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Implementation and Simulation of Energy Efficient Power Drive System for Ac Induction Motor (Squirrel Cage Type)

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Abstract:- Induction motor is a nearly constant speed motor. The necessity for a variable load operation often requires a control method to vary its speed, when other control method are used, the motor runs at full speed and the flow of the output is throttled, or damped. The influence of these methods results in increase in high inrush current and power consumption which result in increment in energy cost. To overcome this problem, this work presents a new concept of Variable Frequency Drive (VFD) for AC induction motor that uses PWM (Pulse width modulation) techniques with a six pulse signal on an inverter to feed the motor with a varying frequency to vary the speed. When a Variable Frequency Drive (V.F.D) was added to the motor driven system for a variable load operation it consumed only about 1.68% of inrush current, reduced power consumption by about 60%, thus, offer potential energy saving in a system in which the load vary with time. Therefore the objective of this design is realized. This project will serve as a useful guide for industry on energy management.

***Keywords**:- Induction motor, Inrush current, Pulse width modulation, Variable Frequency Drive.*

I. INTRODUCTION

In the industry today, amongst other types of machines, induction motors especially the squirrel cage has gained more popularity due to its reliability, ruggedness, low maintenance and reduced cost. However, their operational characteristics are not all that flexible. Many motors especially the squirrel cage type induction motor operates at nearly constant speed [1]. The variation in speed of an induction motor from no load to full load is determined by the slip of the motor. Also at starting, the induction motors take a lot of inrush current for a reasonable amount of time, this current causes voltage drop and also translate into high utility bills charge by utility operators especially when using peak demand charge system for billing [2]. Furthermore, Inrush currents cause voltage sags that can have destructive effects on the motor and can affect other equipment. The speed of the machine is determined mostly by the number of magnetic poles in stator of the machine [3].

When an induction motor rotating at constant speed is driving a device or process that requires less power output, adjustments are required to achieve the desired output level. This adjustment is often achieved by letting the motor run at full speed, while using downstream devices like dampers to block part of the output [4]. The dampers also produce heat which in turn heat up the IM shaft, reducing its life span. Electric motor is likely to use two-thirds of the electricity in industry, so any opportunity to reduce energy consumption even by single digit is highly significant to cost saving in its operation. On average, 97% of the life cycle cost of purchasing and operating a motor is energy-related [5]. Reducing 10% of energy consumption by motor can reduce cost associated with it. Using a variable speed drive (VSDs) also called a variable frequency drive (V F D) is one of the most effective ways to save energy consumption of an induction motor [6]. In general, industrial loads require precise adjustment of speed over the complete speed range. Direct current (DC) motor drives dominated in variable speed applications but, they are expensive; require frequent maintenance and regular replacement of commutator and brush. With the advent of solid-state electronic switches technology Alternating Current (AC) motor drives are now capable of meeting all performances required of a motor. Currently, the trend is towards replacing all conventional DC motor drives with AC motor drives [7].

The merits of VFD with motors are : low starting current (reduced inrush current), high efficiency even at low speeds, high power factor , step less speed variation, torque stability with reduced harmonics components among others. However, to achieve all these merits, induct6ion motor should be properly driven by VFD. This project is on the implementation, simulation and analysis of variable frequency drive, its application in induction motor taking squirrel cage type as the main focus, and its effectiveness on improving energy efficiency.

II. PROBLEM STATEMENT

Fixed speed characteristics of an induction motor limit its application in the industries, it is often desirable to have a motor that operate at two or more discrete speeds, or to have fully variable speed operation. The amount of inrush current consume by induction motor at starting result in voltage drop across the line, attracting higher energy bills and a penalty associated with low power factor. Therefore, minimizing

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running cost by saving cost associated with energy consumption, minimizing investment cost by providing an opportunity to use affordable IMs over a range of speed processes, without the need of having different IMs for specific speed and to reduce energy consumption, hence improve energy conservation there by reducing utility bill charged is the focus of this design.

III. VARIABLE FREQUENCY DRIVE

A variable frequency drive is a device used to control speed by varying the frequency. It consists of four units:

- Rectifier unit
- Dc bus link
- Inverter unit
- Control stage

The basic block diagram of a variable speed drive is shown figure 1.0

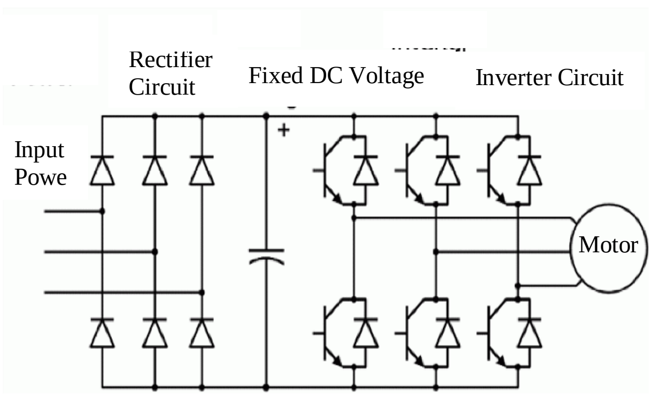

Fig 1:- Block Diagram of a Variable Speed Drive

In this work emphasis is laid on the inverter and control units only.

➢ *Inverter Stage*

This section of the V.F.D is referred to as an “Inverter.” The inverter contains transistors that deliver power to the motor. The “Insulated Gate Bipolar Transistor” (IGBT) is a common choice in modern V.F.D. The IGBT can switch on and off several thousand times per second and precisely control the power delivered to the motor [8]. The IGBT uses a method named “Pulse width modulation” (PWM) to simulate a current sine wave at the desired frequency to the motor. Motor speed (rpm) is dependent upon frequency. Varying the frequency output of the VFD controls motor speed:
Speed (rpm) = frequency (hertz) x 120 / No. of poles
i.e

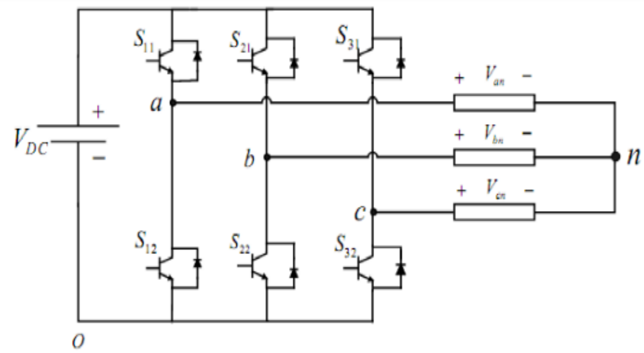

Fig 2:- Inverter Model

The inverter model shown in Figure 2 has eight switch states given in Table 1. In order that the circuit satisfies the KVL and the KCL, both of the switches in the same leg cannot be turned ON at the same time, as it would short the input voltage violating the KVL. Thus, the nature of the two switches in the same leg is complementary.

S11 + S12…………..(1)
S21 + S22…………(2)
S31 + S32…………(3)

S12	12	13	Vab	Vbc	Vca
0			0	0	0
0			0	0	0
0			0	Vdc	Vdc
0			-Vdc	Vdc	0
0			-Vdc	0	-Vdc
1			Vdc	0	-Vdc
1			-Vdc	-Vdc	0
1			0	Vdc	-Vdc

Table 1. switching states in a three phase inverter

The selection of the states in order to generate the given waveform in a three-phase inverter is done by modulating techniques to ensure the use of only the valid state

(S11 + S12) = Van + Vno …………..(4)
(S21 + S22) = Vbn + Vno …………..(5)
(S31 + S32) = Vcn + Vno …………..(6)

Equation (4) to (6) in terms of modulating signal from condition (1) gives the following equations.
(M11) = Van + Vno……………(7)
(M21) = Vbn + Vno……………(8)
(M31) = Vcn + Vno…………….(9)

Adding equations (7,8 and9) yield equation (10)
(S11 + S21 + S31 – S12 – S22 – S32 = Van + Vbn + Vcn + Vno…………(10)

For purpose of balanced voltages,

Van + Vbn + Vcn = 0. This leads to equation (11)
(2S11 + 2S 21 + 2S 31 – 3) = Vno………… (11)

IV. HOW DRIVE CHANGES MOTOR SPEED

As the drive provides the frequency and voltage of output necessary to change the speed of a motor, this is done through Pulse Width Modulation Drives. Pulse width modulation (PWM) inverter produces pulses of varying widths which are combined to build the required waveform as shown in Figure 3. Diode Bridge is used in some converters to reduce harmonics. PWM produces a current waveform that more closely matches the line source, which reduces undesired heating. PWM drive has almost constant power factor at all speeds which is close to unity [9] PWM units can also operate multiple motor on a single drive. Thus the carrier frequency is derived from the speed of the power device switch remains ON and OFF drive. It is also called switch frequency. The higher the carrier frequency of the power line, the higher the resolution of the pulse width modulation. The typical carrier frequency ranges from 3 to 4 KHz or 3000 to 4000 cycles per second as compared with older SCR based carrier frequency which ranges from 250 to 500 cycles per second. Thus it is clear that the higher the carrier frequency the higher will be the resolution of output waveform [10].

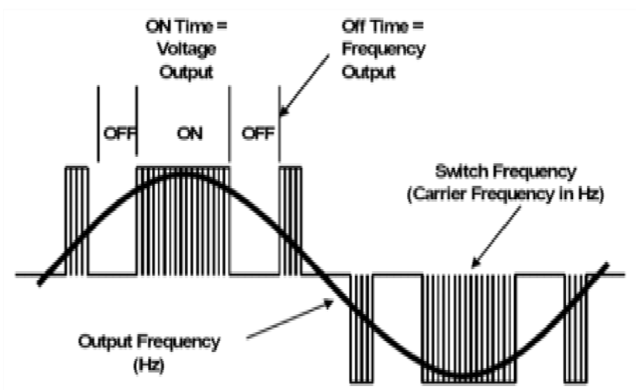

Fig 3:- Pulse Width Generator

V. METHODOLOGY

This project employs the use of mat lab software with Simulink window and Simulink function tools on Simulink library. Simulink function available on Math lab is used for the design, for comparison on result accuracy, an already available model is used. Model A and Model B .

➢ *Model A*

Model A is a direct simulation of readily industrial available model of energy management using most popular Dc supply techniques method with PWM.

➢ *Model B*

Model B is a new design from this project with enhanced features which is compatible with Ac supply in industries, with better energy efficient potential also using PWM techniques in conjunction with ward Leonard AC model.

VI. ASYNCHRONOUS MACHINE (SQUIRREL CAGE) BLOCK

The Asynchronous Machine Squirrel Cage (fundamental) block models a squirrel-cage-rotor asynchronous machine with parameterization using fundamental parameters. Squirrel-cage rotor asynchronous machine is a type of induction machine. All stator connections are also accessible

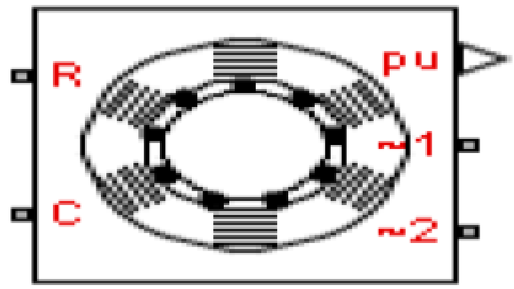

Fig 4:- Machine Block

➢ *Configuration and Design Procedure*

Port ~1 is connected to a three-phase circuit. And also the stator is connected in wye configuration by connecting port ~2 to a Grounded Neutral or a Floating Neutral block on MODEL A. Model B stator is connected in delta configuration by connecting to a Phase Permute block between ports ~1 and ~2.

Parameters	Values
Nominal power, voltage(line to neutral), and frequency	(3 * 746, 230, 60)
Stator resistance and inductance	(1.1150 and 005874)
Rotor resistance and inductance	(1.083 and 005974)
Mutual inductance	0.2037
Inertia constant, friction factor and pole pairs	(0.02, 0,005752)

Table 2. Asynchronous Machine Parameters

Stator resistance and inductance, rotor resistance and inductance are chosen to have smallest values possible to minimize current mitigation. The number of pole pairs is chosen to be 2 to implement a 4 pole motor. Setting the nominal power to 3∗746 VA and the nominal line-to-neutral voltage Vn to 230 Vrms implements a 3 HP, 60 Hz machine with 2 pairs of poles. Its nominal speed is therefore slightly lower than the synchronous speed of 1800 rpm, or Ws= 188.5 rad/s. These are the initial conditions on starting of motor load.

VII. PULSE WIDTH GENERATOR

The PWM Generator (2-Level) block generates pulses for carrier-based pulse width Modulation (PWM) converters using two-level topology. For a three-phase bridge use on this research, the three reference signals are expected to generate the six pulses. The reference signals can also be internally generated by the PWM generator.

➢ *Configuration and Design Procedure*

A modulation index, was used according to standard ratio from 0.1 to 0.9. On this case, 0.9 was selected for MODEL A and 0.4 was selected for MODEL B. Other parameters like Generator type, Carrier frequency (Hz), internal generation of modulating signal (s), Output voltage frequency (Hz) ,Sample time , Inputs and Outputs are showed on the table below a was used on the block.

Parameters	Values
Generator type Three phase bridge	(6 pulses)
Mode of operation	Unsynchronized
Carrier frequency	18 * 60Hz (1080 Hz)
Internal generation of modulating signals	Selected
Modulation index M	0.9
Output voltage frequency	60Hz
Output voltage phase	0 or blank
Sample time	10e - 6 s

Table 3. Pulse width parameters

The block has been discretized so that the pulses change at multiples of the specified time step. A time step of 10 μs corresponds to +/− 0.54% of the switching period at 1080 Hz. One common method of generating the PWM pulses uses comparison of the output voltage to synthesize (60 Hz in this case) with a triangular wave at the switching frequency (1080 Hz in this 36 case). The line-to-line RMS output voltage is a function of the DC input voltage and of the modulation index m as given by the following equation:

VLLrms = = m x 0.612 x Vdc 11

Therefore, a DC voltage of 400 V and a modulation factor of 0.90 yield the 230 $Vrms$ output line-to-neutral voltage, which is the nominal voltage of the asynchronous motor.

VIII. LOADING AND DRIVING THE MOTOR

Assumption on the use of a quadratic torque-speed characteristic (fan or pump type load). The torque T is then proportional to the square of the speed ω.

T = K × ω2………..12

For non-variable torque load

Power ═ speed × torque……….. 13

For variable torque load

Power = speed ˄3……………14
Power = Ir V…………………15

The nominal torque of the motor is
Torque Tn =
Tn = = 11.87 Nm
K = = 3.34 x 10-4

The circuit diagram for model is shown in figure 5

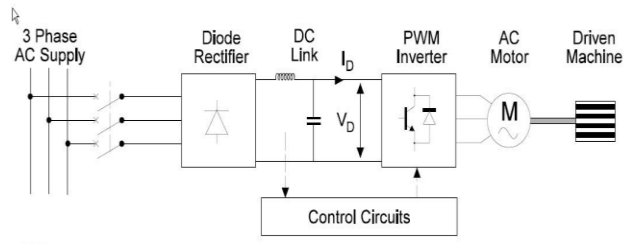

Fig 5:- Circuit Diagram for Model B

➢ *Simulink diagram for model A*

A DC voltage source of magnitude 400V is connected as supply voltage to the circuit. A voltage measurement is also added to measure the output voltage. The circuit Simulink representation is shown in Figure 6.

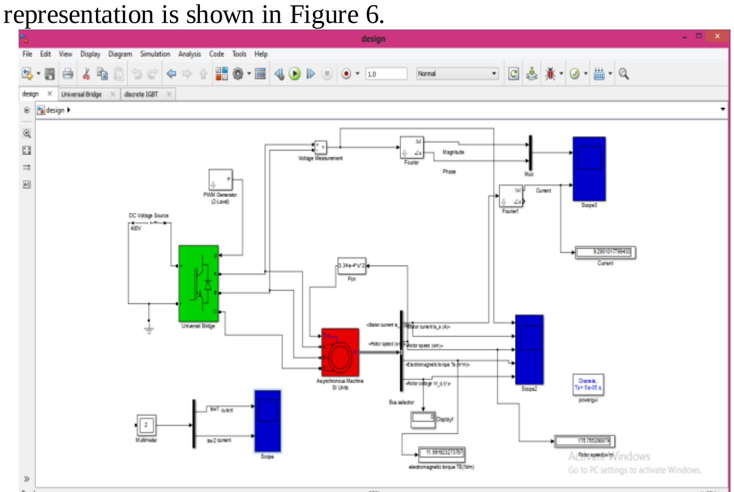

Fig 6:- Simulink Diagram for Model A

➢ *Simulink diagram for model B*

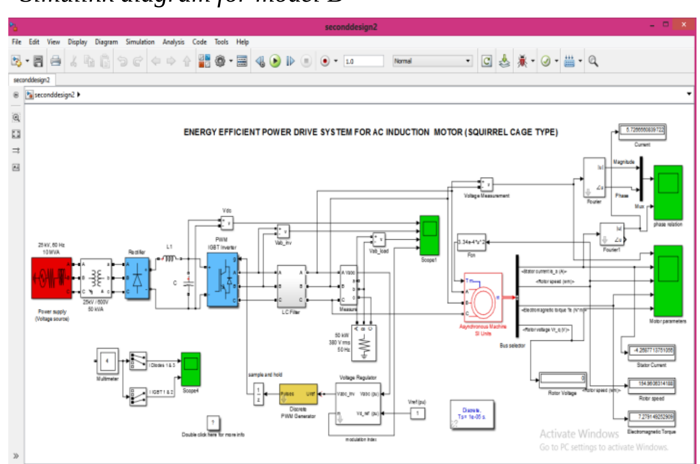

Fig 7:- Simulink Diagram for Model B

IX. RESULT ANALYSIS

For a 230V (rms, 60Hz, 2 pole pairs, 3HP, Nominal power 2238KW, Speed 1800 rpm motor.

➤ *Graphical Result Display*

- *Method A*

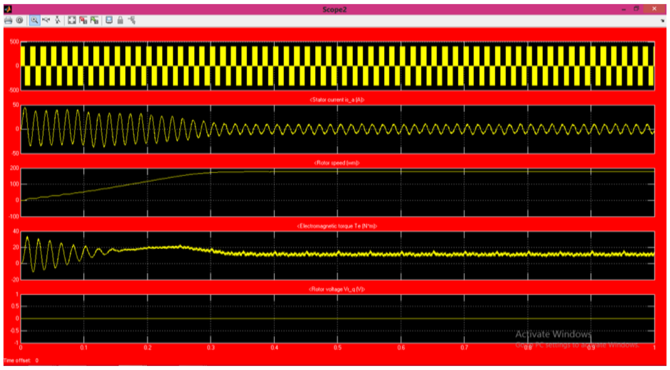

Fig 8:- Graphical Display Result for Model A

- *Method B*

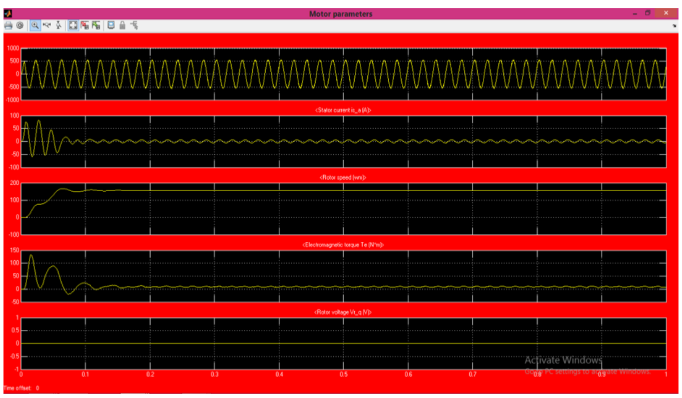

Fig 9:- Graphical Display of Result For MODEL B. (Motor Parameters).

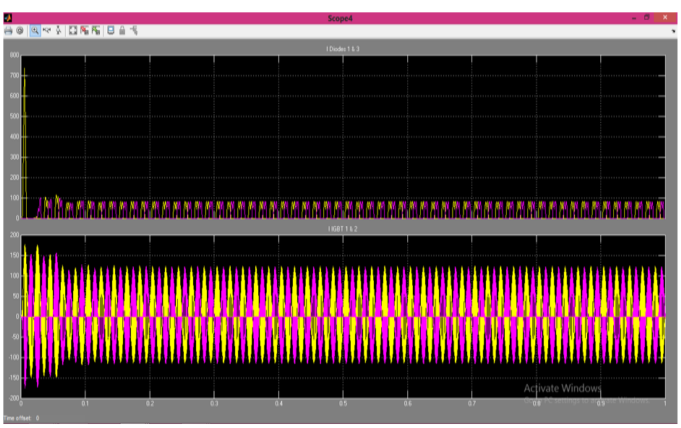

Fig 10:- Diodes and IGBT Function Graphs

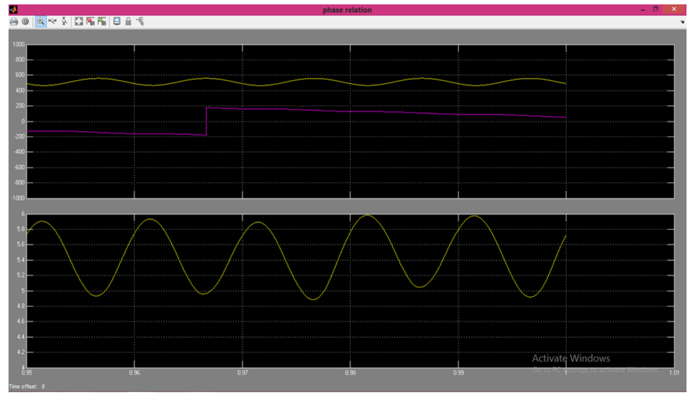

Fig 11:- Phase Relation Display between Voltage And Current

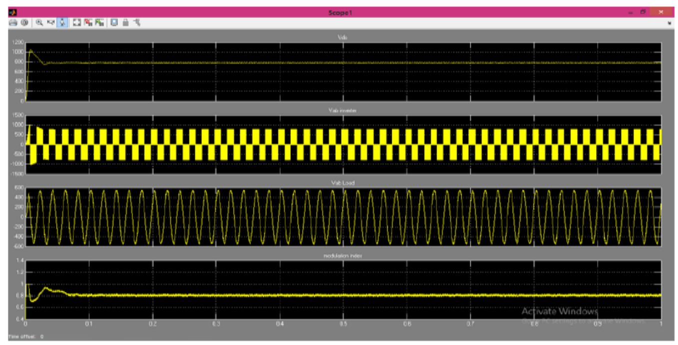

Fig 12:- Rectified Voltage, PWM Cycles, Load Voltage and Modulating Index Display

X. GRAPHICAL RESULT ANALYSYS

➤ *Figure 9 Graphical Display of result for MODEL B. (Motor Parameters).*

Stator current used to generate magnetic flux, Rotor speed, and Electromagnetic torque waveform. At starting the levels of inrush current consume by the induction motor was reduced hence causing limited voltage drop which will reduce voltage sagging. To compare with model A, which takes a significant amount of time for up to 0.3*s* before attaining steady state, allowing higher amount of inrush current. model B attain steady state quickly within a time of 0.1*s* curtailing the amount of current consume, hence reduce power consumption with a possibility to reduce energy bills. Model B has better torque control with insignificant harmonics component, hence reduce motor vibration. Compare to Model A with significant amount of harmonic component with a possibility of uncontrolled motor vibration. Model B has a faster rise time and attain steady state at 0.1*s* for its rotor speed which is operating at half it rated speed.

➤ *Figure 4.4 Phase Relation Display Between Voltage And Current*

The system maintain a phase relation between current and voltage with no noticeable lead and lag behavior, this may provide an opportunity for a reduced energy bill due to low power factor penalty

- *Figure 4.5 Rectified Voltage, PWM Cycles, Load Voltage And Modulating Index*

It shows smooth waveform from the rectification system with insignificant harmonics distortion, PWM signal were properly varied according to the set frequency for its six pulse cycle. The rise time and fall time was accurate as it delivers control signal to the system. The modulation index signal remainS stable at 0.8 to ensure adequate modulating efficiency.

XI. NUMERICAL RESULT ANALYSIS (WITH OUT VFD OR VSDS)

- *From table 2, (Asynchronous Machine Parameters) at rated characteristics*

$T=K\times\omega 2$……………12

Analysis on power and inrush current consume when induction motor was run with a variable torque load without the use of VFD.

$Power =$ Torque x $Speed$ ………..13

The nominal torque of the motor is given as $Torque$ $Tn=PowerSpeed$
Torque Tn =
Speed = = -= 1800 rpm or 188.5 rad/sec.

Torque Tn = = 11.87 Nm
Therefore, the constant k should be
K = = = 3.34 x 10-4

Power consume at rated speed for a variable torque load $Power$=18003= 5832MW

Current Irv Consume at rated speed for a variable load
Irv = = = 2535KA

Analysis on power and current consume when induction motor was run at rated speed, rated torque, for a non-variable torque load

$Power = Speed \times torque$……………13

= 1800 ×1 1.87 = 21366kw/Nm

Inrush current Irn at rated speed and rated torque for a non-variable load operation

Irn = = = 92.8KA

Wasted Current $Irv-Irn$ = 2535 − 92.8 = 2442 KA

- *Numerical Result Analysis (With Vfd Or Vsds)*

Time	Speed	Power
0.1997200000000	151.755762519272	3495
0.1997400000000	151.755499629429	3495
0.1697600000000	151.755419023001	3473
0.9999600000000	151.154299934135	3473
0.9999800000000	151.153513077475	3473
1. 00000000	151.152828473351	

Table 4. Power, Speed Output For A 400V, 60 to 1080 Hz Input

With VFD, Speed stabilizes at 151.1 rpm with varying frequency in response to varying load $Power$ = 151.13 = 3449795.8$W \cong$ 3.449MW

Irv = = = 14.99KA
Inrush Current Reduction With Variable Load (Irv)
Irv without VFD = Irv = = = 25359 KA
Irv with VFD = Irv = = = 14,99 KA

Percentage Consumption
(100/x)% = 2535/14.99 = 169.11. Therefore, 169.11/100=1.69%

From numerical calculation, running the induction motor at rated speed, for a non-variable load consume 2136 KW, the use of dampers to vary the speed after been run at rated speed for a variable load operation consume 5832MW, The use of VFD for an induction motor to vary the speed for a variable load operation consume, 3.449MW. Also, reduce the value of inrush current during a variable load operation from 2535 to 14.99 KA This reduction will have a significant effect in energy bills.

XII. CONCLUSION

A very common problem with induction Motors especially the squirrel cage type is their low power factor, fixed speed operation, high inrush Current at starting and instability when not operating at full load. This leads to serious damage. The use of VFD reduce amount of inrush current, by only consuming 1.69% (14.99KA) from the amount of current consume when using other speed control method for a variable load operation (2535KA) , therefore voltage drop across lines will be significantly reduced with a reduction in energy bill charge because of reduced power consumption from 5832MW to 3.449MW. Also appreciable is the power factor improvement and harmonic components reduction. In a country like Nigeria with struggling electricity supply, this device is of great benefit to industries. These attributes of variable frequency drive tempt the industries to choose it and enjoy extra savings in terms of energy efficiency and conservation in addition to reduced maintenance.

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