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Induction Motor Performance Analysis using H-Bridge Converter

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Abstract— **In this paper, the performance analysis of induction motor using floating H-bridge converter which connected to the grid is implemented using MATLAB Simulink. The H-bridge converter can be connected in series in-between utility grid and induction motor to inject voltage in series with grid voltage. This injected voltage is used to control the motor voltage to control the motor terminal voltage under steady state operation over entire load range to reduce the motor power losses. By inserting three phase H-bridge, the motor terminal voltage can be increase and decrease voltage relative to grid voltage as required. Due to H-bridge converter, the overall performance of induction motor is improved, especially; the efficiency, output power and power factor are improved. When induction motor is operated under rated voltage then maximum output power and efficiency can be achieved by controlling the voltage according to the square root of the measured motor input power. The controller and performance of three phase H-bridge converter are described in this paper. The controller of proposed work results in improved performance of three phase H-bridge and induction motor which illustrated using MATLAB Simulink.**

Keywords—Three phase induction motor, Series voltage, floating capacitor, H-bridge converter.

I. INTRODUCTION

About 50 millions of induction motors are installed every year. In industrial sector, the electrical energy are consumed typically 60-80% and 20-40% of electrical energy is consumed in commercial sector [4].

In power system, the most common problem is that of grid voltage disturbances. Sag and swell of voltage are the most frequent voltage disturbances which are caused by fault at remote bus. The induction motor is associated with energy loss of typically 15% [5, 6]. Hence, grid connected induction motor has major interest from economic and environment viewpoint. The electronics operating systems are used in the application of induction motors. These systems have the significance to achieve the saving of energy, cost reduction and provide grid voltage support. Variable frequency drive (VFD) is the most popular system. Implementation of power electronics to induction motor can be used to limit the starting current; to control the motor voltage under variety of situations; VAR compensation and voltage support; reduce the losses for lower input power. The transformer less three phase H-bridge system connected between grid and induction motor is shown in fig.1. The alternative option with open winding induction motor is also shown in fig.1. The three phase H-bridge can be implemented with 12 switches similar to back to back converter regenerative drive. Normally three phase H-bridge is operating on much lower dc link voltage.

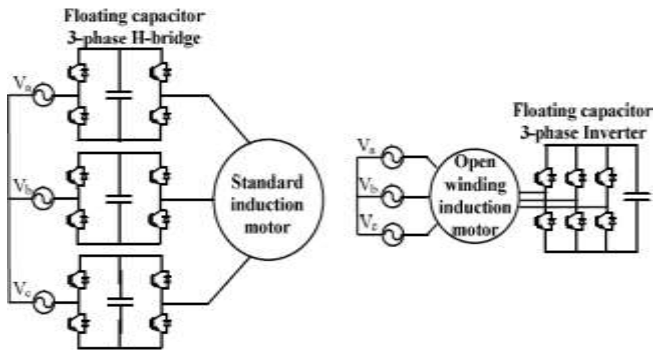

Fig.1 Series voltage compensation of grid connected; three phase H-bridge

To asses and compare the steady state performance of induction motor, this paper is utilizing the simulation data over a wide range of motor load condition. Different situations to analyze the data are:

1. Lower grid voltage, motor operating at rated voltage
2. Under variable load condition.

Additionally, proposed system is providing the operation associated with maximum efficiency and improved power factor by VAR generation.

II. PROBLEM RECOGNITION

To drive induction motor, the three phase H-bridge system has significant of soft starting which helps to increase and decrease the motor voltage under transient as well as steady state operation. This introduces the features of improvement in efficiency and independent of voltage fluctuations.

Different situations of motor voltage control by using H-bridge system are as below:

A. Motor voltage mismatch

Induction motors can be placed where the supply voltage may be continually fluctuating near to permissible voltage variance specified by NEMA (National Electric Manufacturing Association) [1]. The tolerance of higher copper loss and current is -10% and higher iron losses is associated with the tolerance of +10%. A example, in commercial and domestic application the mains are powered by 230V but the induction motors are nearly powered by 207V which insists to compromise the performance of induction motor; In practice at industrial sector, in the evening, the induction motors are lightly loaded as compare to day time loading of induction motor. Under these conditions, the voltage supplied to the induction motor is higher than its rated voltage which compromised motor efficiency [7].

B. Motor with load variation

The induction motors are manufacturing for peak load power. However, the induction motors can operate with low load factor for long duration.

The proposed work can solve these above problems. By proposed system, the induction motor can be operating at rated voltage over a wide load variation. Three phase H-bridge converter can increase and decrease the motor voltage at higher efficiency over wide range of load [2].

III. OPERATING PRINCIPLE

The supplied voltage to the induction motor can be increase or decrease as compared to grid voltage by injecting the phase voltage V_b which is at 90^o to motor current and the voltage across the bridge capacitor can be fluctuate as per the requirement.

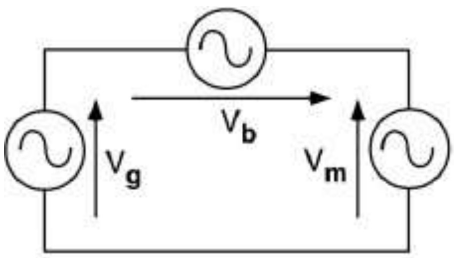

Fig.2 Equivalent per phase circuit

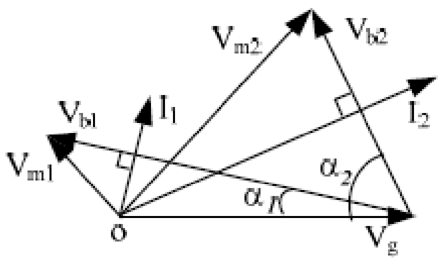

Fig. 3 Phasor analysis of voltage reduction

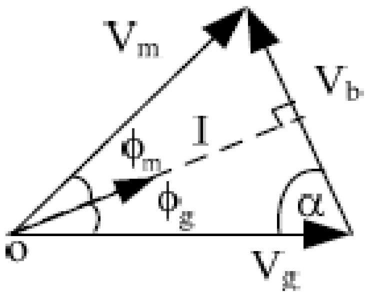

Fig. 4 Phasor analysis of control of rated motor voltage

The simplified equivalent per phase circuit diagram is shown in fig. 2. The phase voltage vector diagram for voltage reduction and rated motor voltage control are shown in fig. 3 and 4 respectively.

The bridge voltage V_b which is leading to the grid voltage V_g by an angle (180-α), injected to the grid voltage V_g which The motor voltage V_m can be reduced or control the rated motor voltage by using the angle α [3]. The bridge fundamental voltage V_b is at 90^o to the motor current to maintain zero net power flow to the bridge capacitor.

α can be increase or decrease with the angular range from 0 to 90^o. As α is increased, the motor voltage V_m is also increase and as α is decreased, the motor voltage V_m is also decrease. Hence the bridge capacitor is allowed to fluctuate with predefined range of an angle α which affects on power factor, to improve the motor power factor [8, 9]. The motor voltage can be set as per the requirement with the reference of grid voltage V_g and measured capacitor voltage. If the grid voltage V_g, phase and bridge dc voltage V_{dc} are known then α is set by the control scheme shown in fig. 3 and 4, to set the desired motor voltage V_m^* in such a way that:

$$\cos\alpha = \frac{V_g^2 + V_b^2 - V_m^2}{2V_gV_b} \qquad (1)$$

V_m^* represents the desired voltage for induction motor terminal voltage. V_m^* can be gradually increase in such a way that the induction motor current can be limit [3]. V_b is the fundamental component of voltage injected by H-bridge which is given by

$$V_b = \frac{m_a V_{cap}}{\sqrt{2}} \qquad (2)$$

resulting in the motor voltage V_m as shown in fig. 3 and 4.

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Where, m_a is the modulation index of H-bridge.

In this paper, the Pulse Width Modulation (PWM) is used. Modulation index is determined by using the equation (2). Modulation index m_a is fixed and set to 1.12 to minimize the bridge capacitor voltage. Normally, H-bridge is producing the ripple of low frequency. Measuring three capacitors voltages of low frequency ripple and taking the average of that measured voltage V_{dc}^{avg} which is used as feedback signal. The three phase H-bridge control scheme is shown in fig. 5.

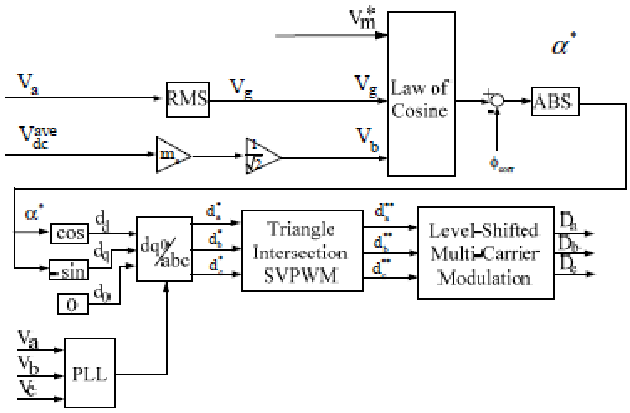

Fig. 5 Control scheme of proposed system

In fig. 5, Three quantities V_m, V_a, V_{dc}^{avg} are used as input to the control block and given to law of cosine. Output of law of cosine is α^* which is derived from equation (1). A phase correction ϕ_{corr} is set at 5^o in a proposed system. The inverse Park's transformation is used to converting the dq0 frame signal that are d_d,d_q,d_0 into the abc frame d_a^*,d *,d_c^*. These three signals are converted into modified signals d_a^{**},d **,d_c^{**} through Space Vector Pulse Width Modulation (SVPWM) [10-12]. The comparison of modified signals d_a^{**},d **,d_c^{**} and the carrier waves gives the gate signals D_a, D_b, D_c for H-bridge.

IV. MATLAB SIMULINK

A three phase H-bridge is choose for the Simulink with standard motor winding. A 5 hp, 230V is set for the MATLAB simulation where three H-bridges are placed between the grid and induction motor.

The induction motor is used with the rating of 5 hp, 60Hz, 4 poles, 230/460V, 12.6/6.3A, and 1760 rpm. IGBT is utilized as power electronic switch. H-bridge is having two legs which are separated by 8mF, 500V. Implementation of Induction Motor performance analysis using H-bridge with the help of MATLAB Simulaink is as shown in fig. 6.

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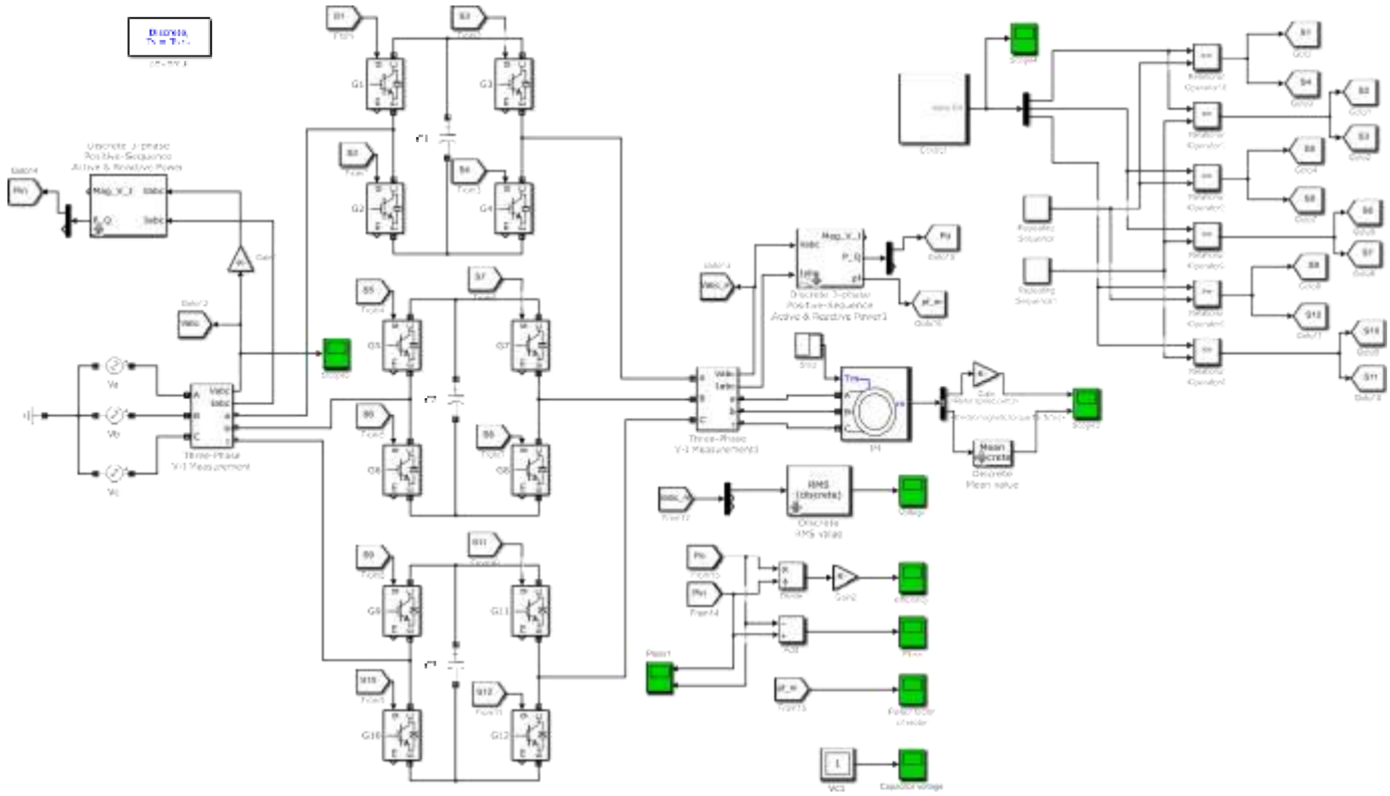
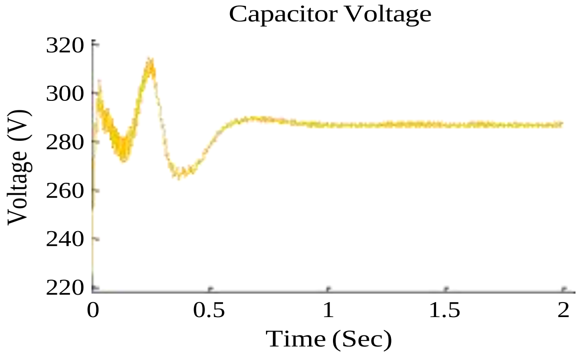


Fig. 6 MATLAB Simulink of Grid Connected Induction Motor

V. PERFORMANCE OF INDUCTION MOTOR

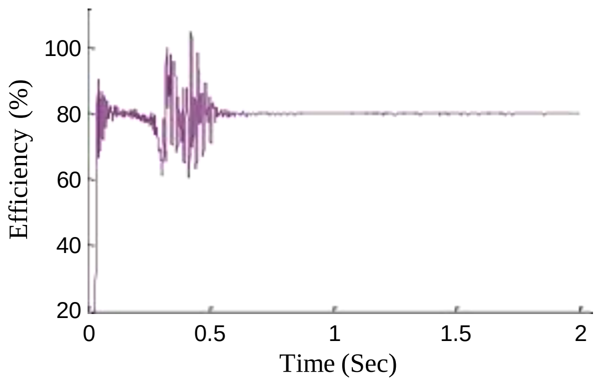
Motor is operated at the grid frequency and it is connected to the grid through three H-bridges. For performance comparison, Capacitor voltage, efficiency, losses and power factor are chosen as the main parameters for steady state analysis over the wide range of motor load.

Capacitor Voltage



(a)

Induction Motor Efficiency



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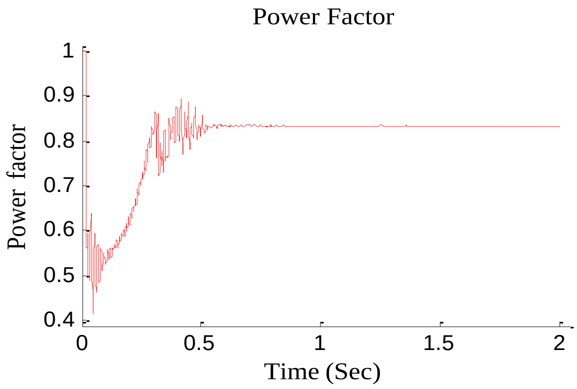

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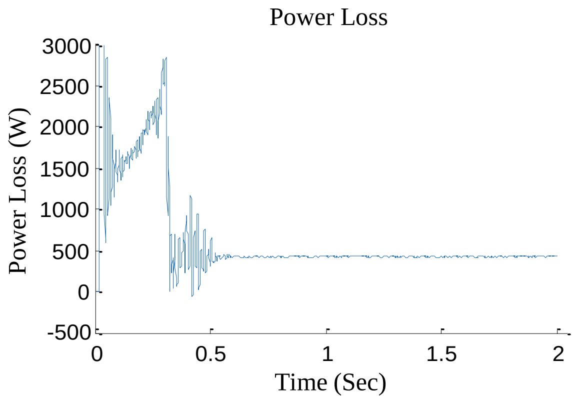

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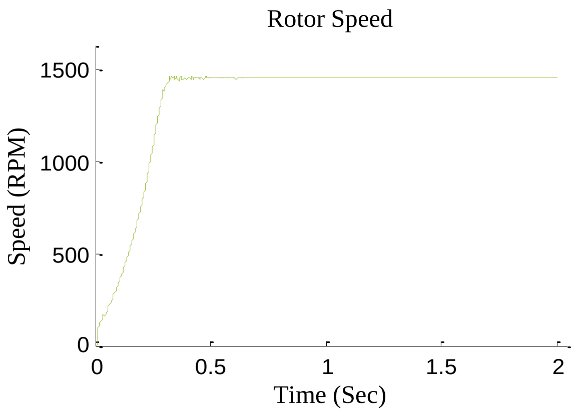


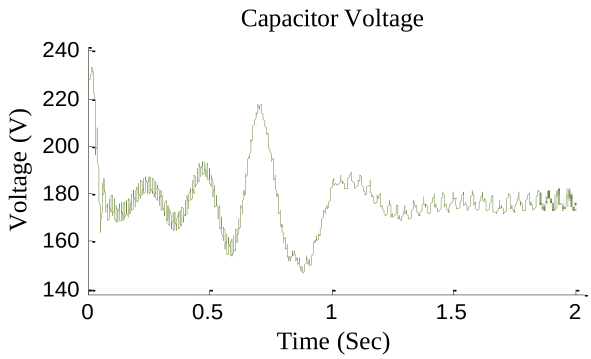
(e)

Fig. 7 Normal operation: (a) capacitor voltage (b) Motor efficiency (c) Power factor (d) Power loss (e) Rotor speed

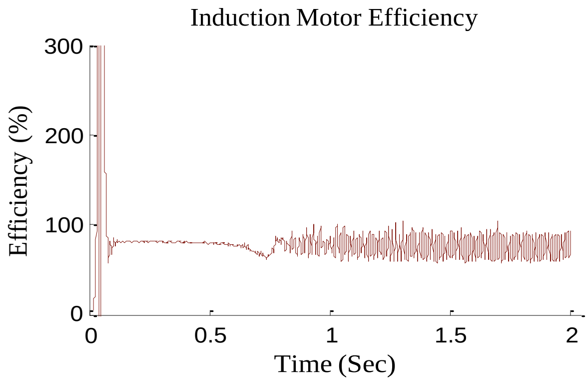
The performance of induction motor is not humiliated by the proposed three phase H-bridge. In case of $V_g = V_m$ The supply voltage of 230V is applied to the H-bridge. And capacitor has appeared the voltage of 280V. The validation of the same is done by the results from MATLAB Simulink as shown in fig. 7.

A. Voltage Mismatch

To inspect the voltage mismatch that is grid voltage is less than motor rated voltage, the grid voltage of 180V is applied to the H-bridge and the results of the same are shown in fig. 8. Fig. 8 illustrates that the motor performance is improved by using three phase H-bridge. Since the H-bridge can deliver the rated voltage to the induction motor which are not elevated to the temperature rise and increased power loss.



(a)



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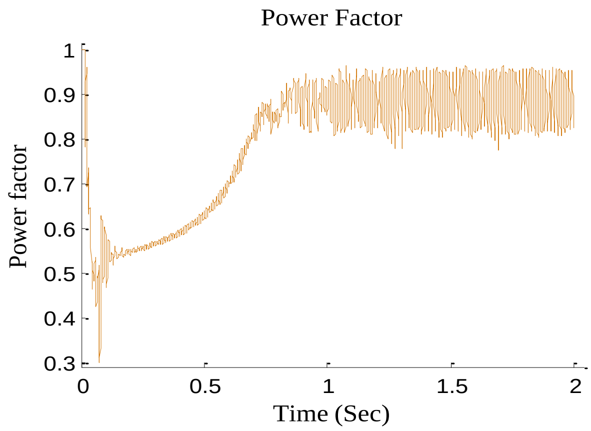

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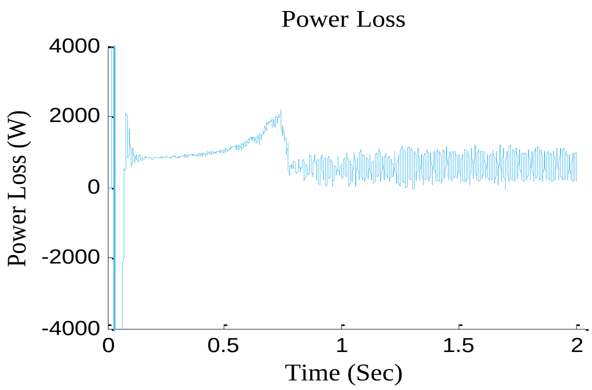

(d)

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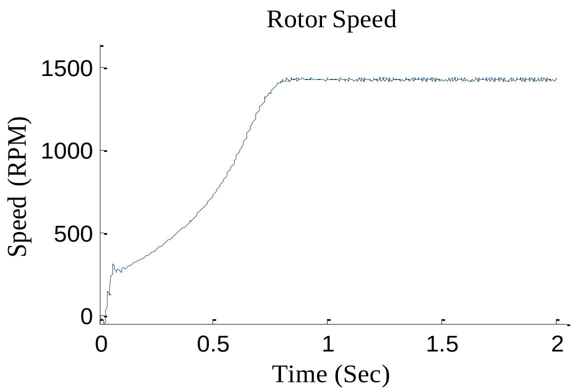


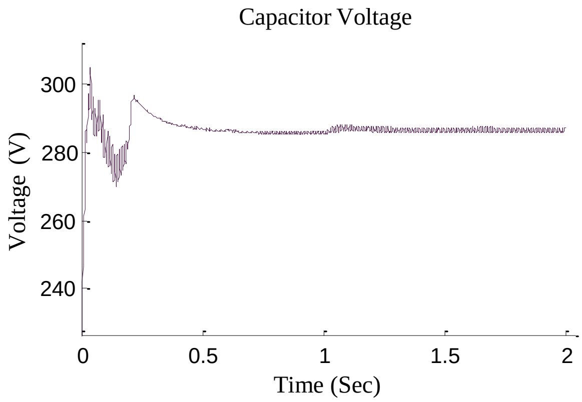
(e)

Fig. 8 Voltage Mismatch: (a) capacitor voltage (b) Motor efficiency (c) Power factor (d) Power loss (e) Rotor speed

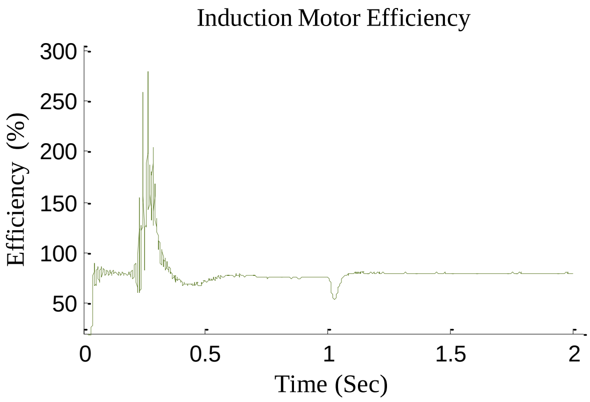
B. Load Variation

In this case, the motor terminal voltage is same as grid voltage with the supplied voltage of 230V but the load variation has been carried out in terms of load torque. The load torque 0.1 has been given for the run time of 1sec. At the run time of 1sec, the load torque has increased to 5.

After increasing the load, the capacitor voltage is remain same to maintain the performance of induction motor as shown in fig. 9. The power factor has improved with the help of H-bridge.



(a)



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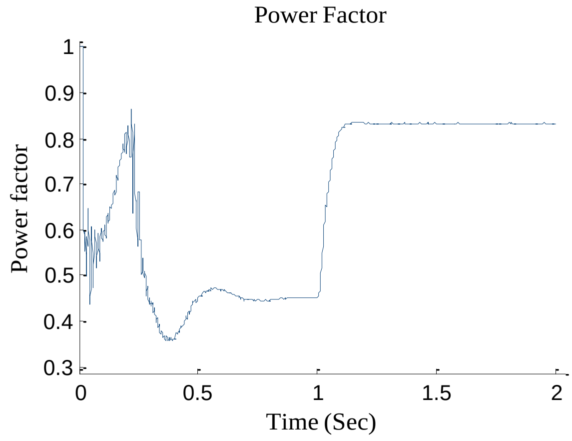

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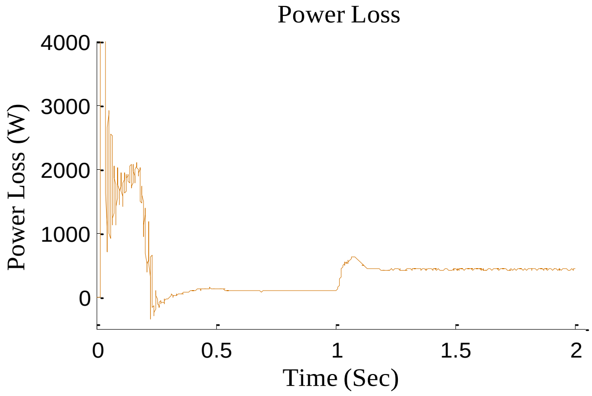

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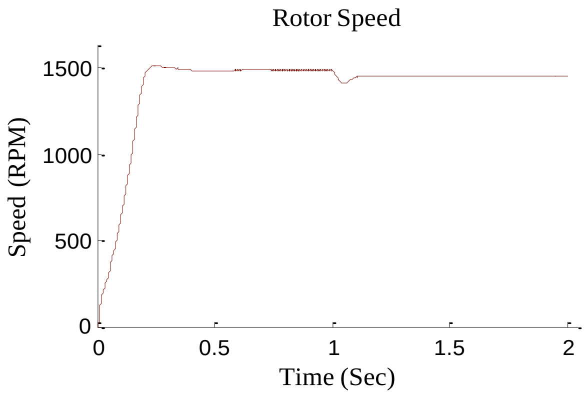

(e)

Fig. 9 Load variation: (a) capacitor voltage (b) Motor efficiency (c) Power factor (d) Power loss (e) Rotor speed

VI. CONCLUSION

The steady state performance of induction motor is offered when working with constant supply frequency. The analysis of induction motor performance has been carried out by using MATLAB Simulink with the two different cases as: (a) Voltage mismatch (b) Load variation, by introducing three phase H-bridge. The proposed system is verified to improved performance of induction motor that are (a) for voltage mismatch or with different voltage of grid and motor, the induction motor has improved performance (b) reducing the power losses which mean to lower temperature rise. The propped system is effective solution where the problem of voltage fluctuation and sag with feasible cost.

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