

# A Study of Inverter Drives and Its Ride Through Capabilities in Industrial Applications

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**Abstract**—In modern industry, majority of the mechanical elements are driven by either induction motors or special motors like servo motors, synchronous motors, BLDC motors. In order to drive the motors and to vary the speed of the motors, electronics drives are required. Since the drives are powered with three phase AC, if the power grid has power quality issue, which directly reflects on to the power electronics drives. As per Indian grid standards, power quality is defined as harmonics, surge, sag, swell, which was formulated in the year of 2003 and further revision was done in 2010. But in the recent day's majority of the industries are constructed in same place (special economic zone), unpredicted industrial loads are increased and inserted in to existing running load, so eventually the power quality definition also changes and even sometimes connections are made as temporary for certain loads. Although these motors typically tolerate variations in utilization voltage, power quality professionals continue to spend a great deal of time answering questions about proper utilization voltage for a given motor. The voltage quality factors that create the most serious problems and confusion in the field include nominal utilization voltage that does not match the motor nameplate, proper voltage sag ride-through protection for the motor control circuitry, and phase-to-phase voltage imbalance. In review article, modern industry premises failure of components list and condition of power quality will be surveyed in various segments. Various failure of inverter drives namely, switching failure, commutation failure, common mode voltage problem, bearing current issues, harmonics etc., are discussed in details from various research article and presented in this review.

**Index Terms**—Power Quality, Industrial Drives, Inverter Drive Failures, VFD.

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## I. INTRODUCTION

With the invention of Tesla's AC machines, the Thomas Edison's counterfeit of the same become unpopular as it was in the post AC invention. Though it was the case, AC motor requires varying magnetic field or number of poles to be changed for their speed control in order to use for industrial applications. Even though AC machines gaining popularity, alteration of frequency remained undaunted task for particular speed control application in industrial process. Also, with respect to manufacturer side, the same has limited to produce the machine with two speed application design for consumers. By late 1980s, AC machine speed control drive technology has reached remarkable changes with cost effectiveness to compete with traditional DC technique. By taking over the AC speed control (Variable Frequency Drives VFD) the said action will be performed in more precisely and with high degree of accuracy. It can able to perform the control 0 r.p.m through full speed at rated torque of the machine, and if situations require super synchronous condition even at reduced torque. In these VFDs, the conventional CSI and VSI inverter get transformed into PWM VFDs due to its very good input PF, higher efficiencies, and lower cost. Although it is having numerous advantages over the drives, harmonics contents ejected from the same is of major concern with regard to VFD drives. Since the drive carried both rectifier and inverter, the two-step conversion leads to additional losses in the system.

Since the industrial processes are very diverse, the need of the same also differs accordingly as shown in Fig. 1. Every process demands required materials and energy to be outfitted to produce the desired task. Even this energy and materials may be processed by thermal, magnetic, electromagnetic, mechanical or even nuclear. During every process, the waste output in energy form is collected, the material process may also be controlled by VFDs. So, the process must be prepared to be well-defined shape and processed. Fig. 2 shows the potential possible level of speed control in industrial drives. In this figure, there are different components exists, energy, motor, transmission, and working machine. The energy, motor, and power together form the drive system and this systems performs the operation and send the energy to working machine for further load process. During these process, there will be one variable which needs to be confirmed so that the desired level of output may be obtained at the load as in Fig. 3. So, drive system, therefore, should ensure this variable must be given different methods of control to meet the desired output.

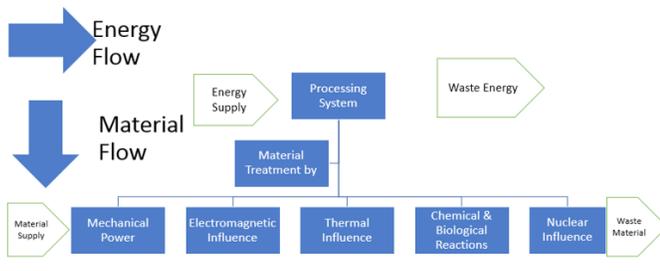


Fig. 1. Process involved in Industrial Drives.

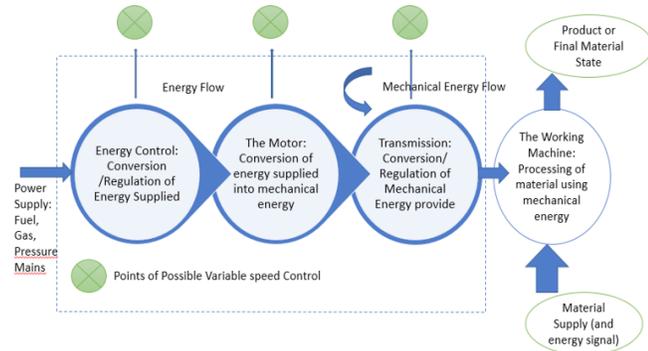


Fig. 2. Energy flow process of Industrial Drives.

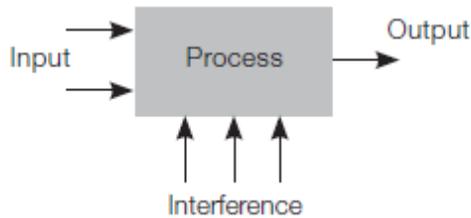


Fig. 3. Control of Variables in Industrial Drives.

## II. PERFORMANCE ANALYSIS OF INDUSTRIAL DRIVES

Being AC drives machines, inverter drives has become heart of the industry process over the years, in particular with regard to precise control of machine speed is of utmost care. Almost all the machines use variable frequency drives as their preferred choice of the same, and reason behind the choice is it delivers high efficiency with great energy saving, higher degree of accuracy in controlling the speed, also to have inbuilt protection of the drives. Of all other drives that are currently used, the power electronic drives play a vital role in industrial market since it has ease of operation at desired level of control without any ride through capability by the operator. The manufacturer is trying to develop the drives with greater ride through capabilities and find herculean task in doing so. Also, the Integrated Motor Drive (IMD) takes a giant leap in current scenario and it have very high advantage over conventional drives like reduce mass, volume, lower cost, improved manufacturability, and much on ride through capability [1]. Manufacturers are trying to put their R&D in both spacing saving as well as integrated drive concept for effectual use of drives in productivity chain. Toyota prius adopted hybrid powertrain electronics control in their design aspect so that fuel efficiency can be even better over

conventional types. Even now with greater advent of technology in electrical drives, there are key challenges still prevalent due to unhealthy power quality issues and they remain unattended. [2] The key challenges are power electrics cost reduction, to overcome thermal limit on drives, reliability.

## III. REVIEW OF ELECTRICAL DRIVES AND ITS RECENT SCENARIO

Sita Ram et al. [1] illustrated a in-depth review of slip power recovery drives, their performance analysis and control techniques employed for the same. Thomas M. Jahns et al. [2] gives the overall view of the past and present state of electrical drives available in the market and their state of art of technologies employed. Also, he draw attention to emphasize bottlenecks that has to be overcome and examine the the integrated motor drives feasibility and future scope of the same. This paper illustrated almost half century old drive system from past to future and their desideratum of electrical drives (IMD) in years to come to have better maneuverability and cross major technical problems that suppress the future growth of the same. Piotr Sobanski et al. [3] deals about the single and multiple power switch failures when fed with drive system with shorter period of time. In this paper, field oriented control (FOC) type of drive technology employed test cases are considered and fault has been analysed. With the fault detection technique, the diagnostic methods been simplified and the versatility of the drives system. Masoud Farhadi et al. [4] discusses about the mean time failure of the inverter drives used in industry. The components failure rate, switching losses employed in different control strategies in wind up the reliability in loss through switches. It gives out the key feature of reliable modulation technique that should be employed in drive system. Based on this work, rating of switch, PF and capacitor may be the key fault parameter in inverter drives applications.

Chunyi Gu et al. [5] emphasizes the commutation failure in industrial drives based on stress due to voltage and current and capacitor parameter. Also the effects due to these faults directly related to capital cost and power loss is been discussed. by adopting suitable control strategy, the commutation failure can be greatly reduced and good performance curves can be observed. Md. Habibull et al. [6] discussed about the cause and effects of inverter drive system due to different switching frequency over the wide range. In this paper, because of finite element analysis of the same, the speed control regime steady state and transient state performance has been improved, switching frequency, torque characteristics has seen improved performance. THD, ripples in flux and torque, load side disturbances, also has significant reduction by using average switching frequency by having more number of voltage vectors in drive system. Aurelien Prudhom et al. [7] underlined the inverter drive motor failure due t bearing current issues over the years. The drives used for industrial purpose is being of VFDs, it lead to common mode voltage in turn results in currents discharged in bearing of the driven motor. The damages caused due to bearing currents has been analysed

using time-frequency analysis and identified the potential problems and being monitored continuously to detect the same. Hadeed A. Sher et al. [8] coined the capacitor link failure in industrial drives because of open circuit condition and due to DC link failure or fault, the quality of the inverter is greatly affected. This literature underlines the ripple in frequency gives ride through capability during this fault scenarios. Mohamed Trabelsi et al. [9] literature gives the idea of open switch fault occurring in inverter and due to this effect, unfaulty switch gets changed because of freewheel diodes. By using of normalized values of inverter current from the output of the same, feedback has to be given and the potential problem may be eliminated. Gerard-Andre Capolino et al. [10] discussed elaborately about the diagnosis of recent advancements in electrical machines and its drive system under various fault condition. The failure identification in electrical machines due to bearing currents, short circuits, power interruption, inverter open circuit, power system fault etc are discussed for the mean cause of various issues in industrial drives. Based on the analysis, various novel techniques to deteriorating losses.

Seyed Kazem Hoseini et al. [11] discussed about the lowering of common mode voltage in AC drives and by doing so, the circulating currents in bearing of electrical machines reduced to greater extent there by saving the motor. It describes the various techniques been used and comparative model is prepared to sort out the best possible solution to the said problem in drives. By adopting the techniques, THD of the inverter drives also reduced to such an extent and efficiency of the drives is improved to next level. P. P. Rajeevan et al. [12] also sketch out the possible solution for common mode voltage due to inverter drives having single voltage source. Using multi level inverter topology, the said problem can be eliminated in the drive applications. Sang Bin Lee et al. [13] emphasizes the VFD system with condition monitoring capability which determines the quality assessment in offline over the unsafe inverter components. The offline quality assessment includes the DC link, connections, cable insulation, and rotor and stator parameter. It also pitched the rank based overhauling of machines to be made in precise manner. Pawan Garg et al. [14] discussed about the fault phase of the VFDs and its tolerance capability. This paper gives out the common mode distortion ratio of the inverter drives and isolating the same will results in mitigating the foresaid problem in drive system. Romero de Souza Araujo et al. [15] provides the persisting failures on bearings in inverter drives induction motor system. The potential problems are analysed by theoretical aspects and then the practical issues are considered and comparative study been made sort out the possible solution in inverter drive system. Romero de Souza Araujo et al. [16] in his continued research article, the author gives the solution for the previously literature article for the same problem as stated above. Because of leakage currents through the motor bearings the problem of motor being temporarily halted or even permanently. The proposed topology in this paper suggest to use the high frequency drives to eliminate the circulating currents in motor bearing thereby protecting the same from prior deterioration.

N. Bianchi et al. [17] literature possible strategies for inverter drive faults in synchronous motor systems. PMSM are used in wide range in industries and their reliability is very uncertain. To avoid the fault and to have the ride through capability, the defective inverter is being isolated electrically as a first prime task and made the inverter to obtain their necessary parameter from remaining phases till the faulty inverter is being restored. Tada Comedang et al. [18] discusses the typical PID controller for any feedback system having current control loop. Since the conventional current control operational amplifier is of not controllable electronically, the said can be controlled electronically by adding current mirror into the same using DT technology. From the authors claim, it is evident that, the use of proposed controller feedback mechanism will limit the maximum overshoot, quick rise time, fast settling time, and reduced steady state error in the system. So, by adopting these controller block in the feedback mechanism, the inverter drives can be made to precise the performance in well manner.

#### IV. POWER QUALITY ISSUES AND ITS POTENTIAL EFFECTS ON INDUSTRIAL DRIVES

From the literature above it is seen that, the major fault causing parameter for the industrial drives is due to unhealthy voltage, current, power factor, harmonics, transients. Because of all these issues either one form or combined together it leads to very adverse effects on drive system that in turn will have a slough drive motor performance. Based on the literature conclusion, to cross check the said problems, the power quality of electrical supply system is required for further analysis. So, in order to get the said power quality issues, the power quality analyzer is being used to capture the data of Indian grid supply quality and is figured out below. The power quality analyzer is kept for testing the same at one textile mills using industrial drives for their manufacturing process. Based on the data, Fig. 4 and Fig. 5 show the flicker on power instantaneous values and cumulative probability of the same. By inference this snapshot, it is understood that, the power instantaneous has experienced the flicker for significant duration of time period and the cumulative probability is between the ranges of 50% to 95%.

Fig 5. tells the line to line voltage disturbances over the 24 hours duration and it emphasizes, average RMS values of voltage per cycle. The orange shades indicate the value below 372.4 V and the average value is 412.4 V. Due to this fact, when the inverter drives runs continuously for stipulated duration of time, some sudden disturbances in any one parameter will lead to adverse effect on the inverter drives. Fig. 6 gives the cumulative probability of the line to line voltage. It shows only 50% the drives are getting rated voltage levels and remain 40%, the drives been supplied with voltage levels of 400 V. So, by inferring this data, the power quality is of major concern with regard to industrial drives.

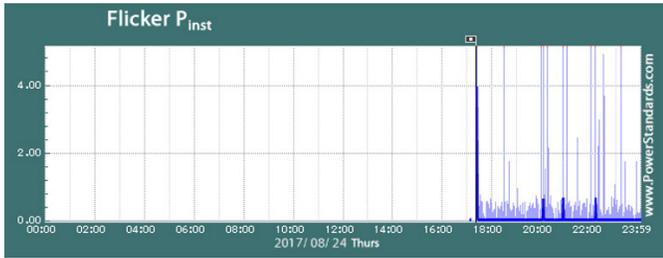


Fig. 4. Flicker on Industrial Drives.

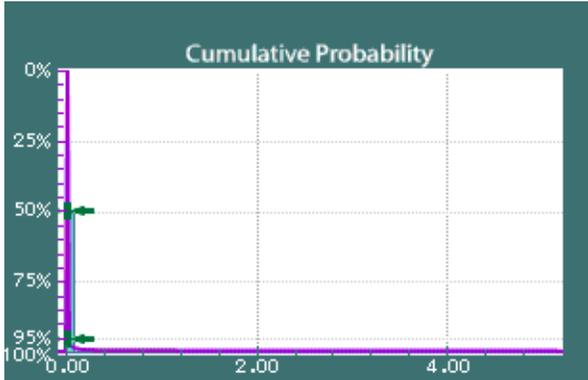


Fig. 5. Cumulative Flicker Probability of Industrial Drives.

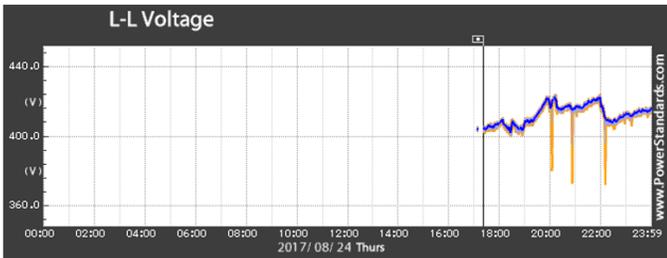


Fig. 6. Line - Line Voltage Disturbance Graph.

industrial grade motor drives, servo drives, compressor etc. are having state of art in this technology and experiencing the convenient of advanced technology. With the rapid developments of the same as it is finding applications in small size device to electric vehicles and even in most advanced strategic importance equipment's, the future of this drive is more prominent and it is of further performance, cost as well as compactness be improved and packed in single module to meet the customer requirement with wireless technology. In near future, the wideband gap semiconductor by using silicon carbide or gallium nitride. This technology is in nourishing stage, and after the development of the same, it may give equal significance to the conventional IMDs. This is due to the better operating characteristics in temperature, efficiency, and switching frequencies. Due to the wide band gap, the leakage current may be low and it results in increased temperature limit. The on-state resistance of the SiC or GaN is 3000 times comparatively less than the silicon devices, gives better thermal conductivity. Also, at the reduction of its mass and volume, the wideband gap devices provide higher switching frequencies at faster rate will tend to shift the application areas to its favor's [2].

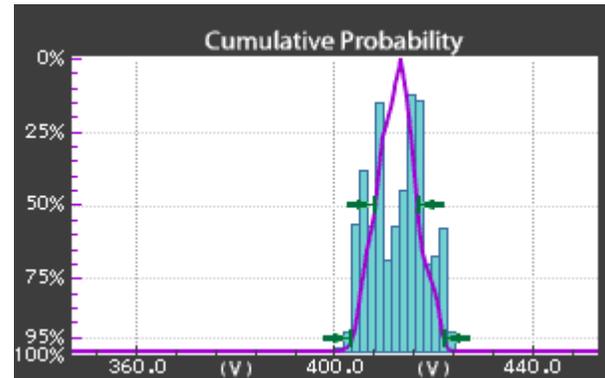


Fig. 7. Line - Line Voltage Disturbance Cumulative Graph.

Apart from this, the THD analysis also been collected to and it reveals, THD levels of voltage are within the permissible limits, but with regard to current is concerned, the levels are exceeding the determined values. Fig. 7 and Fig. 8 shows the THD of voltage and current parameter. The zero-sequence unbalance voltage parameter reached maximum of 999.90% and minimum of 0.80% and average range of 6.60% and the graph of the same is showed in Fig. 9. With that of the current values the ranges from 7.10% to 82.90% and the average values cloaked at 44.90%. THD of current levels are given in Table I. IEC zero sequence Voltage level data are given in Table II to cross check the values recorded vs. graph snapshot obtained from the power quality analyzer. The line to line voltage cycles counting for the particular period of time is been given for further reference in Fig. 11.

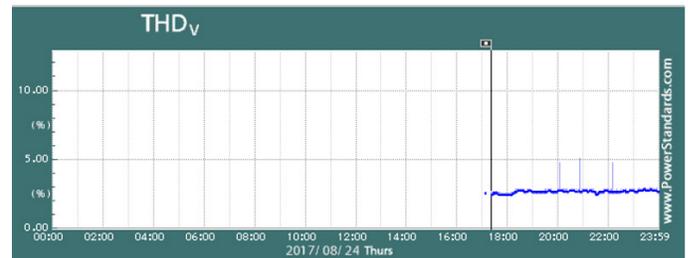


Fig. 7. THD level of Voltage.

#### V. INDUSTRIAL DRIVE TOPOLOGY AND ITS MITIGATING EFFECTS – A REVIEW

With the advent of IMD, almost most of the day to day application becomes very cost effective and convenient to operate at better performance. Automotive industry, fan, water pump,

TABLE I  
THD LEVEL – CURRENT PARAMETER IN %

TDD-A (%)	
Summary	
Median	3.25%
Mode	3.45%
Mean	3.20%
Range - min	-0.05%
Range - max	25.55%

TABLE II  
IEC ZERO SEQUENCE VOLTAGE (IN %)

IEC Zero Sequence Voltage	Percent of Duration
Coverage	28.06%
Uncovered	71.94%
UnderRange	0.00%
OverRange	6.06%

The importance of THD and zero sequence voltage is inferred from the Table I and II. Since the said parameter is unbalanced current flow in the faulty circuit, it adds up the fuel into the system. From the table it has been observed that, the zero sequence voltage and THD limits are getting over ranged during the loading times.

Since the table depicts zero sequence voltage and current majority in the uncovered region, the power quality problems prevails much higher than the normal scenarios in the incoming supply of the drive system. Piotr Sobanski et al. [3] elaborates the operation of induction motor drive, the open circuit fault diagnosis is being considered for the analysis purpose. This fault detection cinches the power failures in very minimal time span. In this paper, the author discusses power converter faults related to power devices and its circuit damages, since this account majority of the fault types almost about 60%. So, to diagnosis this frequent occurring fault, the voltage source inverter needs to be tested and bring it to foreseen picture. To do the fault diagnosis model, the author concentrated on voltage space vectors topology is being implemented. By based on the rotation of space vector against the motor direction, the space vectors are keeps on changed by its numbers as shown in Fig. 12. So, by going for direct torque control schemes with SV PWM technique, the fault diagnosis transistor also gets reduced and to narrow down the faulted transistor rule base is being implemented.

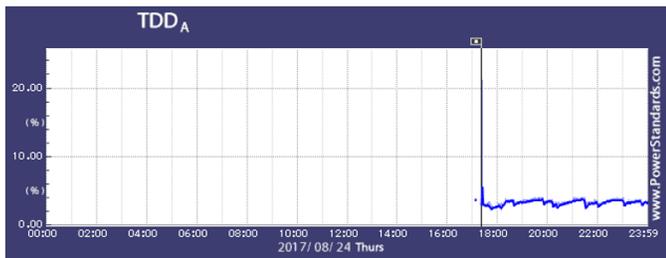


Fig. 8. THD Level of Current.

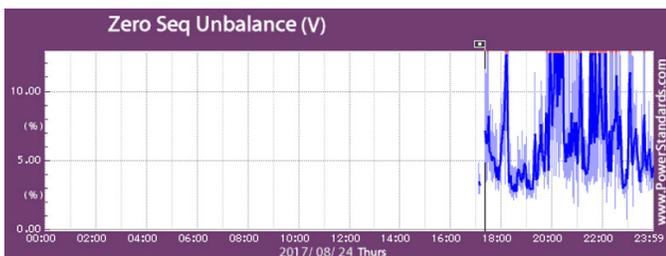


Fig. 9. Zero Sequence Unbalance Voltage.

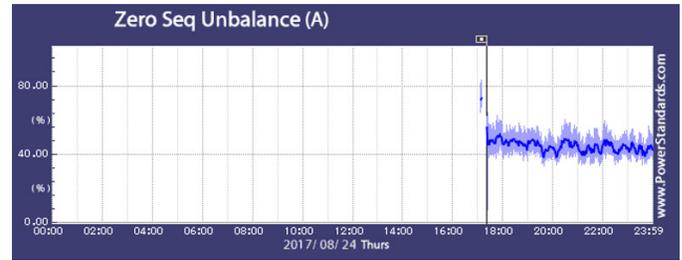


Fig. 10. Zero Sequence Unbalance Current.

In this paper [4], author described the general methodology for failure analysis and evaluation of the inverters configuration, their switching losses, rate of failure, temperature and their conduction losses and determined reliable control strategies. A three-phase three-level NPC inverter have been built for verifying the theoretical analysis and the experimental setup has been made and compared with simulation and results and author found out both simulation and experimental results are same. The author analysed the thermal image of the NPC topology converter configuration during their evaluation strategies. This article gives the comprehensive reliability analysis between the SPWM, THIPWM and SVPWM. NPC converter control strategy and their life time and based on the results obtained SVPWM becomes most feasible control strategy for Inverter drives configurations. This articles also confirms the power switches most assailable components and leads to loss distribution. Author [5] cites the commutation failure in inverter drives and the mitigating the same using thyristor based full bridge module (TFBM). The proposed topology by the author presents evolutionary line commutated converter operates with thyristor in each arm in full bridge scheme and using TFBM the mitigating efforts is being performed in stage wise manner. Commutation support performance has been enhanced using this topology and to evaluate the susceptibility of CFs the immunity index is adopted which is given by

$$CFII = V^2 / (\omega * L_{min} * P_{dc}) * 100.$$

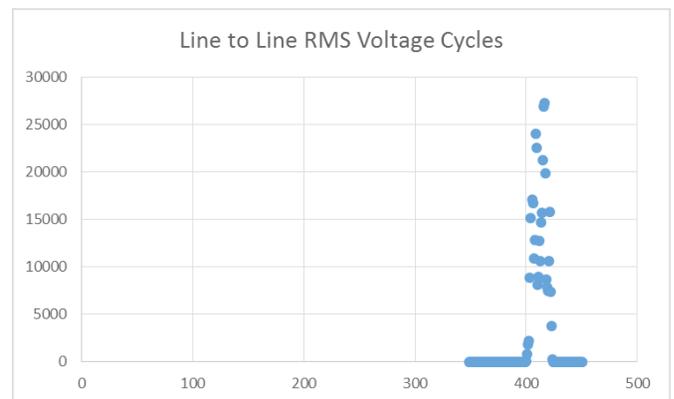


Fig. 11. Line line RMS Voltage Cycles.

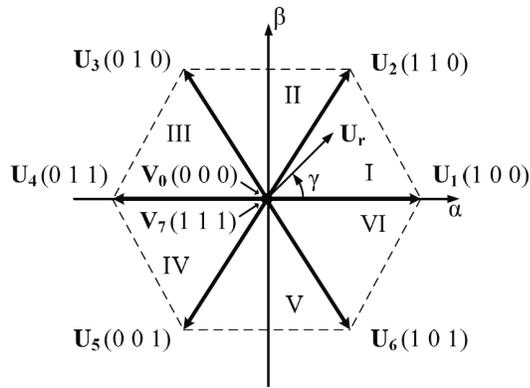


Fig. 12. Vector Control scheme of voltage space vectors to diagnosis of open circuit fault.

Md. Habibullah et al. [6], discusses the torque control of inverter drive suffering from high and variable switching frequencies in a wide range of inverter applications. To make stator currents with low harmonics, low torque ripple, the authors integrates the finite state predictive schemes of torque control in this article. Using this topology, the torque and flux ripples are reasonably good from the experimental results. Since the dead time incorporated in the inverter circuits, the higher order harmonics are relatively low compared to other methodology. Hadeed A. Sher et al. [8] discussed the experimental study of DC link capacitor failure in induction motor drive. Open circuit of the same has been discussed and analysis possible causes and effects for the said fault. From the analysis, it has been found out that, higher ripple frequencies will enable us to give better ride through capabilities to this particular fault. The three-phase induction machine model is created for the simulation and compared with single phase system, based on the simulation output the experimental setup was performed to validate the results obtained in simulation. The simulation block is presented in Fig. 13 which is used for ride through capabilities of DC link capacitor fault failure.

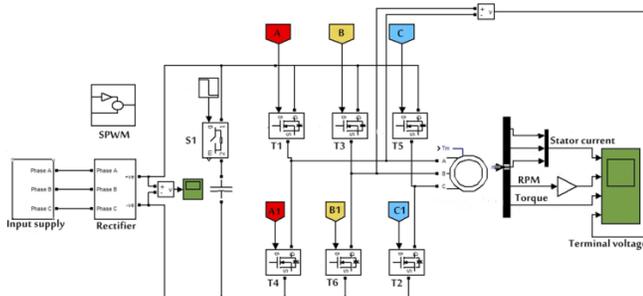


Fig. 13. Analysis of Inverter fed Induction Motor Drive under DC Link Capacitor Failure Scheme.

## VI. CONCLUSION

Based on all the literature survey and testing of the industrial drives, it reveals the fact that the major prime factors for inverter drive failure or fault is due to the poor power quality issues from the supply side or intermittent side from grid supply

to load through industry process as said early in introduction. Since the grid is having their own set of standards and rules to address these power quality issues, and even after taking lots of efforts to control the same to permissible levels, a sudden abnormality arises either in supply side or load side to inject disturbance in equipment's used for the process. Because of these sudden disturbances for very short time duration turned to be vulnerable to load as well as driving system associated with the load. Due to these vulnerabilities, the load parameter may get altered and accordingly the feedback systems get deviated from the prescribed limits there by affecting the inverter drives often. So, the possible solution for the same may be use of IOT integrated with the supply system as well as end customer equipment, so that any vulnerability arises, the necessary steps to ease out from the system will be carried out. From this literature survey article, the new and novel techniques have to be developed for making the industrial drives to ride through these vulnerabilities and having higher degree of operation performance with health monitoring system and predictive data maintenance systems (PDM). Because of the PDM, the manufacturer as well as customer can able to analysis the performance of a machine then and there, thereby the failure and health of the particular drive system is monitored regularly.

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