damage the environment. Moreover, the first 90% of electrical energy producers listed above are not considered long term sustainable sources. There are many long-term but not commonly used sustainable/renewable sources for both high and low power applications. These sustainable sources could eventually replace their fossil fuel and chemical counterparts for electricity production. The drawback to renewable sources is that they are subject to random environmental factors such as sunlight being blocked from solar arrays or intermittent wind conditions at wind turbine farms. Satellites orbiting the earth are powered from solar panels and encounter an extended period of time in the Earth's shadow where they need stored energy to operate. As a result of their low capacity factors renewable are not considered reliable enough to guarantee power delivery to the grid at all times .To help renewable play a larger role in the world electrical needs, given these kinds of operating conditions, better intermittent and long term energy storage methods are needed. Both large and small scale electrical energy storage is limited by technological, environmental or economic drawbacks.

Small scale energy storage options such as batteries often contain heavy metals which can damage the environment while large scale options such as superconducting magnetic energy storage have high material cost and refrigeration energy requirements.

Small scale energy storage is most easily achieved with batteries. Large scale energy storage methods can range from electrochemical such as in batteries, to chemical such as hydrogen, to mechanical such as in flywheels, to thermal such as molten salt. One of the oldest of these energy storage methods is the flywheel.

1.1 LAYOUT DIAGRAM AND ANALYSIS OF DYNAMIC UPS WITH FLYWHEEL

A flywheel is a simple speed drive increases system efficiency form of mechanical (kinetic) energy and allows the use of a smaller motor storage. Energy is stored by causing a disk or rotor to spin on its axis. Energy is proportional to the flywheel's mass and the square of its rotational speed. In order to develop loss less magnetic bearing for long time and high speed application new magnetic bearing is proposed which uses Lorentz force for bearing force calculation. Therefore Stator-coil is constructed by four air core coil segments and the stator holder while flywheel-rotor is constructed by two outer permanent magnets two inner permanent magnets back yoke and housing. However, coils are fixed to base as a stator. The kinetic energy stored in a flywheel is proportional to the mass and to the square of its rotational speed according to Eq. $E_K = 1/2\ I\omega^2$

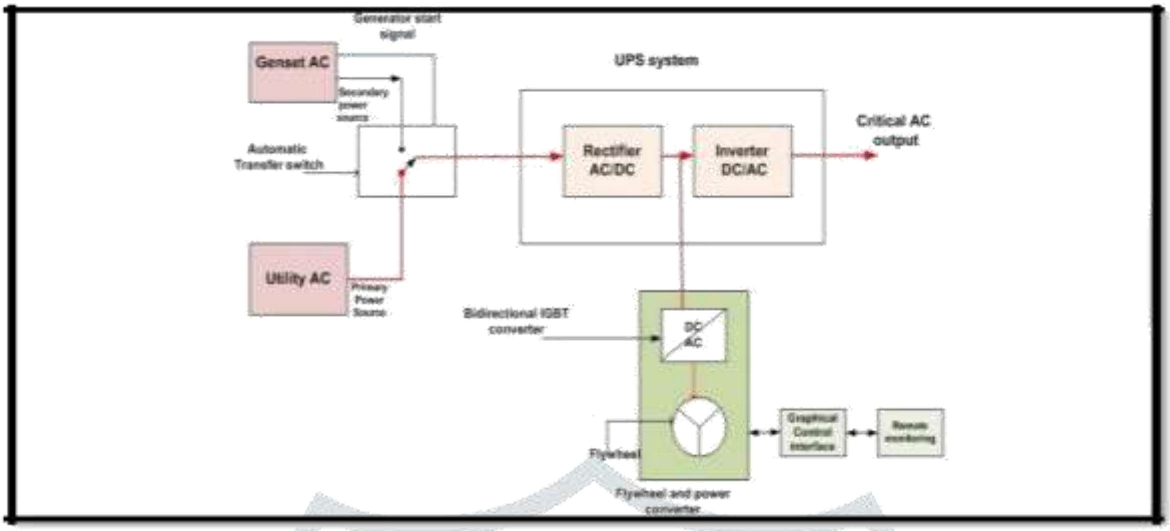

Fig.1 Layout of flywheel system

II. Literature Review in the field of UPS and Flywheel system

Power quality solutions for critical loads have to satisfy some specific needs such as reliability, cost, environmental impact and power conditioning capability. A correct trade-off between these depends on each specific application. The most typical solution for the supply of critical loads is by means of a double conversion UPS that takes the backup energy from batteries.

G. Zanei, et al. [1] shows how new technologies already successful in other applications (such as flywheel energy storage systems and fuel cells) can become a useful alternative to existing power quality solutions for critical loads. In particular, the focus is on flywheels as a partial or complete replacement for batteries as a backup power in UPS.

Chen Junling, et al. [2] proposed the flywheel itself is a very old technology that allows energy to be stored mechanically in the form of a rotating mass. Indeed, the flywheel has been used in the power quality industry for the last few decades in rotary UPS and as a replacement for batteries, with heavy and slow rotating masses supported by ceramic bearings.

Hansjoachim Dolezal [3] gives new technologically advanced materials and magnetic bearings are making a wider field of application possible thanks to the higher rotational speeds which can be achieved, and hence, lower weight, increased efficiency and higher energy density.

Christopher A. Haller and Gregory M. Hand [4] proposed an increasing number of high-grade technical consumer groups require nowadays an uninterrupted power supply. These are consumer of electric power such as large-scale computer systems for data processing, computer-controlled centers for the supervision of traffic in cities and on rail road's as well as airport runway lighting systems, mention only a few.

Ian F Bitterlin et al. [5] in this paper will focus on the empirical results derived from the use of a new fully levitated flywheel, using magnetic bearings, with a core rotating mass that uses aerospace grade high strength steel providing 140kW of power for 15 seconds.

Kerry Mclallin et al. [6] gives an industrial plant with sensitive production lines will depend on an uninterrupted supply of electric power. The question is why additional systems are actually necessary to safeguard an uninterrupted power supply.

III. Flywheel Dynamic UPS System

The consideration flywheel Dynamic UPS System is illustrated in fig. 3.4 schematically, it consists of:-

- An isolating choke (of high inductance value) between the supply side and the load side.
- A synchronous machine connected on the load side of the above choke through a MV/LV transformer, depending on the system, a small coupling inductance may also be connected in series on the feeder between the connections point of the synchronous machine and the load side.
- A kinetic energy storage system, this may be a flywheel, or a special a synchronous machine with a very heavy rotor or whatever type of system able to store kinetic energy and to restitute whenever needed.

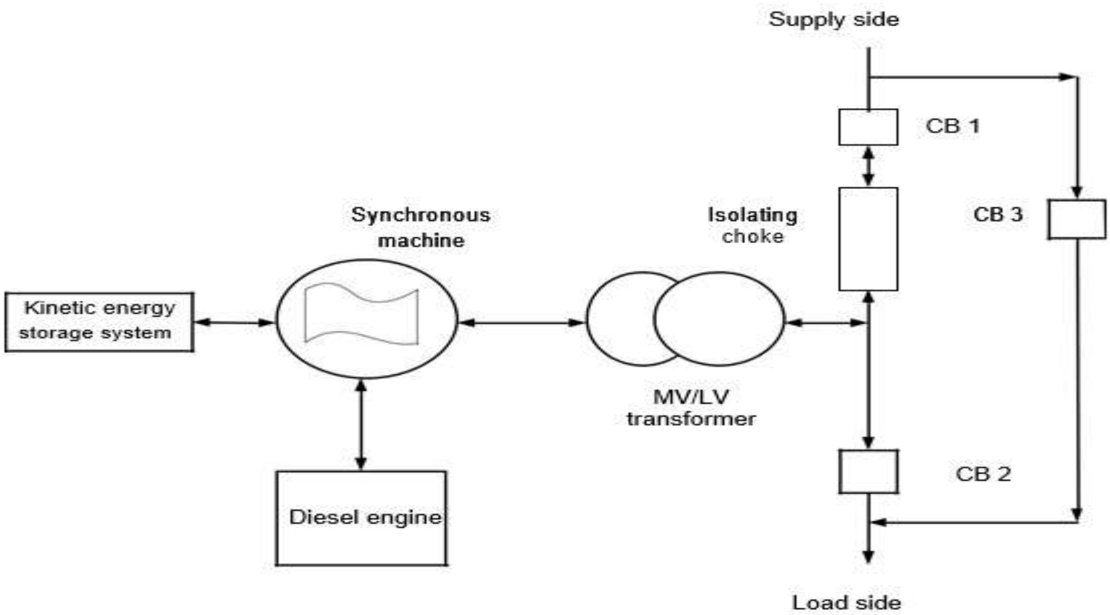

Fig. 2 Flywheel Dynamic UPS System

- Finally a diesel engine that provides the required mechanical power in the case of long duration power cut or any detecting fault condition, power is provided to the load.

In fig. 2 normal operating condition, circuit breaker CB1 and CB2 are closed and CB3 is open. The power supply is provided by the HV network through the HV/LV substation and the isolating chock. In case of disturbance on the supply side (limited voltage dips or very short power cuts), the voltage and frequency on a HQ feeder are regulated by the dynamic flywheel UPS system. When severe voltage dips or power cut occur on the supply side, CV1 opens.

UPS system is disconnected from the main network and operates in islanded condition on its HQ feeder. For the first few second, the mechanical power is supplied to the UPS synchronous machine by the kinetic energy storage system.

Depending upon the configuration chosen by the manufacturer, the diesel engine is then started and progressively pickup the load. A part of produced power is used to reconstitute the kinetic energy reserve. After the disturbance has disappeared, the UPS system synchronizes itself with the supply side and then reconnects to the main network (CB1 closes).

3.1 Uninterruptible Power Supply (UPS)

Systems provide uninterrupted, reliable, and high-quality power for vital loads. They, in fact, protect sensitive loads against power outages as well as overvoltage and under voltage conditions. UPS systems also suppress line transients and harmonic disturbances. Applications of UPS systems include medical facilities, life support systems, data storage and computer systems, emergency equipment, telecommunications, industrial processing, and on-line management systems. Generally, an ideal UPS should be able to deliver uninterrupted power while simultaneously providing the necessary power conditioning for the particular power application. Therefore, an ideal UPS should have the following features.

- Regulated sinusoidal output voltage with low total harmonic distortion.
- (THD) independent of the changes in the input voltage or in the load, linear or nonlinear, balanced or unbalanced.
- Low THD sinusoidal input current and unity power factor.
- High reliability.
- Bypass as a redundant source of power in the case of internal failure.
- High efficiency.
- Low electromagnetic interference (EMI) and acoustic noise.
- Electric isolation of the battery, output, and input.
- Low maintenance.
- Low cost, weight, and size

The advances in power electronics during the past three decades have resulted in a great variety of new topologies and control strategies for UPS systems.

3.2 FLYWHEEL BASICS

Flywheels have been used for a long time as mechanical energy storage devices. The earliest form of a flywheel is a potter's wheel that uses stored energy to aid in shaping earthen vessels. The wheel is a disc made of wood, stone or clay. It rests on a fixed pivot and can be rotated around its centre. The energy stored in a potter's flywheel is about 500J, which is by no means negligible. The main disadvantages are friction and material integrity. Most of energy is lost in overcoming frictional losses.

Flywheels is store energy in the form of kinetic energy. The amount of energy 'E' stored in a flywheel varies linearly with moment of inertia 'I' and with the square of the angular velocity 'ω'.

$$E = \frac{1}{2}\, I.w^2 \quad \textbf{(1)}$$

The moment of inertia is a physical quantity, which depends on the mass and shape of the flywheel. It is defined as the integral of the square of the distance 'x' from the axis of rotation to the differential mass 'd_{mx}'.

$$I = \int x^2 d_{mz} \quad \textbf{(2)}$$

The solution for a cylindrical flywheel of mass 'm' and radius 'r' will be,

$$I = m.r^2 \quad \textbf{(3)}$$

AND

$$E = \frac{1}{2} m.r^2.w^2 \quad \textbf{(4)}$$

Since the energy stored is proportional to the square of angular velocity, increasing the angular speed increases stored energy more effectively than increasing mass. To increasing angular speeds results in increased frictional losses and hence thermal problems. With the help of magnetic bearing technology, the frictional losses due to bearings can be overcome, but at the expense of reliability.

Also the energy stored can be expressed in terms of peripheral velocity 'v', which is defined as the product of perpendicular distance from the axis of rotation and angular speed as,

$$E = \frac{1}{2}\, m.v^2 \quad \textbf{(5)}$$

The tensile strength, σ, of the material limits the peripheral velocity, and hence the amount of energy stored. For a mass density 'ρ', the tensile strength is defined as,

$$\sigma = \rho.v^2 \quad \textbf{(6)}$$

Energy density is a term generally used to characterize an energy storage system. Usually high energy density is preferred, but this can pose thermal problems. Energy density, Em, is loosely defined for a flywheel as the ratio of energy stored to its mass.

$$E_m = \frac{1}{2} r^2.w^2 \quad \textbf{(7)}$$

The volume energy density, Ev, is obtained by substituting m in the stored energy equation, as the product of volume and the mass density.

$$E_v = \frac{1}{2} \rho.r^2.w^2 \quad \textbf{(8)}$$

Therefore, if the dimensions are fixed, the maximum energy stored per volume '$\mathbf{E_{vmax}}$' depends on the tensile strength of the material as,

$$E_{vmax} = \frac{1}{2}\sigma_{max} \quad \textbf{(9)}$$

Where σ_{max} is the maximum tensile strength of the flywheel material

Similarly the maximum energy stored per mass '$\mathbf{E_{mmax}}$' is

$$E_{mmax} = \frac{1}{2\rho}\sigma_{max} \quad \textbf{(10)}$$

Therefore, the maximum energy storage capacity can be achieved by using a material with a low density and high tensile strength. Depending on the application, either volume energy density or mass energy density takes precedence during the design stage. For a transportation application, mass energy density is a major consideration, since mass is a limiting factor.

The energy density expressions above apply for a simple rim type flywheel. There are many designs for flywheels, and the general expression of maximum energy stored per mass is,

$$E_{mmax} = \frac{k}{\rho}\sigma_{max} \quad \textbf{(11)}$$

3.3 MODELLING AND SIMULATION OF UPS SYSTEM

The UPS System used in our project is mainly used for Voltage control for flywheel system. So the UPS system is integrated with boost converter as shown in fig5.1 below. The input is given 24 v a.c single phase supply and then it convert into d.c using Rectifier and then boost up using boost converter and then fed to inverter for d.c to a.c conversion.

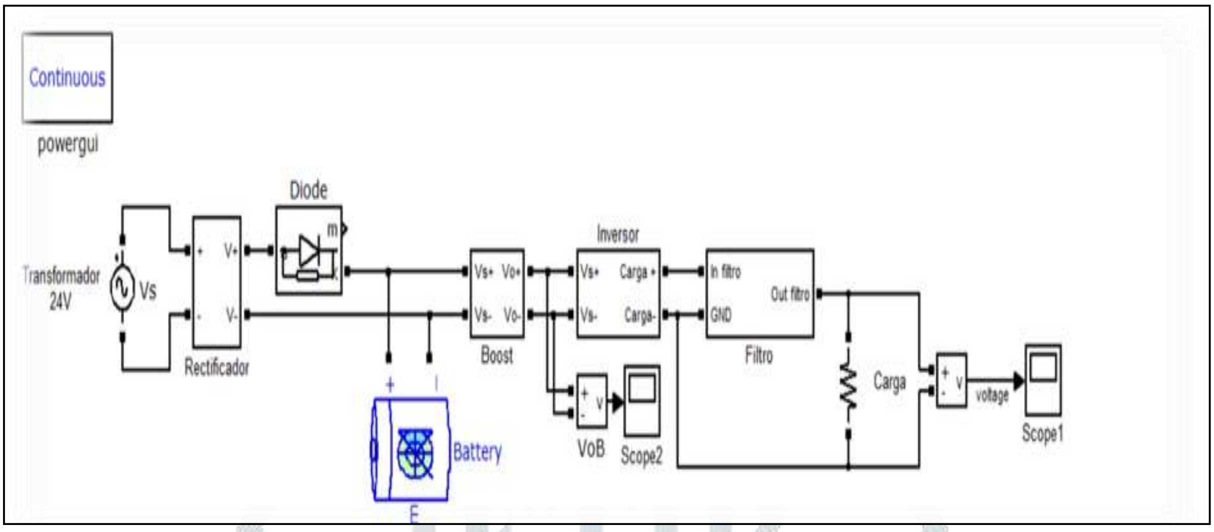

Fig 3.1 - Basic UPS System

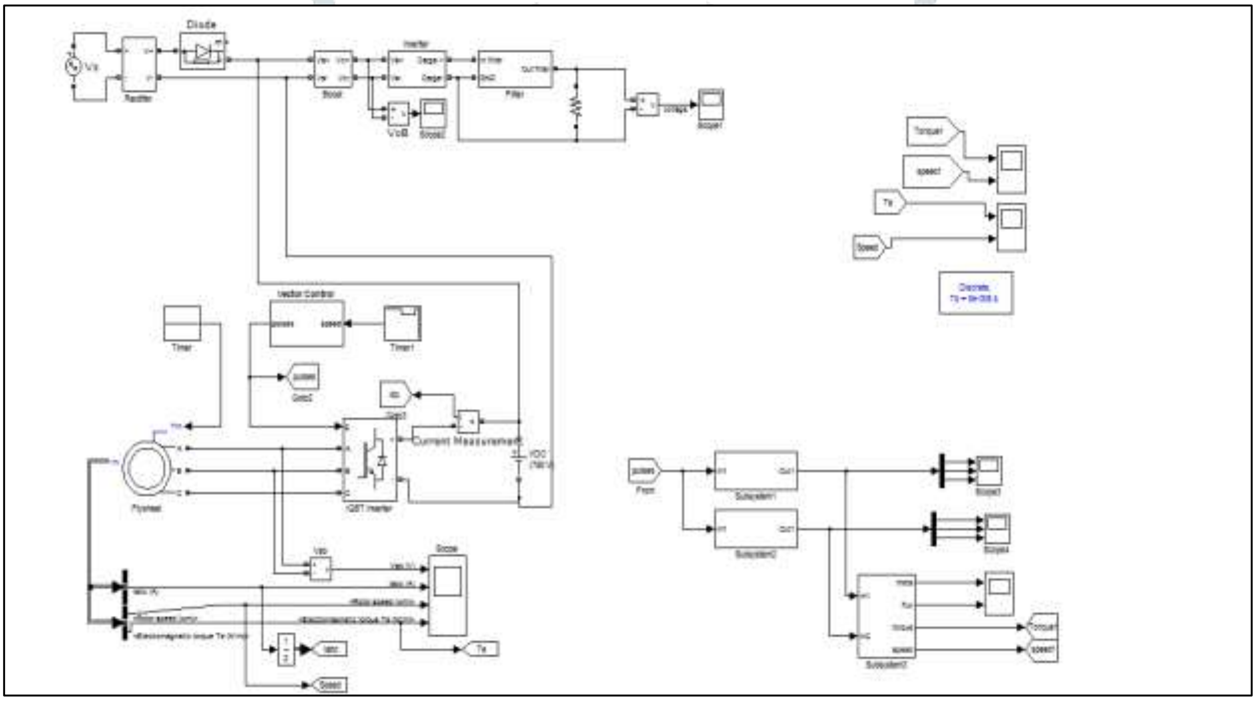

Fig 3.2- Flywheel with UPS System

IV. SIMULATION AND RESULTS

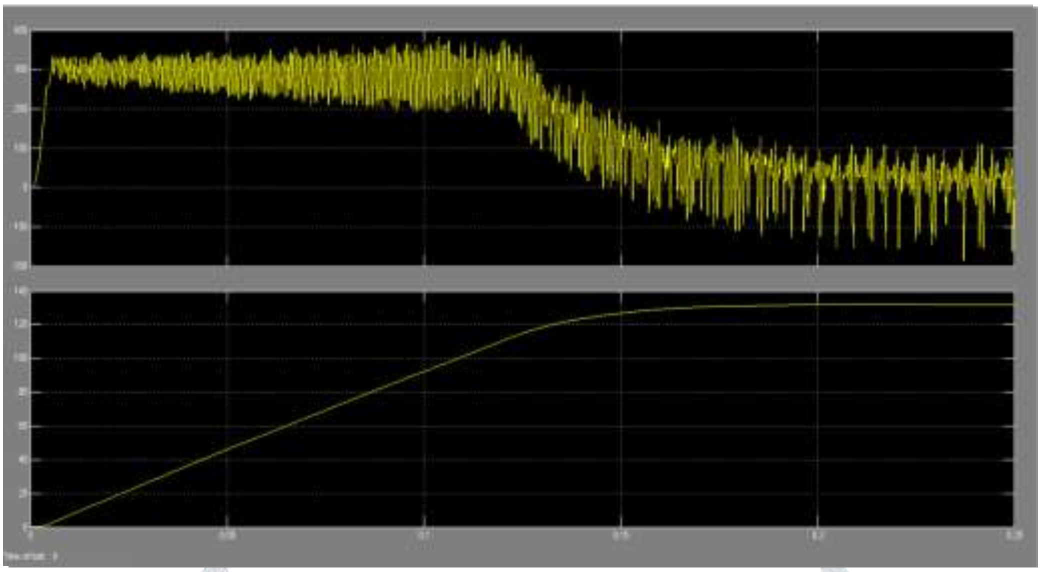

Fig 4.1- Torque and speed of FLWHEEL

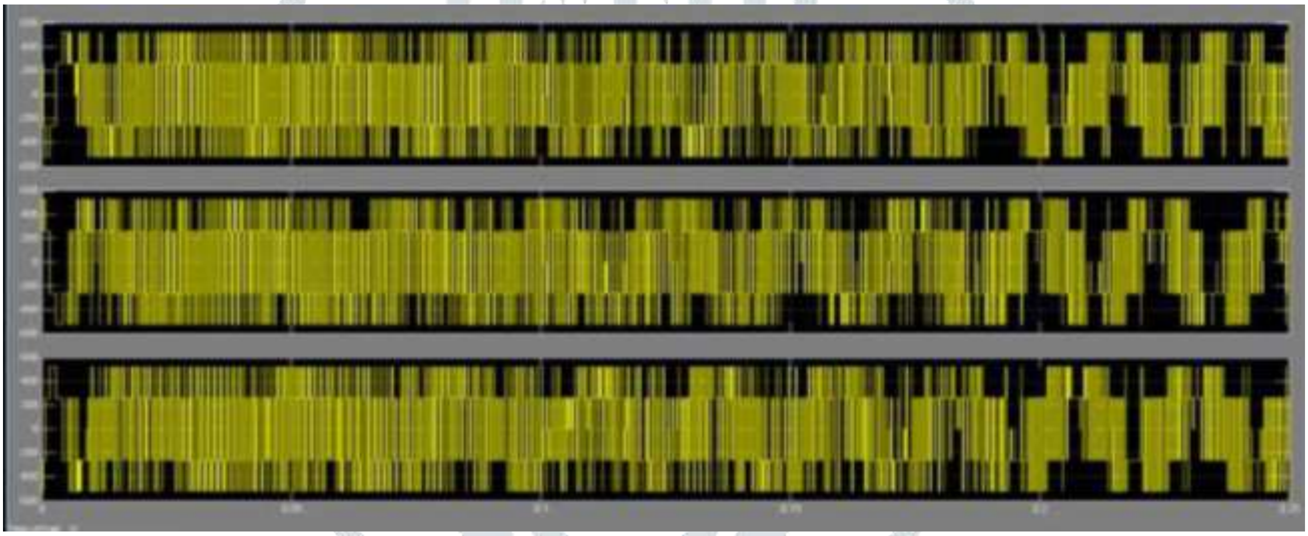

Fig 4.2. - Gate Pulses

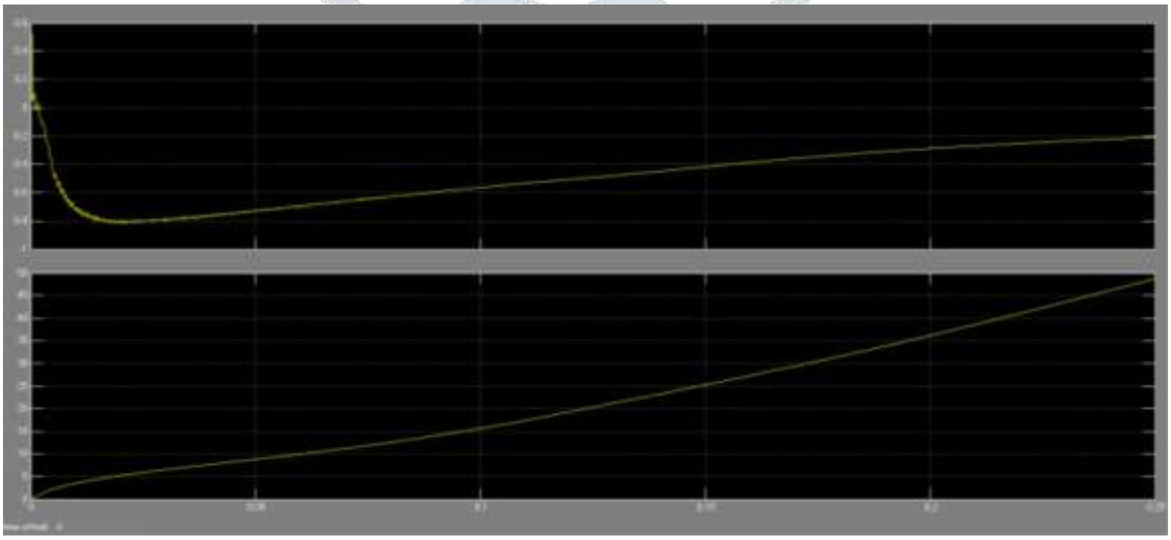

Fig 4.3- Flux angle and Variation

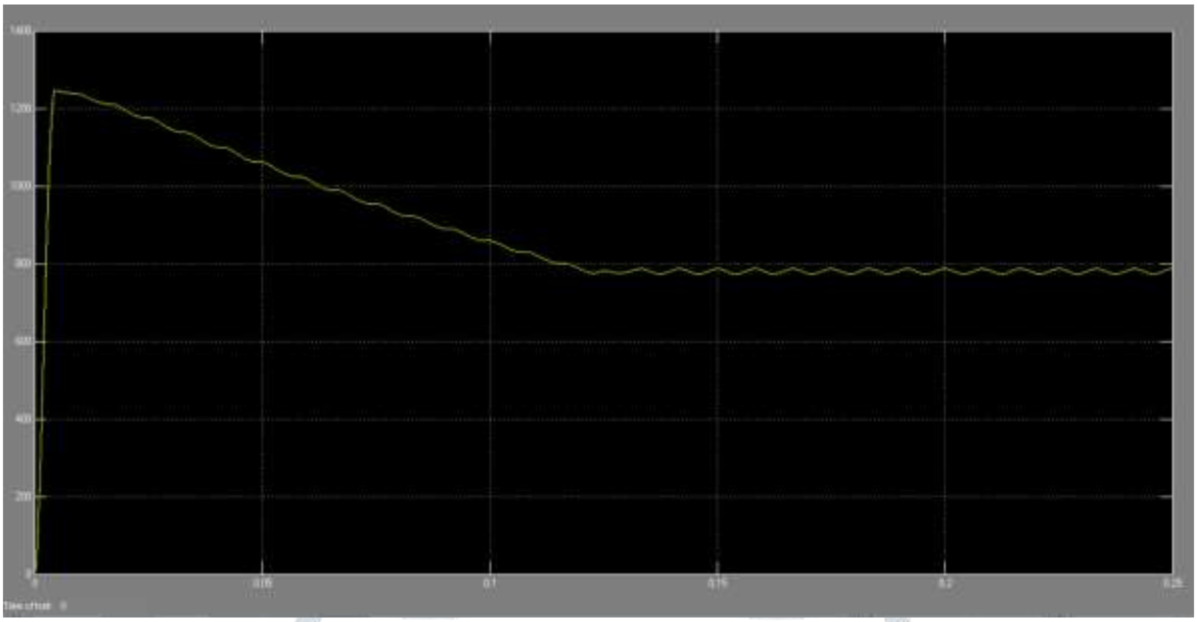

Fig 4.4- Boost Voltage

Output Parameters

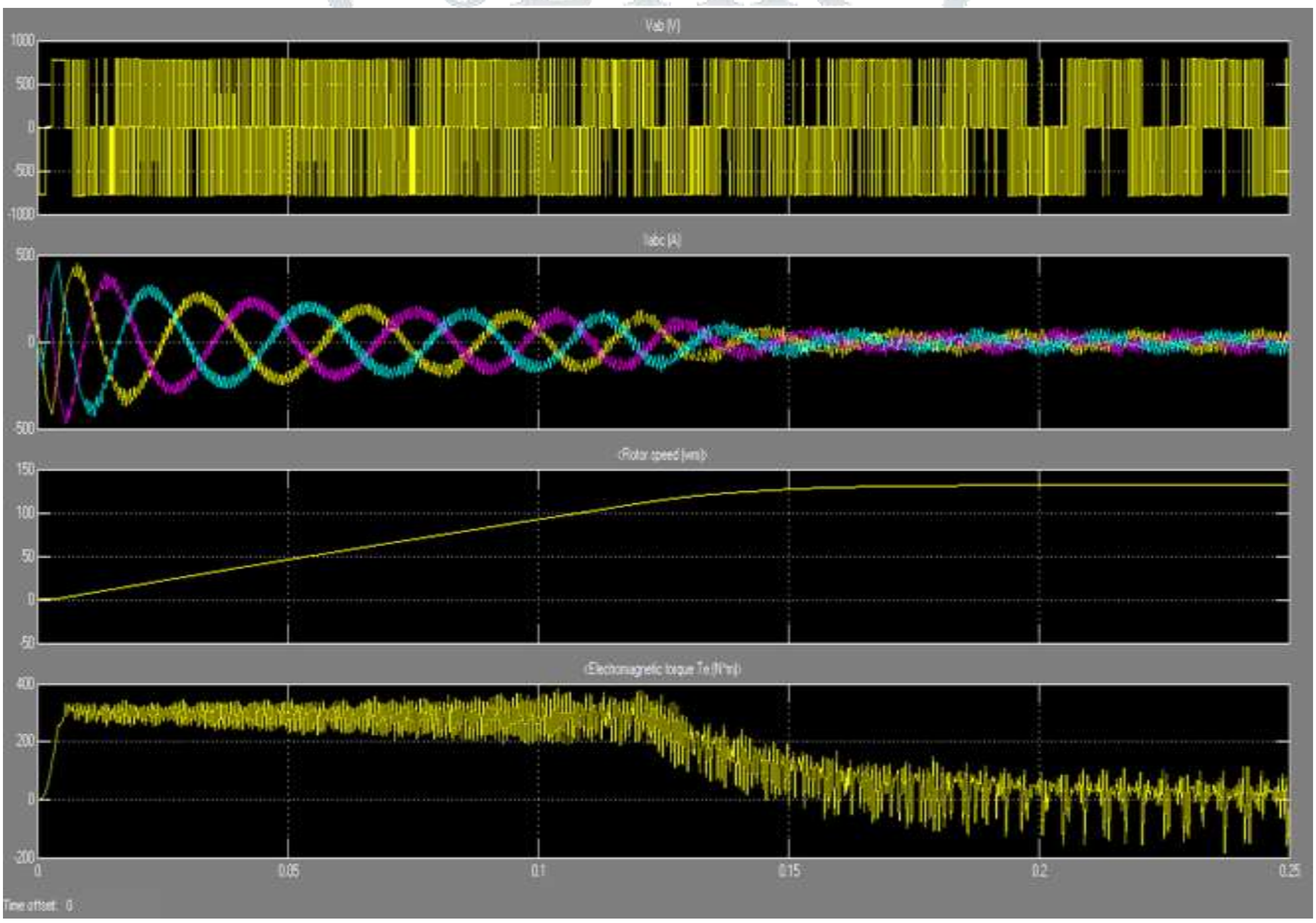

Fig 4.5- Flywheel Output Parameters

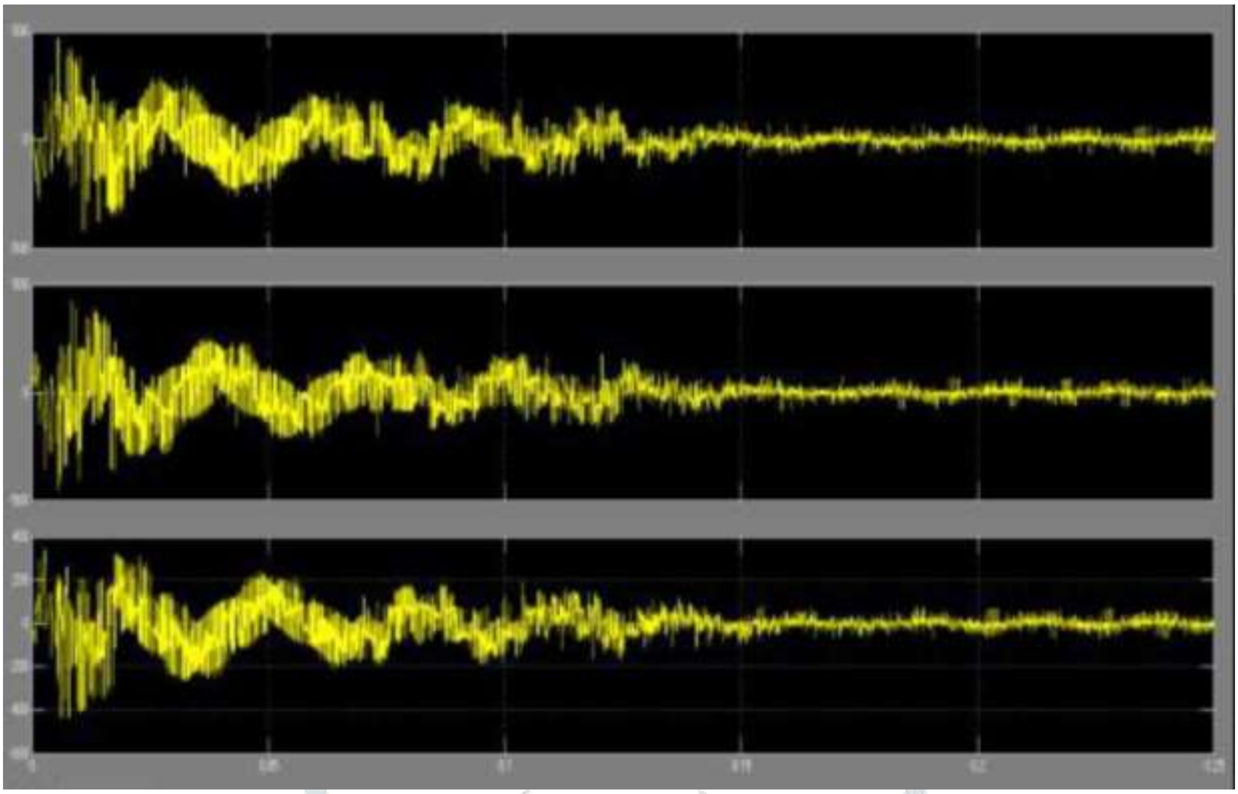

Fig 4.6- Output control Pulses

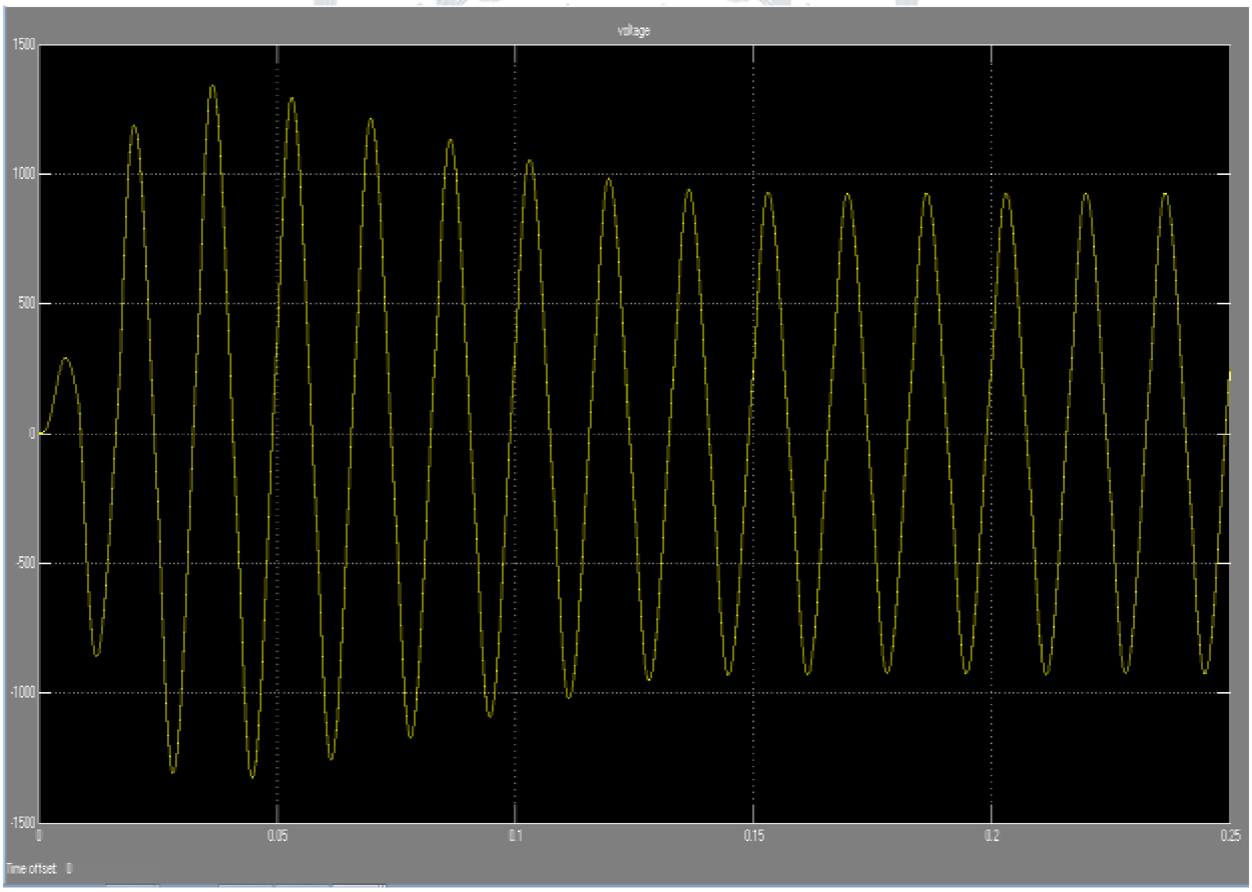

Fig 4.7- Stable Output Voltages

4.1 Design Simulation and Analysis of Dynamic UPS with Diesel Engine & Flywheel

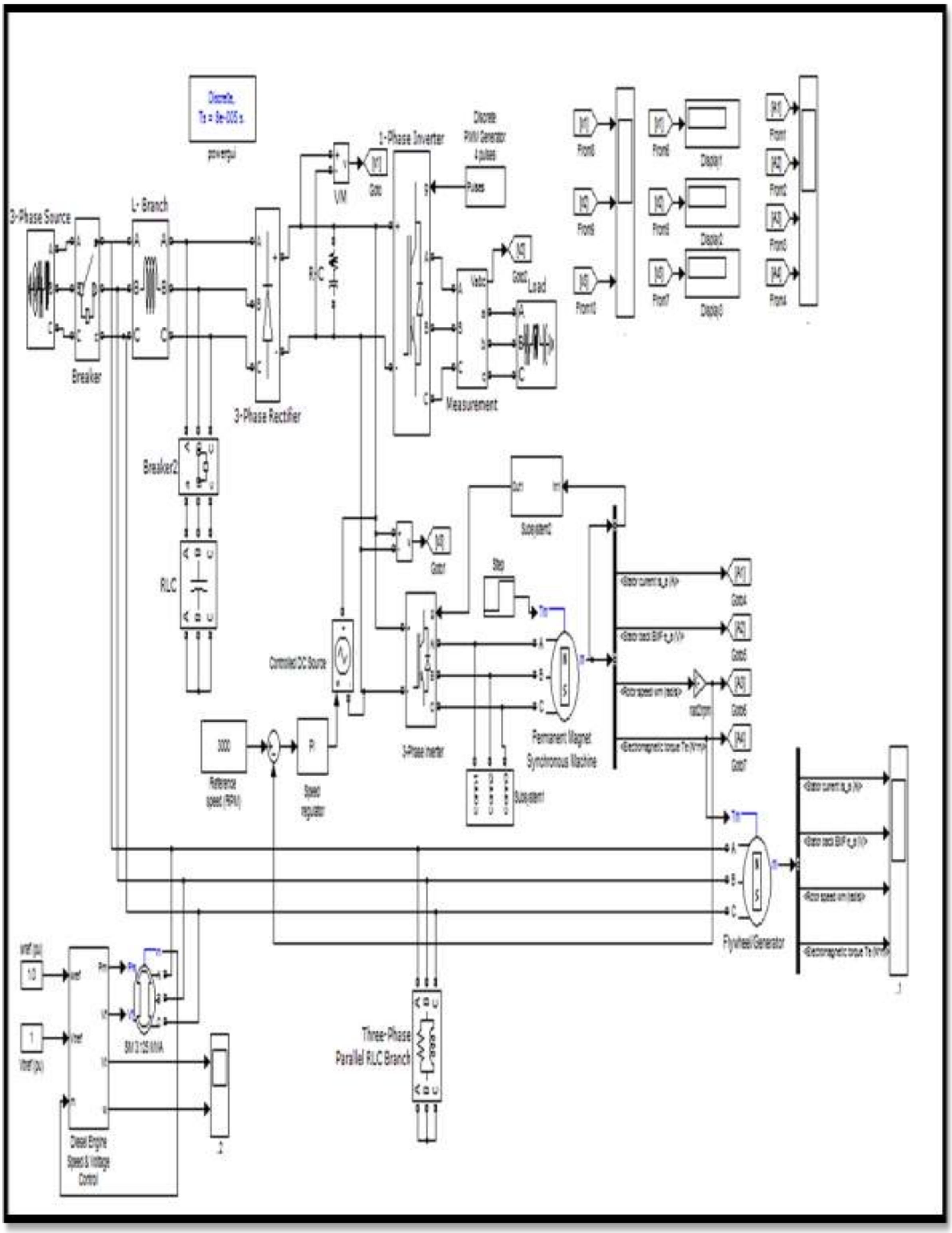

Fig.4.8 –Dynamic UPS with Diesel Engine

4.2 The Output of the PMSM and Flywheel

In those waveforms diagram have been given the stator current, stator emf, rotor speed and electromagnetic torque at Steady state.

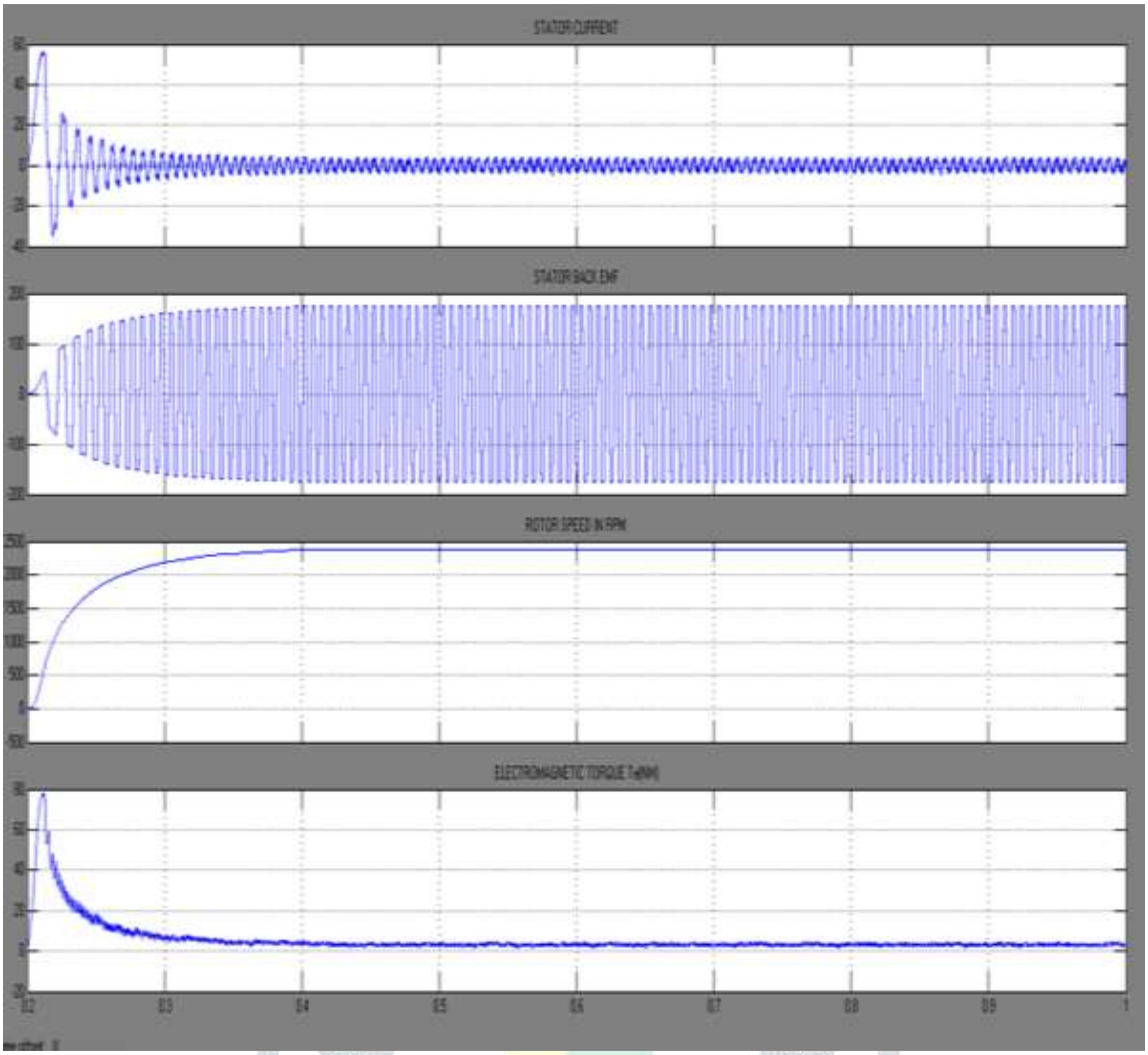

Fig: 4.9 - Output of PMSM Stator Current, Stator Back EMF, Rotor Speed and Te

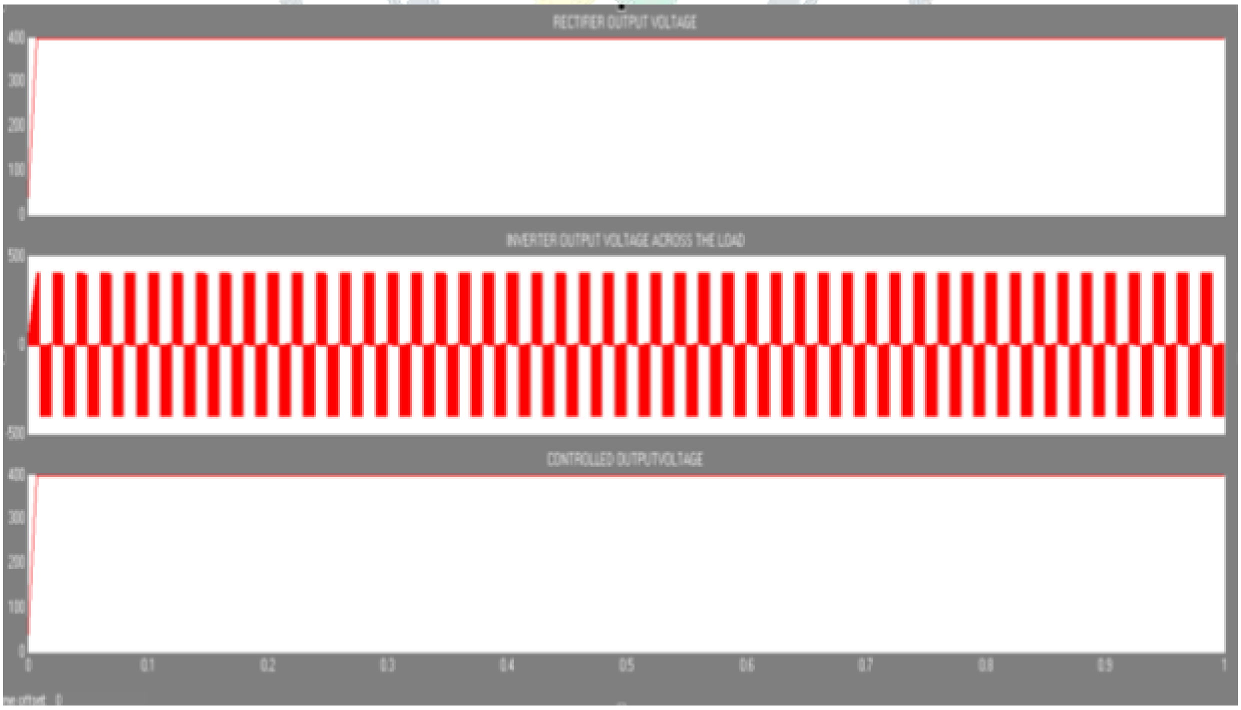

Fig 4.10 - Output Parameter of Rectifier controlled voltage and Inverter

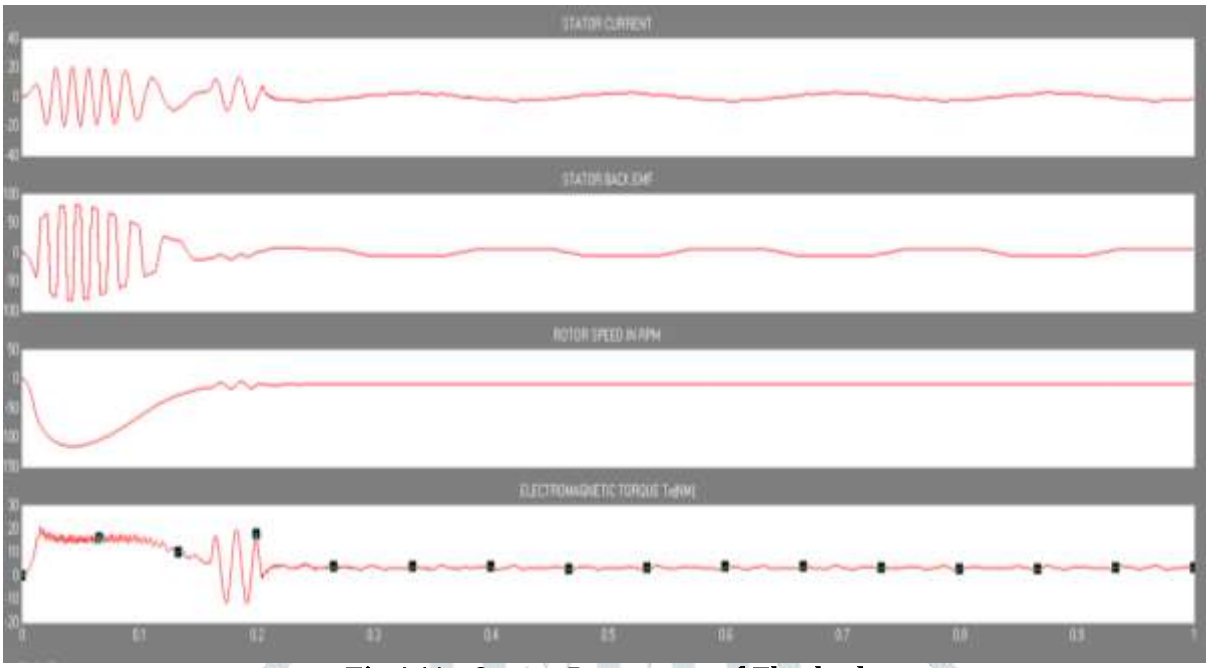

Fig 4.11 - Output Parameters of Flywheel

4.3 DYNAMIC CONDITION OF UPS AND FLYWHEEL

Due to Fault (Short Circuit, Surging, Power Quality Issue) the circuit breaker get trip than supply feed by flywheel and Diesel shed. Dynamic UPS with Diesel Engine & Flywheel is able to provide the supply is continuing to the load.

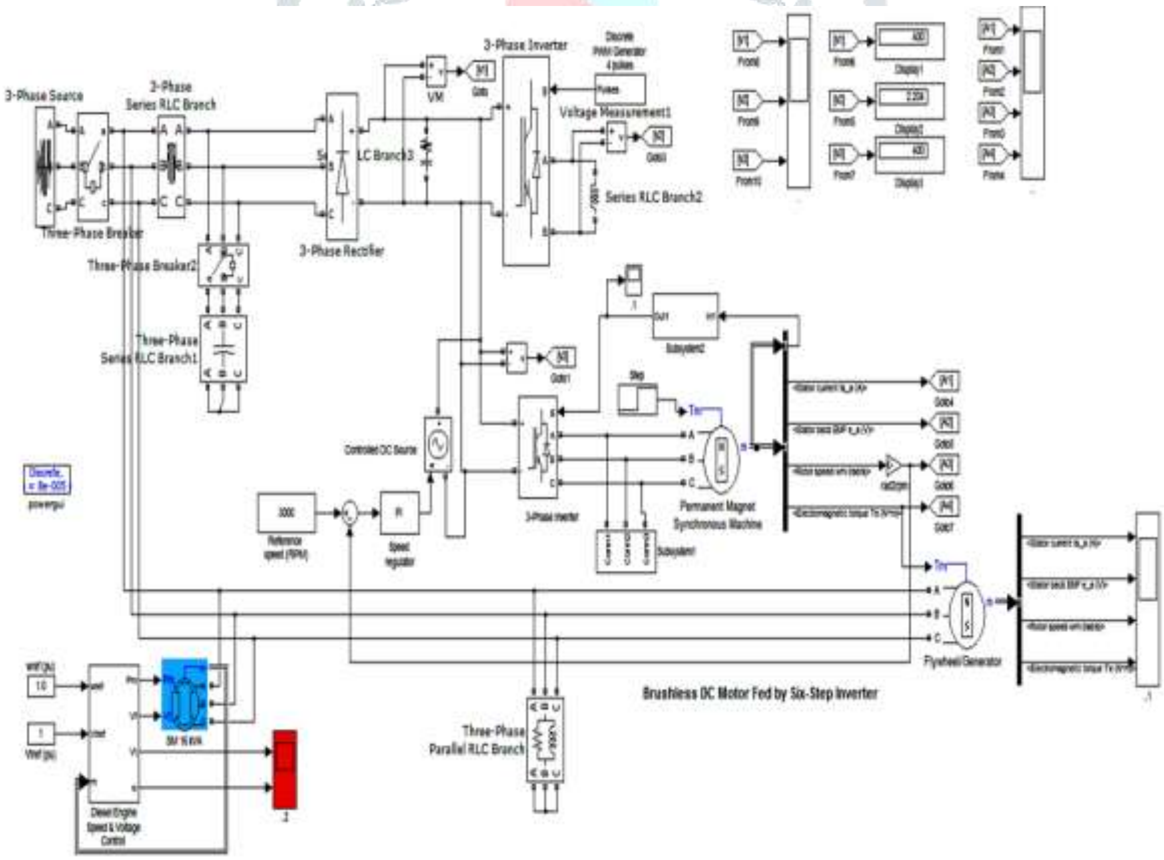

Fig 4.12 - MATLAB simulation of Dynamic UPS

4.4 OUTPUT OF THE PMSM

Stator current, Stator EMF, Rotor Speed and electromagnetic Torque. The Steady state output of the PSMM in fault condition (In MATLAB it is created by ground fault block).

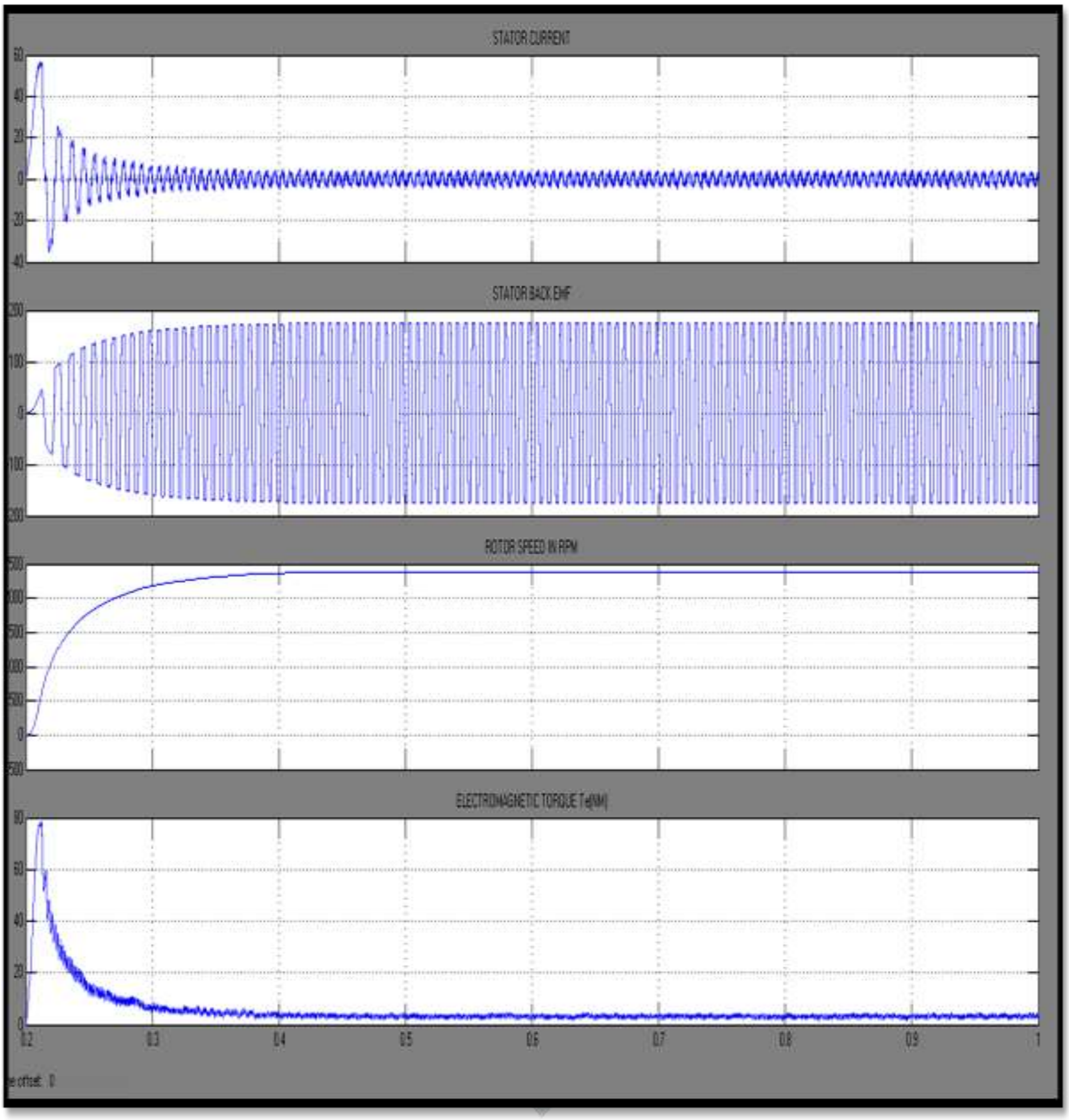

Fig. 4.13 - Output of the PMSM (Stator current, Stator EMF, Rotor Speed and Te.

4.5 OUTPUTS OF THE 3-PHASE INVERTER:-

In this pictorial view of different waveform has been given the reference voltage, output voltage waveform of load and control voltage output waveform of the inverter.

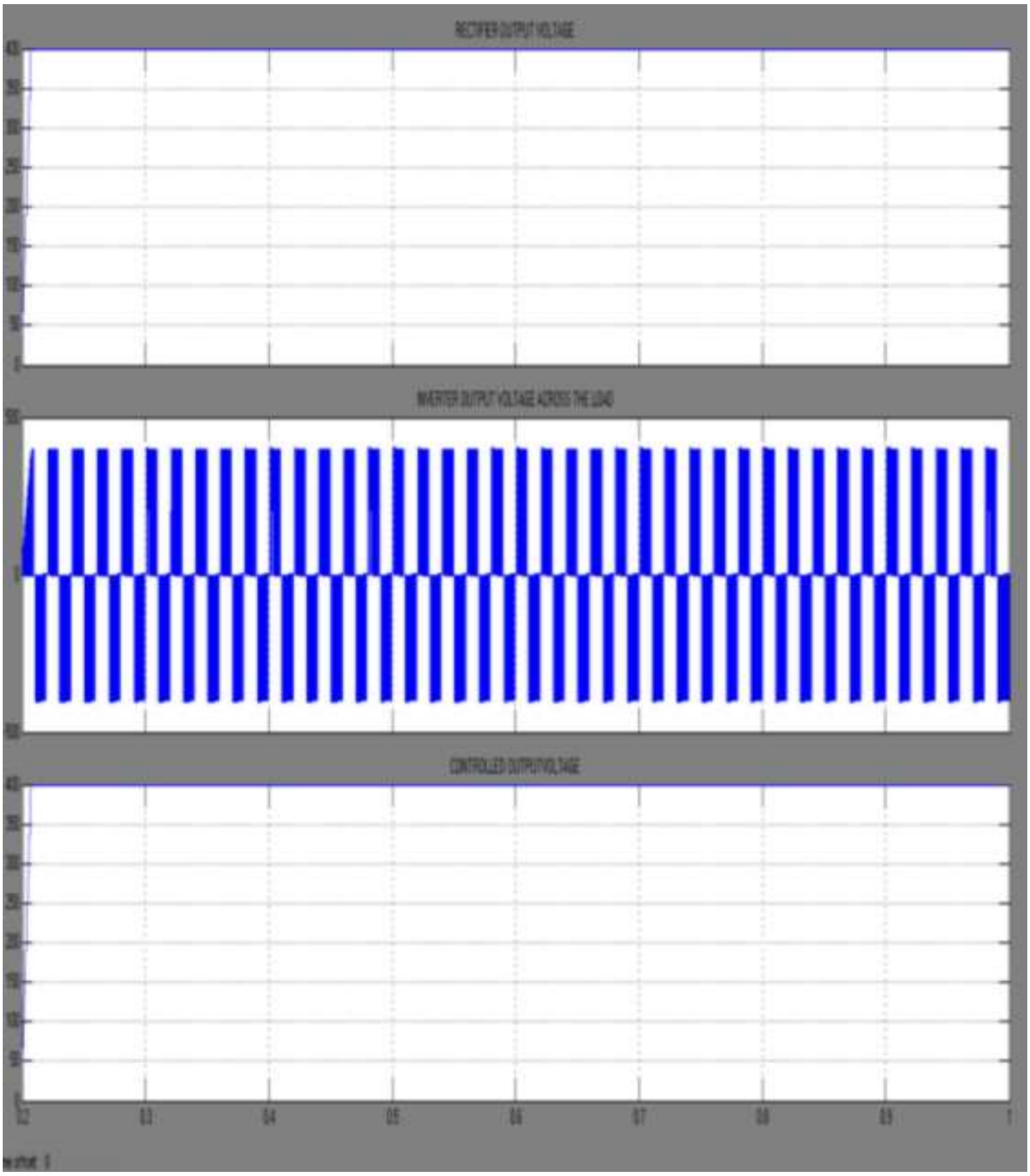

Fig. 5.6 Output waveform of the 3-phase Inverter

Table 4.1 - Comparison between Normal condition and abnormal condition

Se. No.	NORMAL CONDITION		ABNORMAL CONDITION
1.	The Output of the PMSM		The Output of the PMSM
	Stator Current	AFTER 0.3 S is steady state	AFTER 0.4 S is steady state
	Stator Back EMF	AFTER 0.4 S is steady state	AFTER 0.4 S is steady state
	Rotor Speed Rpm	AFTER 0.4 S is steady state	AFTER 0.4 S is steady state
	Electromagnetic Torque	AFTER 0.4 S is steady state	AFTER 0.4 S is steady state
2.	FFT Analysis of Stator current AND Percentage THD		
	Fundamental (50hz)	19.90%	33%
	THD	39.90%	17.14
3.	FFT Analysis of Stator Back EMF AND Percentage THD		
	Fundamental (50hz)	42.06%	15.59%
	THD	76.38%	17.14%
4.	FFT Analysis of Rotor Speed(Rad/s) Percentage THD		
	Fundamental (50hz)	44.03%	32.00%
	THD	60.63%	67.27%
5.	FFT Analysis of Electromagnetic tourque(NM) And Percentage THD		
	Fundamental (50hz)	30.33%	12.72%
	THD	38.14%	52.35%
6.	Output of 3-phase inverter		
	Rectifier Output Voltage	After 0.2 s is steady state	After 0.2 s is steady state
	Inverter Output Voltage	After 0.2 s is steady state	After 0.2 s is steady state
	Controlled Output Voltage	After 0.2 s is steady state	After 0.2 s is steady state
7.	FFT Analysis of Inverter output voltage across the load And Percentage THD		
	Fundamental (50hz)	29.30%	29.20
	THD	58.30%	38.30
8.	Output of Flywheel/Generator		
	Stator Current	it is varying +25 to -25 to continue	it is varying +25 to -25 to continue
	Stator Back Emf	After 0.4 S is stead state	After 0.6 S is stead state
	Rotor Speed Rpm	After 0.7 S is stead state	After 0.9 S is stead state
	Electromagnetic Torque	it is varying +25 to -25 to continue	it is varying +25 to -25 to continue
9.	FFT Analysis of Flywheel/Generator stator current And Percentage THD		
	Fundamental (50hz)	12.09%	33.00%
	THD	45.30%	41.48%

10.	FFT Analysis of Flywheel/Generator stator Back EMF And Percentage THD		
	Fundamental (50hz)	16.67%	15.59%
	THD	26.16%	17.14%
11.	FFT Analysis of Flywheel/Generator Rotor speed in RPM And Percentage THD		
	Fundamental (50hz)	33.60%	32.00%
	THD	62.60%	60.67%

CONCLUSION

In this paper, has been study based on the MATLAB simulation, analyzing the output result in Normal condition and abnormal condition (interruption of supply due to fault). In normal condition the our system is running in all aspect well, at the same time the electrical energy is saved in the form of magnetic field in (windings), due any fault the supply is disconnected, at this time the all inductive load are reversing the energy to the rectifier or UPS. Therefore inductive load working as a flywheel for little time than diesel engine provide the supply to drive the load. Therefore the comparison normal and abnormal condition is having the all most similar result.

As in case of normal condition stator current tends to steady state at a very less time as in comparison to abnormal condition. If we do FFT analysis of stator current then in normal condition the fundamental is very less and in abnormal condition it is to high. FFT analysis of rotor speed in fundamental is good enough to accelerate as in abnormal condition it is about 15.59% which is very less. Output of the 3 phase inverter in rectifier output voltage is same as of normal condition and also in abnormal condition. Output of the flywheel generator after as stator current is varying between a particular limit ib both abnormal and abnormal condition and stator back emf in normal condition is less and more in abnormal condition and rotor speed is also less and more in abnormal condition.

V. ACKNOWLEDGMENT

Words are not always enough to reveal one's deep regards. A complete interpretation of this work is can never be the outcome of single person efforts. This is very thankful opportunity to express my profound sense of gratitude and respect to all those who helped me through the duration of this thesis. First of all I would like to thank the supreme power who has always lead me to walk on right way without his grace this would never come to be real.

This work would not have been possible without the encouragement and able guidance of my guide **PROF. PUSHPAK B. PATEL**. Their enthusiasm and optimism made this experience rewarding.I would like to express my deep sense of gratitude towards HOD who has been a constant source of inspiration for me throughout this work. I would also like thank all the faculty members of the department and my friends who directly or indirectly helped me in completion of my thesis.No words of thanks are enough for my respected parents and dear friends whose support and care makes me stay on earth. Thanks to be with me.

REFERENCES

Papers

[1] G. Zanei, E. Cevenini, H. Ruff and O. Ulibas "Integrated Systems for UPS: New Solutions in the Power Quality Chain". Telecommunications energy conference,2007, pp. 582-586

[2] Chen Junling, Jiang Xinjian, Zhu Dongqi and Wei Haigang "A Novel Uninterruptible Power Supply using Flywheel Energy Storage Unit", IEEE. Power electronics and motion control conference, 2004., vol. 3, pp no. 1180-1184.

[3] Hansjoachim Dolezal "UPS Dynamic Rotary Systems with Flywheel and Diesel Engine" CH2477-8/87/000-0187 $01 .00 © 1987 IEEE. Telecommunications energy conference, 1987,pp 187-192.

[4] Christopher A. Haller and Gregory M. Hand "Dynamic Energy Management using Flywheel Energy Storage Systems: Design & Applications" Fall 2008 – ECE 530 Contemporary Energy Applications, Dynamic Energy Management with Flywheel Storage Systems,2008, pp 105-111.

[5] Ian F Bitterlin, Active Power "Flywheel energy storage - an alternative to UPS batteries," A 2001 study by the Electric Power Research Institute (EPRI) found that electric power problems, US2009, pp 123-128.

[6] Kerry Mclallin "NASA Flywheel System Development," Space Power Workshop.2001, 1-23.

[7] Bitterly J G "Flywheel Technology." Past Resent, and 21st Century Projects. IEEE Aerospace and Electronic Systems Magazine.1998, 13:pp. 13-16.

[8] Takahashi ,Y. Iton, and 1. Andoh " Development of A New Unintemptible Power Supply Using Flywheel Energy Storage Techniques," Conference Recoid of the 1989 IEEE IAS +a1 Meeting, San Diego, pp. 71 1-716. Bitterly J G, Flywheel

Technology:Past, Resent, and 21st Century Projects. IEEE Aerospace and Electronic Systems Magazine. 1998, 13:pp. 13-16.
[9] S.H. Wang, and D.Q Shu, Intelligent Control System and Application Beijing: China Machhe Press, 1999(in Chioese). 151 Shamim Choudhury, "implementing triple conversion single phase on-line UPS using TMS32K240," Texas Instruments, Application Report SPRA589A,Sept 1999. 161 TMS320LFnC240Xa DSP Controllers Reference Guide, Texas Inrt" ents, Application Repon SPRU357A, Sept 2001, pp 123-129.
[10] W.P. Turner, J.H. Seader, K.G.Brill “Tier Classification Define Site InfrastructurePerformance”, The Uptime Institute Tier Performance Standards White