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Novel Energy Conservation Scheme for Three Phase Induction Motor Drives Employed in Constant Speed Applications

***Abstract**. Due to low price, less maintenance, robustness and reliability, induction motors are used in most of the industrial applications. Nowadays, energy conservation is an important factor for the industries. This paper describes a smart Maximum Efficiency Slip Speed (MESS) energy conservation scheme for three phase squirrel cage induction motor drives, employed in constant speed varying load torque type applications. This paper discusses the advantage of proposed scheme under various set speeds, compared to existing scheme. A complete induction motor drive set up employing MESS scheme is developed and simulated for 5.4 HP, 4 Pole, 400V, 1430Rpm and 50Hz three phase squirrel cage induction motor in Matlab Simulink. The practical verifications is also done in 1 HP, 1400Rpm, 50Hz and 4 Pole three phase squirrel cage induction motor. The results for both simulation and hardware are discussed in this paper.*

***Streszczenie.** W artykule przedstawiono metodę sterowania trójfazową klatkową maszyną asynchroniczną w napędach o stałej prędkości i zmiennym obciążeniu, polegającą na regulacji poślizgu dla uzyskania maksymalnej sprawności energetycznej. Przedstawione w badań symulacyjnych i eksperymentalnych potwierdziły skuteczność proponowanej metody. (**Nowa metoda sterowania dla oszczędności energii w trójfazowej maszynie indukcyjnej w napędach o stałej prędkości**)*

Keywords: Energy Conservation, Constant speed applications, SPWM technique, MESS scheme please.
Słowa kluczowe: Oszczędzanie energii, napędy o stałem prędkość, technika SPWM, MESS

1. Introduction

Many energy saving schemes are available for induction motors. They are classified into online and offline methods [1], [2]. In offline method, the energy conservation is achieved by replacing unwanted higher rating motor with suitable rating motor for driving the load. For example, if a 10 Hp motor is used to drive a constant load, which is 50% of the rated load that can be driven by the motor, then the motor can be replaced by 5Hp motor. This will reduce the total losses and cost of the motor. In online method, the energy conservation is done by flux optimization in induction motors. In the flux optimization, a controller is used to reduce the flux level of the induction motor by reducing the voltage applied to the motor for every load condition, upto no change in its output power. Similarly many energy saving schemes are reported for induction motor. Energy saving is essential nowadays because of growing demand for electrical power throughout the world. Constant speed operation of induction motor is used in applications such as spinning drive in textile industry, mine hoist load, drill presses and wood saw [3],[4]. Here load is varying from no load to full load at constant speed. Flux optimization is useful for these applications to conserve energy. The difference between ordinary induction motor and energy efficient induction motor is in the loss; the iron loss in the energy efficient motor is reduced to low value by selecting good quality core, compared to ordinary motors [3]. In energy efficient induction motor, the balance between copper loss and iron loss is achieved at light loads due to reduction in iron loss. So, maximum efficiency is achieved even at light load conditions.

The proposed MESS scheme can be employed to both ordinary and energy efficient induction motors. Neural network based flux optimization for single phase induction motor with ac voltage regulator was discussed in [5]. Here flux optimization is achieved for different load conditions by varying the voltage, upto no change in the motor's output power for corresponding loads. To improve the controller's performance, intelligent controller is used to optimize the flux for different load conditions in three phase induction motors [6], [7]. Comparison of controller's performance with the combination of PSO and fuzzy, GA and fuzzy was discussed in [7]. On line efficiency estimation of three phase induction motor with genetic algorithm was discussed in [8]. Harmonics in the motor causes problems in the controller and makes the speed to oscillate. So, harmonics are reduced to improve the controller's performance [9]. For harmonics reduction, Sinusoidal Pulse Width Modulation technique (SPWM) can be used. Energy saving by voltage reduction in three phase induction motor was discussed in [10]. Voltage source inverter fed three phase induction motor drive for loss minimization was discussed in [11].

This paper presents a new scheme namely Maximum Efficiency Slip Speed (MESS) scheme for three phase induction motor drive employed for constant speed applications. This MESS scheme differs from existing flux optimization scheme by reducing the input power (by reducing the flux) upto no change in output power and also maintaining the slip speed constant at maximum efficiency slip speed between no load to maximum efficiency load point. This scheme provides better improvement in efficiency compared to existing flux optimization technique. Simulation is done for 5.4 Hp three phase squirrel cage induction motor. The practical verification is done in 1 Hp three phase squirrel cage induction motor. In this paper, the voltage source inverter (VSI) is constructed using Insulated Gate Bipolar Transistor (IGBT) switches and employs Sinusoidal Pulse Width Modulation technique (SPWM). This paper is organized as follows; section 2 explains the ordinary V/F control and the existing flux optimization technique; section 3 explains the Maximum Efficiency in induction motor, section 4 explains the proposed Maximum Efficiency Slip Speed (MESS) scheme and section 5 explains the lookup table formation and section 6 explains the conclusion.

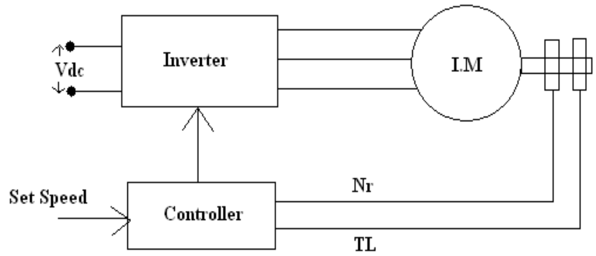

Fig.1.Block diagram for existing flux optimization control

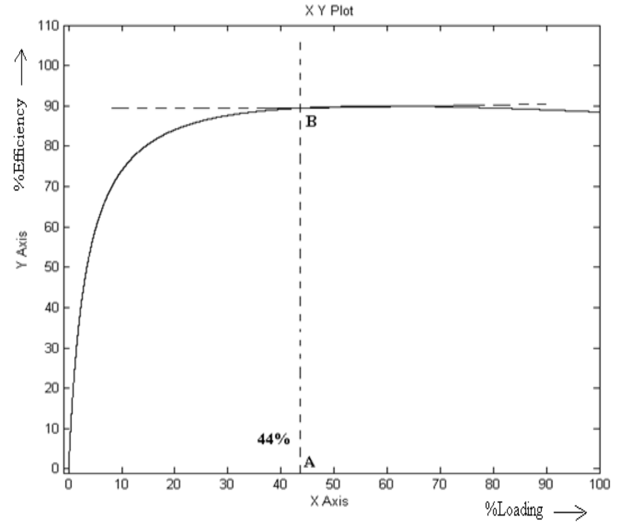

Fig.2.Efficiency Vs % Load curve for 5.4Hp motor in Matlab Simulink

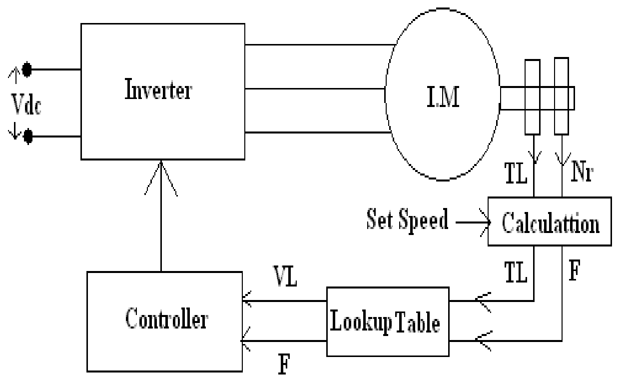

Fig.3.Block diagram for Proposed MESS scheme

2.Existing Flux Optimization

In industries, induction motor drives are used for the constant speed applications such as drill presses, wood saw etc. For these applications the load is varied from no load to full load at constant speed. Generally in induction motor the flux requirement varies from no load to full load. If an induction motor is running under varying load conditions, with constant rated voltage and frequency then the flux is maintained constant at full load flux level for all the load conditions, from no load to full load. So, flux optimization techniques are used for these kinds of applications to give the optimum flux corresponding to the load. This is called flux optimization technique. In induction motor drive for constant speed operation, V/F control is preferred. Figure 1 shows the block diagram of existing flux optimization control for the constant speed operation of induction motor drive. Table 1 and 3 shows the simulation and practical readings of VSI fed V/F controlled 5.4 Hp and 1Hp induction motor drive for the set speed of 1173 rpm and 1400Rpm. Table 2 and 4 shows the simulation and practical readings of VSI fed existing flux optimization controlled 5.4 Hp and 1Hp induction motor drive for the set speed of 1173 rpm and 1400Rpm. Figure 2 shows the efficiency versus %load curve obtained for 5.4 Hp induction motor in Matlab Simulink by conducting load test. From this curve, it is clear that maximum efficiency occurs for this motor at 44% of load and point B in the curve is called as maximum efficiency point and point A is called as maximum efficiency load point. Appendix A gives the meaning of different symbols.

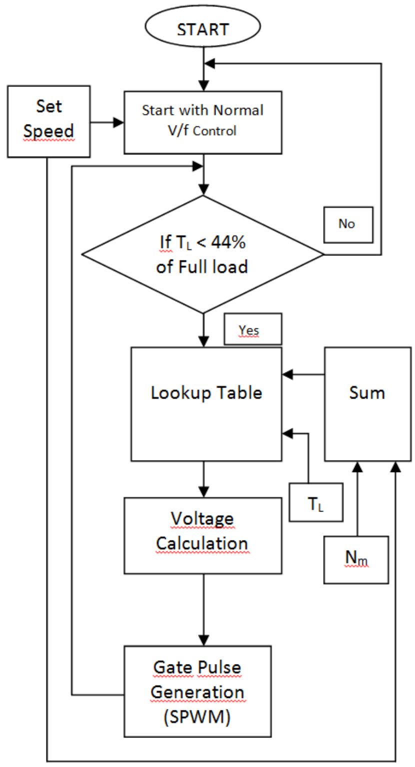

Fig.4.Flow chart for Proposed MESS scheme

(1) Input power = 3 V I cos α

(2) Output power $=2 \pi N_r T_L / 60$

(3) Slip Speed $= N_s - N_r$

(4) $N_{sm} = N_s - N_m$

Table 1. Simulation Readings for V/F Control in 5.4Hp for the set speed of 1173 Rpm

%Load	Input power (W) 5.4Hp	Output power (W) 5.4Hp	%Efficiency
00.00	116	-	-
03.70	240	123	51.25
07.40	365	246	67.39
11.10	489	368	75.25
14.80	616	491	79.70
18.50	745	614	82.41
22.20	875	737	84.22
29.60	1133	983	86.76
33.30	1266	1105	87.28
42.55	1576	1412	89.59
50.00	1867	1658	88.80
100.0	3745	3316	88.54

In the existing flux optimization technique for every load condition from no load to maximum efficiency load point, the flux levels are decreased upto no change in the motor's output power. Here maximum efficiency load point means, the %load at which maximum efficiency occurs in the motor. From the table 1, 2, 3 and 4, it is clear that the output powers are same for all the corresponding load conditions and the input power is large in V/F control compared to existing flux optimization control, upto maximum efficiency load point. In existing flux optimization control, the flux levels are varied upto no change in the output power of the motor and hence the input power for the existing flux optimization control is reduced compared to V/F control. Thus efficiency of the motor drive is increased from no load to maximum efficiency load point compared to V/F control. The output power is calculated from equation (2).

Table 2. Simulation Readings for Existing Flux Optimization Control in 5.4Hp for the set speed of 1173 Rpm

%Load	Input power (W) 5.4Hp	Output power (W) 5.4Hp	%Efficiency
00.00	74	-	-
03.70	204	123	60.29
07.40	336	246	73.21
11.10	469	368	78.46
14.80	601	491	81.69
18.50	734	614	83.65
22.20	864	737	85.30
29.60	1123	983	87.53
33.30	1254	1105	88.11
42.55	1576	1412	89.59
50.00	1867	1658	88.80
100.0	3745	3316	88.54

Table 3. Practical Readings for V/F Control in 1Hp Induction Motor for the set speed of 1400 Rpm

%Load	Input power (W) 1Hp	Output power (W) 1Hp	%Efficiency
0	74	-	-
10	125	78	62.40
20	246	194	78.86
40	368	304	82.60
60	511	451	88.25
80	668	586	87.72
100	829	724	87.33

Table 4. Practical Readings for Existing Flux Optimization Control in 1Hp Induction Motor for the set speed of 1400 Rpm

%Load	Input power (W) 1Hp	Output power (W) 1Hp	%Efficiency
0	48	-	-
10	118	78	66.10
20	239	194	81.17
40	364	304	83.51
60	511	451	88.25
80	668	586	87.72
100	829	724	87.33

3.Maximum efficiency in induction motor

In induction motors, efficiency is maximum when iron loss equals the copper loss. Equation (5) shows the condition for maximum efficiency. When an induction motor is supplied with constant voltage and frequency from no load to full load, the iron loss becomes constant and copper loss increases from no load to full load and makes equal with iron loss at particular load, this particular load point is the maximum efficiency point.

(5) Iron loss = Stator copper loss + Rotor copper loss

In induction motors, iron loss depends on voltage and frequency, and copper loss depends on current and the slip speed. The rotor copper loss increases when the slip speed increases. If the slip speed is maintained constant at maximum efficiency slip speed by adjusting the voltage applied to the motor from no load to maximum efficiency load point, such that the copper loss and iron loss are equal, then maximum efficiency can be obtained from no load to maximum efficiency load point. This makes a balance condition between copper loss and iron loss from no load to maximum efficiency load point and increases the efficiency.

In this paper, the maximum efficiency load point and Nsm are calculated by conducting ordinary load test on 5.4 Hp motor in simulink and for 1Hp motor by practical experiment. The value of maximum efficiency load point occur at 44% load for 5.4 Hp motor (Nsm = 27 Rpm). The value of maximum efficiency load point occur at 60% load for 1 Hp motor (Nsm = 40 Rpm). The maximum efficiency load point, varies from motor to motor. In conventional (older) induction motor, the equality in copper loss and iron loss occurs near the full load. In energy efficient induction motor, this equality occurs at light load condition because of good quality core. Good quality core in induction motor makes reduction in iron loss and thereby making the equality between the iron loss and copper loss even at light load condition.

4.MESS Control

The proposed Maximum Efficiency Slip Speed (MESS) energy conservation scheme can be employed to both conventional induction motors and energy efficient induction motors. Figure 3 shows the block diagram of proposed MESS scheme. Table 5 and 6 shows the simulation and practical readings obtained from MESS controlled VSI fed 5.4 Hp and 1 Hp induction motor drive for the set speed of 1173 rpm and 1400Rpm. In the proposed scheme, maximum efficiency slip speed (Nsm) is maintained constant from no load to maximum efficiency load point to improve the efficiency. Figure 4 shows the flow chart of proposed MESS scheme for VSI fed 5.4 Hp induction motor drive in Matlab Simulink. In this scheme, the motor is first started with ordinary V/F control scheme and then the load is checked whether it is below 44%; if it is true, MESS control is applied, if it is false, normal V/F control is continued.

(6) MESS Synchronous Speed = Set Speed + N_{sm}

(7) Frequency = (P × (MESS control Synchronous Speed)) ÷ 120

In the MESS control for a set speed, synchronous speed is calculated by equation (6). From this speed, frequency is calculated by equation (7). Then with this frequency and corresponding load torque, suitable voltage is obtained from a lookup table. The lookup table consists of optimum V/F ratios for different load conditions. It is explained in lookup table formulation section. The gate pulses are generated with SPWM technique for obtaining the required voltage and frequency. It is done by adjusting the amplitude and frequency of reference sine wave used in the SPWM. Then the motor runs at set speed for this voltage and frequency. The above procedure is repeated as shown in the flow chart. Thus efficiency is increased from no load to 44% load (maximum efficiency load point) due to this MESS scheme.

5.Lookup Table Formation

Table 7 shows the lookup table for the MESS controlled VSI fed 5.4Hp motor in Matlab Simulink. In the proposed MESS scheme, Nsm is taken as constant for various synchronous speeds. Here it is explained with an example. The flux is directly proportional to V/F. In V/F control, the flux is constant for various set speeds and various load conditions. If a 4-pole motor's no load slip speed is 10 rpm, then for rated voltage and frequency (V/F= 400/50 = 8), the motor runs at 1490 Rpm and for 200 volt and 25 Hz (V/F= 200/25 = 8), the same motor runs at 740 rpm. The slip speed is same for the synchronous speed of 1500 Rpm and 750Rpm, this is because fluxes during the both cases are same. Similarly the motor maximum efficiency slip speed and maximum efficiency load point are same for different synchronous speeds. Lookup table data are obtained by running the motor for different load conditions from no load to maximum efficiency load point.

In the 5.4 Hp motor used in the simulation, for a set speed of 1323 Rpm, the lookup table data is calculated by first finding the MESS synchronous speed using equation (6) which is 1350 rpm which is the sum of set speed (1323 Rpm) and maximum efficiency slip speed (27 rpm). The frequency corresponding to this MESS synchronous speed is found using equation (7) which is obtained as 45 Hz.

Table 5. Simulation Readings for MESS Control in 5.4Hp

%Load	Input power (W) 5.4Hp	Output power (W) 5.4Hp	%Efficiency
00.00	49	-	-
03.70	184	123	66.84
07.40	318	246	77.35
11.10	453	368	81.23
14.80	587	491	83.64
18.50	722	614	85.04
22.20	854	737	86.29
29.60	1118	983	87.92
33.30	1251	1105	88.32
42.55	1576	1412	89.59
50.00	1867	1658	88.80
100.0	3745	3316	88.54

Table 6. Practical Readings for MESS Control in 1Hp

%Load	Input power (W) 5.4Hp	Output power (W) 5.4Hp	%Efficiency
0	33	-	-
10	113	78	69.02
20	235	194	82.55
40	359	304	84.67
60	511	451	88.25
80	668	586	87.72
100	829	724	87.33

Table 7. Lookup Table and Voltage applied to motor for 5.4Hp motor in Matlab Simulation for Proposed MESS Control

%Load	Optimum (V/F) Ratio for 5.4Hp motor	VL for frequency of 45 Hz (V)	VL for frequency of 40 Hz (V)
00.00	1.40	63	56
03.70	2.70	121	108
07.40	3.60	162	144
11.10	4.25	191	170
14.80	4.85	218	194
18.50	5.45	245	218
22.20	5.90	266	236
29.60	6.73	303	269
33.30	7.10	320	284
42.55	8.00	360	320

Then the lookup table data for different load conditions for this set speed are obtained by maintaining the frequency constant at 45Hz and decreasing the voltage till the speed reached the set speed of 1323 Rpm for different load conditions between no load to maximum efficiency load point. Then with the obtained voltage and frequency for a particular load, the optimum V/F ratio for that load is calculated. Similarly for different load conditions, the optimum V/F ratios are calculated which provides the optimal flux for the corresponding load conditions and is given in Table 7. Using this optimum ratio, voltage can be calculated for any set speed and load condition.

In on-line application, from the set speed and load, the corresponding voltage and frequency is found out, which is explained with an example. For the set speed of 1173 Rpm in 5.4 Hp motor, the synchronous speed is calculated by adding the set speed and maximum efficiency slip speed. Then the synchronous speed equal to 1200 Rpm (1173 + 27). Then by knowing the synchronous speed, frequency is calculated from equation (7) as 40Hz. Using that frequency and load, the corresponding voltage is calculated from the lookup table for maximum efficiency. If the load is 11.10% of rated load then the optimum V/F ratio taken from the lookup table is 4.25 as shown in Table 7. If the set speed is 1173 Rpm then the frequency calculated is 40 Hz and the voltage to be applied to the motor is equal to 40 × 4.25 = 170 Volts. Then by using SPWM technique gating pulses are generated for the corresponding voltage and frequency. Similarly for the different set speeds and load conditions between no load to maximum efficiency load point, voltage and frequency are calculated.

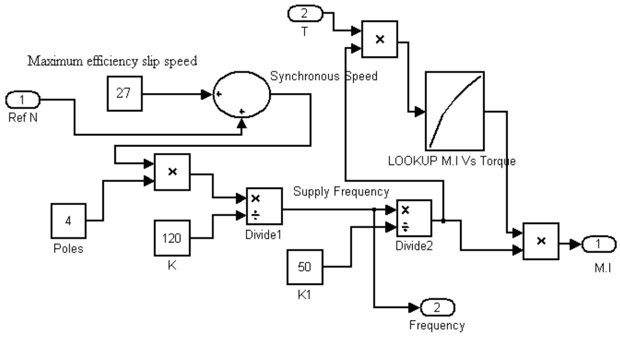

Fig.5.Matlab simulink diagram of Control part in Proposed MESS scheme

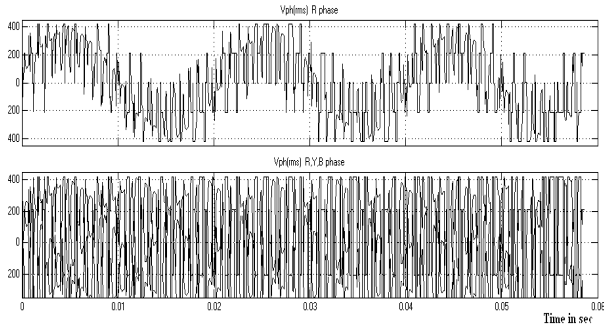

Fig.6.Simulated Voltage waveform of Induction motor in Proposed MESS scheme

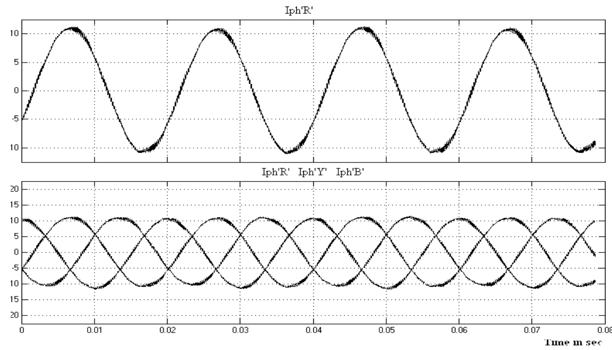

Fig.7. Simulated Current waveform of Induction motor in Proposed MESS scheme

Figure 5 shows the Matlab simulink diagram of control part in proposed MESS scheme. Figure 6 shows the applied voltage waveform of induction motor in proposed MESS scheme. Figure 7 shows the current waveform of induction motor in proposed MESS scheme. Figure 8 shows the efficiency Vs %load curve obtained in the simulation work on 5.4Hp Induction motor. Comparing the V/F and existing flux optimization technique, the efficiency is slightly improved in MESS scheme. Experimental verification is also done for 1 Hp induction motor.

Figure 9 shows the experimental setup for practical verification. Figure 10 shows the applied voltage waveform of induction motor in proposed MESS scheme. Figure 11 shows the current waveform of induction motor in proposed MESS scheme. Figure 12 shows the efficiency Vs %load curve for the practical work in 1Hp induction motor. Comparing with the V/F and existing flux optimization technique practical results, efficiency is slightly increased in MESS control.

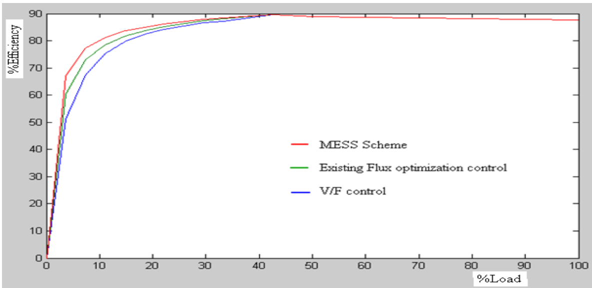

Fig.8.Efficiency Vs %Load comparison wave form for the simulation work in 5.4Hp Induction motor

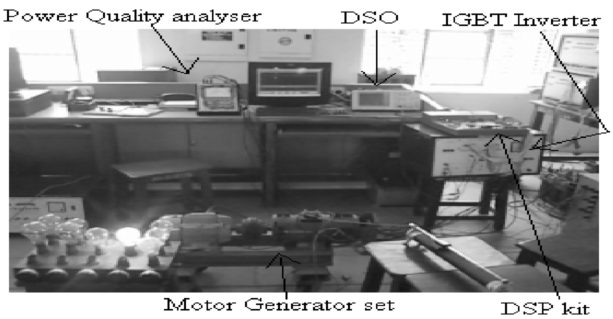

Fig.9.Experimental Setup for practical verification

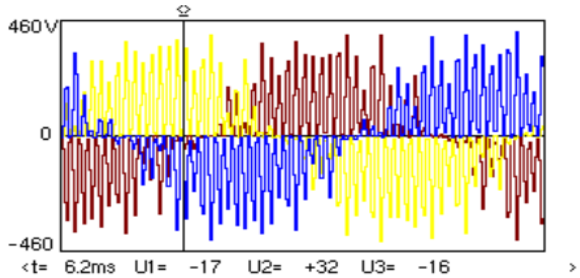

Fig.10.Practical Voltage waveform of Induction motor in Proposed MESS scheme

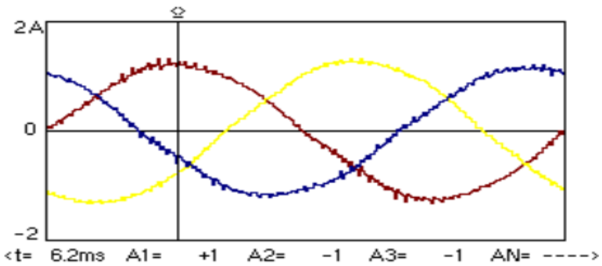

Fig.11.Practical Current waveform of Induction motor in Proposed MESS scheme

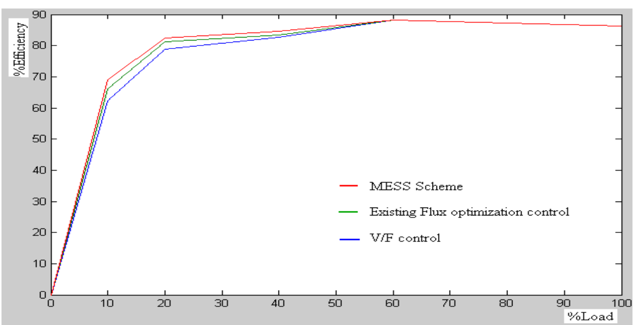

Fig.12.Efficiency Vs %Load comparison wave form for the practical work in 1Hp motor

6.Conclusion

This paper presents a new Maximum Efficiency Slip Speed (MESS) energy conservation scheme for three phase squirrel cage induction motor, operating under constant speed varying load torque conditions. The simulation and practical verification is done for the proposed scheme. The efficiency improvement achieved in MESS scheme between no load to maximum efficiency load point is slightly high compared to existing flux optimization control which is normally used in industries for efficiency improvement in induction motors. Implementation of MESS scheme in industries will result in more energy conservation in industries compared to existing flux optimization control.

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Appendix

V = Phase Voltage in Volts, V_L = Line Voltage in Volts, I = Phase Current in Amps, F = Frequency in Hz, N_r = Rotor speed in Rpm, N_s = Synchronous Speed in Rpm, N_m = Speed at which Maximum Efficiency occurs, N_{sm} = Slip Speed at which Maximum Efficiency occurs, T_L = Load Torque in Nm, α = Angle between voltage and current

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