International Journal of Electrical and
Electronics Engineering (IJEEE)
ISSN(P): 2278-9944; ISSN(E): 2278-9952
Vol. 8, Issue 2, Feb- Mar 2019, 1-8

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

DESIGN AND PERFORMANCE EVALUATION OF CEILING FAN, MOTOR USING MATLAB

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ABSTRACT

Induction motors find applications in a wide range of application the overall performance of induction motors depends heavily on the quality of supply voltage and frequency fluctuations. The aim of this work is analyzing the effect of voltage variation under no load conditions as well as loaded conditions on the performance characteristics of the ceiling fan. The method adopted for this work involves a successive variation of voltages from 180V to 220V under the stated conditions above. A mathematical model of the capacitor starts, capacitor run is carried out using MATLAB SIMULINK. The process is set up and the Simulink carried out to illustrate the variation in voltage and the consequent effect on efficiency and speed respectively under the condition stated above. The results obtained show a clear increase in efficiency with increasing voltage under the no-load condition, which negates the standard operating principles of a ceiling fan motor (single phase motor). Under loaded condition however, therefore, was a reduction in efficiency which is in tandem with standard operating principles. The result is tabulated in the table shown for easy perusal and referencing and recommendation on improvement is cited in the later part of the work.

KEYWORDS: *Ceiling Fan, Induction Motor, Capacitor Start Motor, Motor Performance*

Article History

Received: 26 Nov 2018 | Revised: 17 Jan 2019 | Accepted: 29 Jan 2019

INTRODUCTION

Ceiling fan motors are essentially induction motors employing the principle of Electromagnetic induction in the performance of their operations. The optimal performance of a ceiling fan would, therefore, depend greatly on the health of the induction motor employed. Basically, single phase induction motors are employed in the design of ceiling fans. Ceiling fan motors present an exciting, yet challenging aspect of cooling this is due to their small weight, low cost and very high efficiency Atui M. et al, (2012).

Single-phase induction motors are similar to those of three-phase induction motors except that the stator has a winding suitable of operation from a single-phase supply only instead of a winding type generally used with poly-phase machines. Performance characteristics of single-phase induction motors are less satisfactory than three-phase induction motors. In recent years, there has been strong growth in the use of small capacity portable motor-driven appliances in various industrial, commercial, rural and domestic sectors. For these applications, it is most practical to utilize single-phase motors. In addition, there are large regions in the world especially rural & remote sectors, where only single-phase distribution network are used to supply electricity to the few consumers involved. All these factors have together resulted in a steadily growing demand for reliable single-phase motor. Elwy E. et al (2005).

The electrical parameter design of the ceiling fan motor is based on the idea that it will be operating in such a way that the speed will vary as a function of a varying input voltage set by standard fan regulator speed settings. The magnetic material used to design motor has an impact on the voltage. Its unique design operating structure is such that when the output of the motor is subjected to a varying load and load power factor (lagging) with less than unity, the output speed of the motor will change Jatin J.P, et al (2014).

Also when the motor is subjected to a line current change, the output torque will also change. The regulation of a ceiling fan motor can be designed to be better than a few percents. Investigations have shown that Proper operation and power capacity of a ceiling fan motors depends on the inductor and capacitor values used in the design system. Hence the circuit is designed assuming that the input voltage is a sinusoidal input voltage, with an ideal input inductor, L, and a series capacitor, C connected to a capacitor step-up winding so as to isolate the output from the input. Experience has shown that the LC relationship is:$LC\omega^2$ Jim Hendershot (2012).

During the design process the values for input voltage range (V_{in}), line frequency (f), output Voltage (V_{out}), output power (VA), motor current density(J), capacitor voltage (V_c), capacitor coefficient (K_c), Efficiency goal (100)), magnetic material, flux density (B), and Temperature rise goal (T_r) was been specified while others are been derived and calculated. The derived parameters include: stator (V_s), Reflected Resistance back to the stator ($R_{o(R)}$), the required capacitance (C), the new capacitance value using the higher voltage across the capacitor (C_n), the capacitor current (I_c), the rotor current (I_r), the stator current (I_s), the apparent power (P_t), the number of turns stator winding (N_p), the stator bare wire area ($A_{ws(B)}$), the stator resistance (R_s), the stator copper loss (P_s), the required turns for the capacitor winding (N_c), the capacitor winding bare wire Area ($A_{wc(B)}$), the capacitor winding resistance (R_c), the capacitor winding copper loss (P_c), the number of turns for the secondary (N_s), the rotor bare wire Area ($A_{ws(B)}$), the rotor winding resistance (R_s), the rotor winding copper loss (P_s), the total copper loss (P_{cu}), the watts-per-kilogram (W/K), the core loss in watts (P_{fe}), the total losses (P_Σ), the motor surface watt density (ψ), the temperature rise (T_r), and the motor efficiency (η), Nithia K. et al (2013).

Purpose of Study

The correct working of the ceiling fan is directly related to the motor performancecharacteristics, therefore it becomes necessary to evaluate the performance of these motors in relation to voltage variation and other power quality issues.

Statement of Problem

The performance of a ceiling fan is dependent on the motor design and by extension the efficiency of the motor. However the major constrain to the optimal performance of the single-phase induction motor required for the operation of the ceiling fan includes variation in voltage and frequency fluctuations. To get the ceiling fan to operation efficiently, these parameters must operate at rated conditions.

This study proposes to establish the relationship between motor design and performance of ceiling fans by carrying out a comparative evaluation of the performance characteristics of motors for ceiling fans.

Scope and Limitation of Study

The design of this motor is such as to operate at a related frequency of 50Hz and a voltage of between 180-220V to analyze the speed and efficiency. It is to be noted that at zero loading, the motor increased voltage from 180V to 220V which resulted in an increased in efficiency from about 73.59% to 82.14%. This however is against the standard operating principle of a ceiling fan motor. However, with the rated voltage increased under a loaded condition from 180V-220V speed was increased to 321rpm with a consequent reduction in efficiency from about 89% to 85.84%.

DESIGN METHODOLOGY AND ANALYSIS

Table 1: Electrical Design Specified Parameters

Electrical Parameters	Specified Value
Input voltage range, V_{in}	180-220Volts (about 20% variation)
Line frequency, f	50Hertz ± 2.5%
Output voltage, V_r	220 ± 5%Volts
Output power P_0	50 Watts
motor current density, J	300 amps/cm^2
Capacitor voltage, V_c	440 Volts
Capacitor coefficient, K_c	1.5
Efficiency goal, η(100)	85%
Magnetic material	Silicon
flux density, B_s	1.95 Tesla
Temperature rise goal, T_r	50^{0}C
Power factor, cosΦ	0.95

The electrical parameter design equations and calculations are done following the other as shown below:

Stator voltage,

$$V_s = V_{in\,(min)} \cos\Phi = (180)(0.95) \quad = 171.0 \text{ [Volts]} \qquad 2.1$$

Reflected resistance back to stator,

$$R_{o(R)} = \frac{(V_s)\eta}{P_o}, = \frac{(171.0)(0.85)}{50} = 2.89\text{[ohms]} \qquad 2.2$$

Required inductance and capacitance

$$L = \frac{R_{o(R)}}{2\omega} = \frac{2.89}{2\times 377} = 0.00383 \approx 0.0038[Henry] \qquad 2.3(a)$$

$$C = \frac{1}{3.3\omega R_{o(R)}} = \frac{1}{3.3(377)(2.89)} = 0.000278\text{[farads]} \qquad 2.3(b)$$

The new capacitance value using the higher voltage,

$$C_n = \frac{C(V_s)}{(V_c)^2} = \frac{(0.000278)(171.0)}{(440)^2} = 2.455\mu F \qquad 2.4$$

The capacitor current

$$I_c = K_c V_c \omega C = 1.5(440)(377)(2.455 \times 10^{-6}) = 0.61 \text{ [Amps]} \qquad 2.5$$

The rotor current

$$I_r = \frac{P_o}{V_r} = \frac{50}{220} = 0.227[Amps]. \quad 2.6$$

The stator current related to the rotor due to capacitor winding

$$I_s = \frac{I_r(V_r)}{\eta(V_s)}\left[1 + \sqrt{\frac{V_r}{V_c}}\right] = \frac{0.227(220)}{0.85(171.0)}\left[1 + \sqrt{\frac{171.0}{440}}\right] = 0.5577[amps] \quad 2.7$$

The number of stator turns

$$N_s = \frac{V_s(10^4)}{K_f B f A_c} = \frac{171.0(10^4)}{4.44 \times 1.95 \times 50 \times 18.8} = 210.11 \cong 210[turns] \quad 2.8$$

The stator bare wire area

$$A_{ws(B)} = \frac{I_s}{J} = \frac{(0.5577)}{(300)} = 0.00185925[cm^2] \quad 2.9$$

Designing the Mechanical Parameters

Table 2: Specified Mechanical Parameters and Values

Mechanical Parameters	Specified Values
Windows Utilization, K_u	0.4
Core number	EI-175
Magnetic path length, MPL	26.7 cm
Core weight, W_{tfe}	3.85 kilograms
Mean Length Turn, MLT	35.6 cm
Iron Area, A_c	18.8 cm^2
Window Area, W_a	15.1 cm^2
Area product, A_p	300 cm^4
Core geometry, K_g	83.5 cm^2
Surface Area, A_t	655 cm^2
Winding length, L_g Lamination tongue, E	0.276.cm 3.49 cm
No. of poles No. of stator slots / Magnet poles No. of laminations on stator Thickness of stator lamination No. of turns/ coil Overall diameter of motor Winding conductor diameter Outer diameter of the magnet Inner diameter of the magnet Thickness of the magnet (mm) Axial length of the magnet (mm) Outer diameter of the stator (mm) Axial length of the stator (mm) Length of air gap (mm) Thickness of the rotor back iron (mm) Axial length of the back iron (mm) Shaft diameter (mm) Weight of copper	18 9 / 18 49 0.51(mm) 450 140.9 (mm) 0.47/ 26 (mm/ AWG) 137.3(mm) 121.76 (mm) 7.77(mm) 34.5 (mm) 120.00 (mm) 25.00(mm)

Weight of magnet Weight of iron in stator laminations Weight of rotor back iron	0.88 (mm) 1.80 (mm) 56.74 (mm) 17~18 (mm) 442.8 (gm) 392 (gm) 997.30 (gm) 338.20 (gm)

The other mechanical parameters are calculated as follows:

The Area Product, A_p.

$$A_p = \frac{P_t(10^4)}{K_f K_u f B_s J} = \frac{(1544.77)(10^4)}{(4.44)(0.4)(50)(1.95)(300)} = 297.368[cm^4] \qquad 2.10$$

The window utilization, K_u

$$K_u = \frac{N_s A_{ws(B)} + N_c A_{wc(B)} + N_r A_{wr(B)}}{W_a} = \frac{((210)(0.00930)) + ((330)(0.01013)) + ((270.17)(0.00387))}{(15.1)} = 0.419 \qquad 2.11$$

Simulink Analysis of the Ceiling Fan Induction Motor

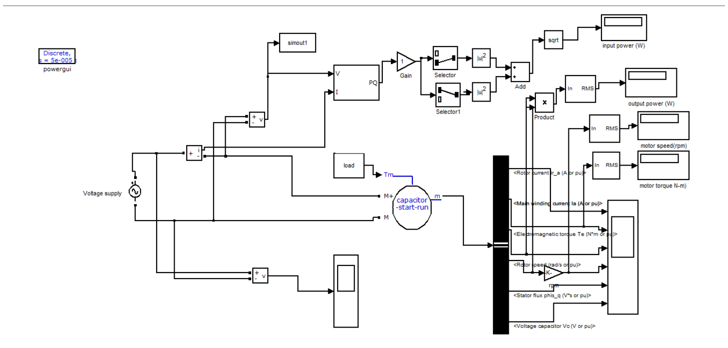

Figure 1: Matlab Simulink of the Ceiling Fan Motor Design

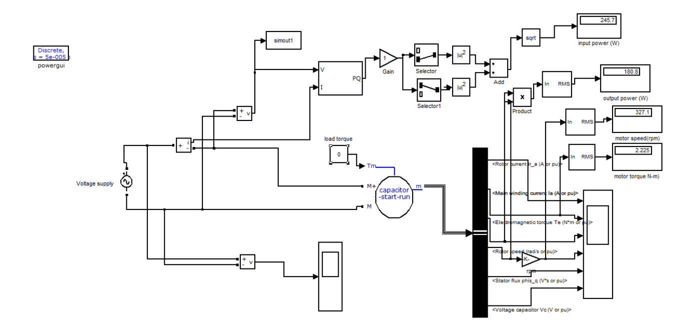

Figure 2: Matlab Simulink of the Motor Undersupply of 180V at Zero Loading

The specifications for the motor model are the values calculated and gotten from the manufacturer data sheet.

RESULT ANALYSIS AND DISCUSSIONS

The waveform in figure 3 shows the values of the Rotor current, main winding current, electromagnetic Torque, motor speed and voltage of the capacitor.

While figure 4 shows the waveform of the motor performance when the motor runs at its full load torque of 12Nm hence has a more stable speed performance although at the same voltage of 180V.

The result got from figure 3 and figure 4 shows a very close agreement with the expected speed of 333rpm based on the design specification. This is in concord with the principle underlying ceiling fan motor designs.

Table 4-9

Wire Table

AWG	Bare Area		Resistance μΩ/cm 20°C	Heavy Synthetics								
				Area		Diameter		Turns-Per		Turns-Per		Weight
	$cm^2(10^{-3})$	cir-mil		$cm^2(10^{-3})$	cir-mil	cm	Inch	cm	Inch	cm^2	$Inch^2$	gm/cm
1	2	3	4	5	6	7	8	9	10	11	12	13
10	52.6100	10384.00	32.7	55.9000	11046.00	0.2670	0.105	3.9	10	11	69	0.46800
11	41.6800	8226.00	41.4	44.5000	8798.00	0.2380	0.094	4.4	11	13	90	0.37500
12	33.0800	6529.00	52.1	35.6400	7022.00	0.2130	0.084	4.9	12	17	108	0.29770
13	26.2600	5184.00	65.6	28.3600	5610.00	0.1900	0.075	5.5	13	21	136	0.23670
14	20.8200	4109.00	82.8	22.9500	4556.00	0.1710	0.068	6.0	15	26	169	0.18790
15	16.5100	3260.00	104.3	18.3700	3624.00	0.1530	0.060	6.8	17	33	211	0.14920
16	13.0700	2581.00	131.8	14.7300	2905.00	0.1370	0.054	7.3	19	41	263	0.11840
17	10.3900	2052.00	165.8	11.6800	2323.00	0.1220	0.048	8.2	21	51	331	0.09430
18	8.2280	1624.00	209.5	9.3260	1857.00	0.1090	0.043	9.1	23	64	415	0.07474
19	6.5310	1289.00	263.9	7.5390	1490.00	0.0980	0.039	10.2	26	80	515	0.05940
20	5.1880	1024.00	332.3	6.0650	1197.00	0.0879	0.035	11.4	29	99	638	0.04726
21	4.1160	812.30	418.9	4.8370	954.80	0.0785	0.031	12.8	32	124	800	0.03757
22	3.2430	640.10	531.4	3.8570	761.70	0.0701	0.028	14.3	36	156	1003	0.02965
23	2.5880	510.80	666.0	3.1350	620.00	0.0632	0.025	15.8	40	191	1234	0.02372
24	2.0470	404.00	842.1	2.5140	497.30	0.0566	0.022	17.6	45	239	1539	0.01884
25	1.6230	320.40	1062.0	2.0020	396.00	0.0505	0.020	19.8	50	300	1933	0.01498
26	1.2800	252.80	1345.0	1.6030	316.80	0.0452	0.018	22.1	56	374	2414	0.01185
27	1.0210	201.60	1687.0	1.3130	259.20	0.0409	0.016	24.4	62	457	2947	0.00945
28	0.8046	158.80	2142.0	1.0515	207.30	0.0366	0.014	27.3	69	571	3680	0.00747
29	0.6470	127.70	2664.0	0.8548	169.00	0.0330	0.013	30.3	77	702	4527	0.00602
30	0.5067	100.00	3402.0	0.6785	134.50	0.0294	0.012	33.9	86	884	5703	0.00472
31	0.4013	79.21	4294.0	0.5596	110.20	0.0267	0.011	37.5	95	1072	6914	0.00372
32	0.3242	64.00	5315.0	0.4559	90.25	0.0241	0.010	41.5	105	1316	8488	0.00305
33	0.2554	50.41	6748.0	0.3662	72.25	0.0216	0.009	46.3	118	1638	10565	0.00241
34	0.2011	39.69	8572.0	0.2863	56.25	0.0191	0.008	52.5	133	2095	13512	0.00189
35	0.1589	31.36	10849.0	0.2268	44.89	0.0170	0.007	58.8	149	2645	17060	0.00150
36	0.1266	25.00	13608.0	0.1813	36.00	0.0152	0.006	62.5	167	3309	21343	0.00119
37	0.1026	20.25	16801.0	0.1538	30.25	0.0140	0.006	71.6	182	3901	25161	0.00098
38	0.0811	16.00	21266.0	0.1207	24.01	0.0124	0.005	80.4	204	4971	32062	0.00077
39	0.0621	12.25	27775.0	0.0932	18.49	0.0109	0.004	91.6	233	6437	41518	0.00059
40	0.0487	9.61	35400.0	0.0723	14.44	0.0096	0.004	103.6	263	8298	53522	0.00046
41	0.0397	7.84	43405.0	0.0584	11.56	0.0086	0.003	115.7	294	10273	66260	0.00036
42	0.0317	6.25	54429.0	0.0456	9.00	0.0076	0.003	131.2	333	13163	84901	0.00030
43	0.0245	4.84	70308.0	0.0368	7.29	0.0069	0.003	145.8	370	16291	105076	0.00024
44	0.0202	4.00	85072.0	0.0316	6.25	0.0064	0.003	157.4	400	18957	122272	0.00019

Figure 3

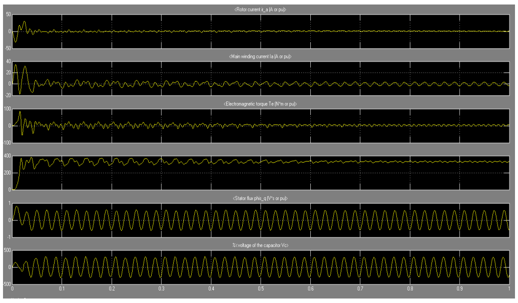

Figure 4: Motor Performance Operating under 180V Supply and a Zero Load Torque

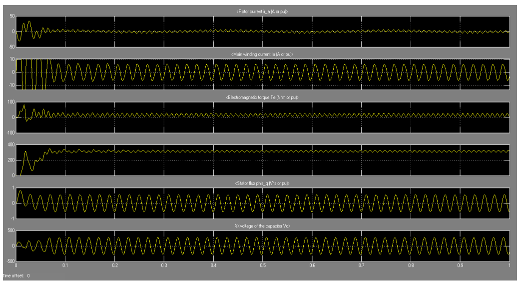

Figure 5: Motor Performance Operating under 180V Supply and Full Load Torque (12Nm)

The simulations above are initially carried out with specified data showing the voltage variation range. The motor is said to be set under standard operating data based on its rated value of 230V, 1□, 50Hz, 50W ratings. The parameters used for the motor winding resistance, inductances, inertia, number of turns, turns ratio, friction factor and winding core dimensions and wire dimensions are calculated based on the design equations.

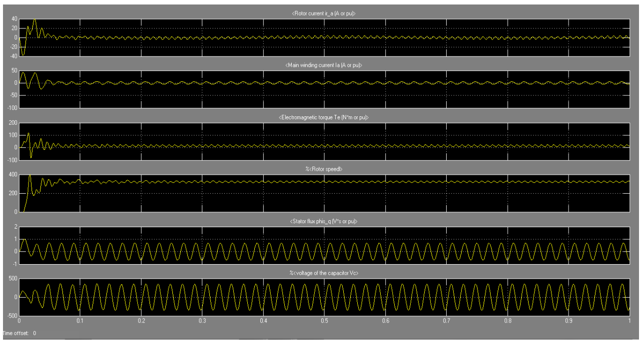

Figure 6: Shows the Variation of the Speed and Other Parameters under a Supply Voltage of 220V

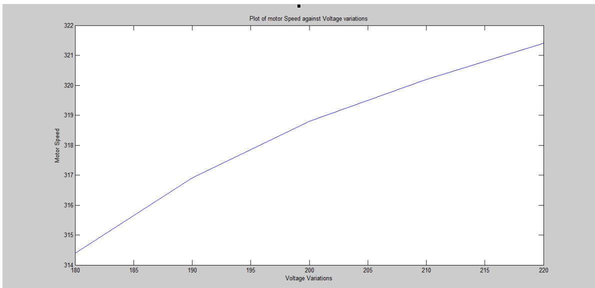

Figure 7: Plot of Motor Speed against Voltage Variations

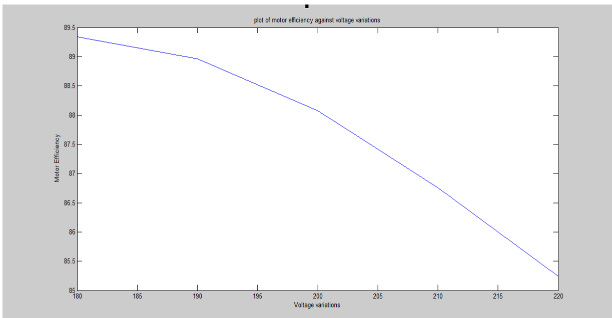

Figure 8: Plot of Motor Efficiency against Voltage Variations

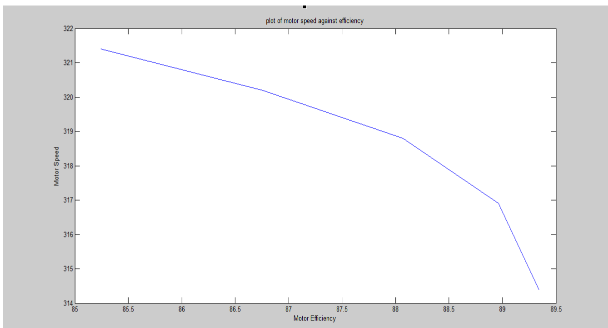

Figure 9: Plot of Motor Speed against Motor Efficiency

CONCLUSIONS

Ceiling fan motor design affects the efficiency of the motor and hence overall performance of the ceiling fan itself. The speed of the motor can be proper design taking cognizance of factors such as speed, torque etc and of voltage and current relationship enhances the motor efficiency and general performance of ceiling fans. It is therefore imperative to design ceiling fan motors for optimal performance. The design process is not without its own fans and one challenge which mostly comprises of cost.

RECOMMENDATIONS

Replacing the conventional one phase induction motor with energy efficient is a phase induction motor. This can be achieved through the following approaches;

- Increase in copper bars
- Increase in iron.

Another means of ensuring improvement is replacing the conventional I phase induction motor with single or time phase permanent magnetic block direct current motor.

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