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PERFORMANCE PREDICTION OF INDUCTION MOTOR UNDER THE INFLUENCE OF VOLTAGE UNBALANCE

Mr P Sethupathi[1] , P Pranesh[2]
,D Sandhiya[3] , K Sri charan[4] ,
V Sudhakar[5]
Assistant professor (Sr G),
Department of EEE,
Kongu Engineering College,
Erode, India.
sethupathi.eee@kongu.edu

Abstract - Electric motors are used to drive majority of the applications such as pump, compressor, conveyor, machine tools, and crusher etc., for industrial, commercial and agricultural purpose. Hence almost major portion of the generated electrical energy is consumed by electric motor particularly three phase induction motor. Voltage unbalance is the unavoidable issue present in the power system which reduces the operating performance of the induction motor. During power generation and transmission Voltage measured across neutral line is almost equal in all three phases, but during distribution, voltage across the three phases are varies from one phase to another due to uneven single-phase loading, unbalanced power factor improvement capacitor bank and fault or open circuit. In this proposed work various motor performance parameter like losses, efficiency and input power consumption of three phase squirrel cage induction motor under the influence of various voltage unbalance condition (0%, 2.5% and 5.5%) are studied and reported using RMxprt and Simplores. The proposed method provides accurate result which is more useful to reduce the performance degradation due to Voltage Unbalance during design stage. Results of the proposed Co-Simulation method is validated with the prototype testing and existing analytical Method. By considering Voltage Unbalance effect in the design of Induction Motor huge amount of operating cost is saved for the industrial consumer and also for the government in terms of subsidy, if we design the motor to withstand the voltage unbalance effects.

Key words: Induction motor, Voltage unbalance, RMxprt and Simplores.

1.INTRODUCTION TO VOLTAGEUNBALANCE

Three phase induction motor consumes almost 70% of the total generated electricity and it is used in verities of industrial and commercial application. It makes attention to the user because of its inherent simple construction, low cost and maintenance free operation. Absence of slip-rings and brushes makes more interest on user because it can be used for hazardous applications like coal mining, petrochemical industries etc., Voltages unbalance is an unavoidable incidence happen in the power system due to various in voltage from one phase to another. Unbalance voltage exists in almost all three-phase power system networks. The level of unbalance is considerably large in weak power systems and also those supplying large single- phase loads. The presence of unbalance is mainly due to unbalanced single-phase uneven loadings, faults, and unbalanced power factor correction capacitor. The single-phase uneven loadings, the resistance of the three-phase system are identical but current is solely depending upon the load. Hence it leads to uneven voltage drop in three phases system which cause voltage unbalance. Improper motor design, faulty operation of power factor correction equipment, an open circuit on the distribution system primary, unbalanced transformer bank, two-phase to three-phase converting capacitor for agricultural purposes, tree touching the line these are also the major reasons for voltage unbalance. These disturbances will cause to reduce the quality of electrical power and it will generate massive losses to the power consumer. The operation of induction motor under voltage unbalance conditions develops two rotating fields one that rotates in motor shaft rotation direction (positive sequence) and the other one which is rotating in opposite to that shaft rotation (negative sequence). If we, operates motor under voltage unbalance for long time leads which leads to raise the temperature of motor to a large extent more than the normal condition. There are two types of voltage unbalances, one is the voltage of three phases are different and their phase angles are equally spaced by 120 degree with each other. Another type of voltage unbalance is three phase voltages are same and angles of them are not displaced equally by 120 degree with each other. The former one is most commonly occurred voltage unbalance and the later one is mostly not occurred because of transformer, generator and transmission systems are designed well to avoid voltage unbalance in distribution side. As per NEMA and IEC standards operations of any electrical apparatus above 5% is not recommended. If it exceeds so, performance of motor will affected and motor starts de-rating. For this analysis 0%, 2.5%, 5.5% voltage unbalance factors are considered. Other authors are considered the effect of negative sequence on motor and by using software they analyze the line current, losses, output power, and efficiency. The effect of voltage unbalance leads to low operating efficiency and power factor which leads to increase the input power consumption, hence user has to pay more electricity bill because of voltage unbalance in the system. Three phase induction motor consumes more than half of the generated electricity worldwide. Because of the low efficiency motor due to voltage unbalance will indirectly increase the overall power wastage as a losses and also indirectly increases the greenhouse gas emission to the environment. Voltage unbalance cause excess losses and its associated temperature rise which also leads to reduce the life time of the motor. Voltage unbalance in the power system unbalances the current which will again increases the voltage unbalance. The various studies proposed in the existing literature are relatively complicate because it involves huge analytical calculations also motor can be analysed only after the post development of three phase squirrel cage induction motor. Because of rapid emerging technologies, Industries for designing an motor they are using motor designing software, by using this we can change the parameters of the motor before manufacturing and reduce the voltage unbalance effects. Hence in this paper a new approach is introduced to exactly identify the impact of voltage unbalance in induction motor. It will provide platform for the designer to eradicate the excess losses in induction motor due to voltage unbalance during design stage. The result of the proposed method is confirmed with the support of existing analytical method and 1 hp induction motor prototype testing.

2.ANSYS COSIMULATION

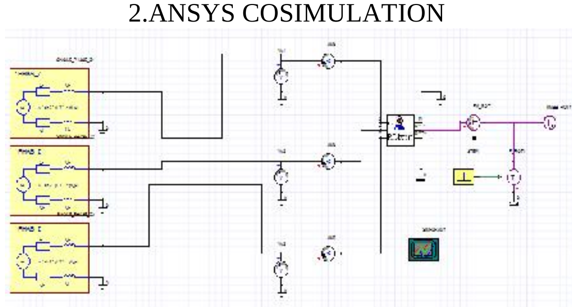

Fig.2.THREE-PHASE INDUCTION MOTOR DESIGN

The above diagram is the design of a three phase induction motor. This diagram drawn by using Ansys software. For input we take three single phase supply. In order to measure the three phase current, voltages separately, we connected the voltmeter and ammeter across each phase. RMxprt block represents the three phase induction motor. For analysing three phase induction motor under voltage unbalance conditions, we import the motor to Ansys implorer software. For loading, the necessary things are given. We analyse by giving three different voltages. For zero percent unbalance we give the same voltage to all phases and note the performance. For 2.5% and 5.5% VUF we give unbalanced voltage by using this circuit.

2.1. EFFECTS OF 0% VUF

In this condition the motor run with balanced supply. Three phases of the motor are feed with same voltage. The performance of an induction motor is not affected in the voltage balanced conditions. The following graphs shows the three-phase balanced voltage, current, torque and speed characteristics under balanced voltage conditions

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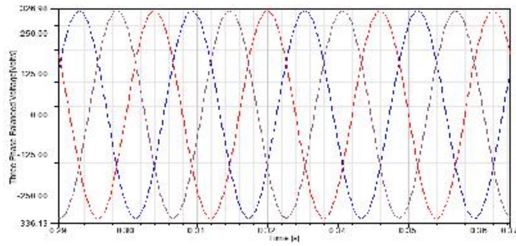

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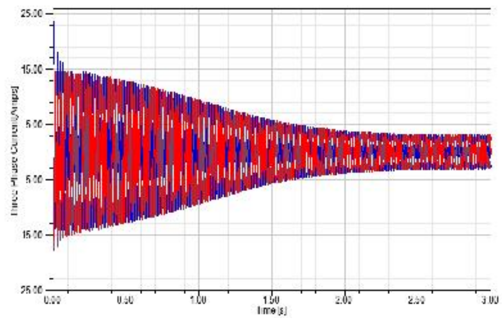

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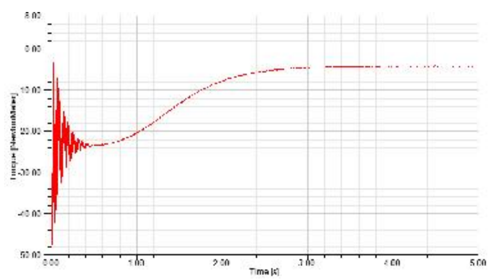

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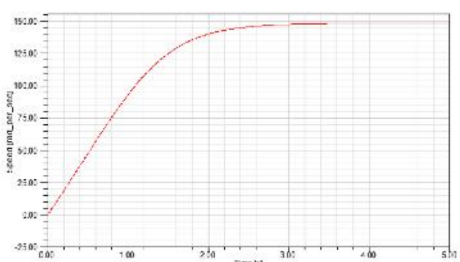

(d)

Fig.2.1 (a),(b),(c),(d) represents the voltage, current, torque and speed waveform for 0% VUF

2.2. EFFECTS OF 2.5% VUF

Journal of Current Research in Engineering and Science
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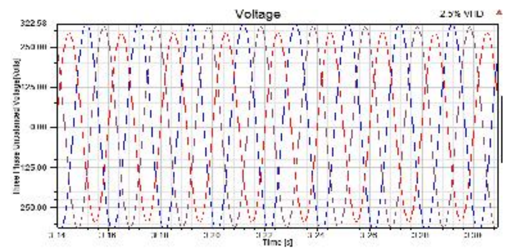
Volume 5- Issue 2, Paper 16 August 2022

The motor is supplied with unbalanced condition and performance are evaluated.



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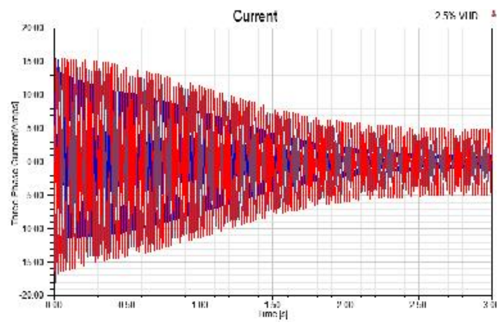

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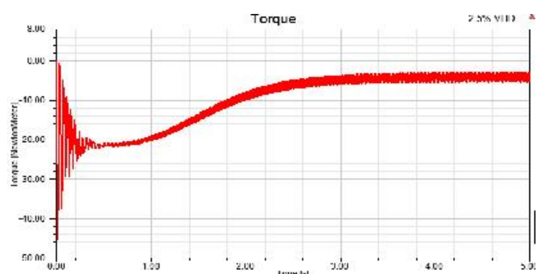

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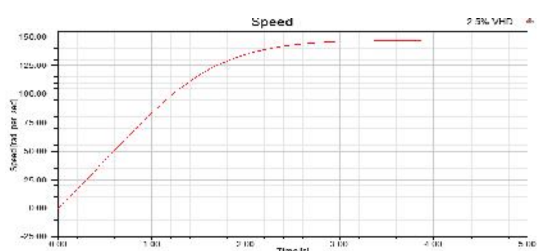

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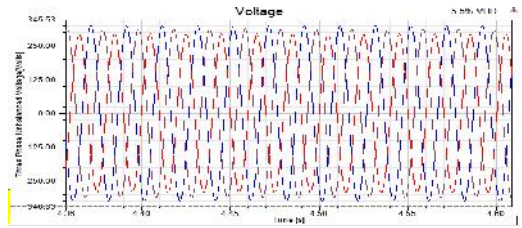
Fig.2.2 (a),(b),(c),(d) represents the voltage, current, torque and speed waveform for 2.5% VUF

2.3. EFFECTS OF 5.5% VUF

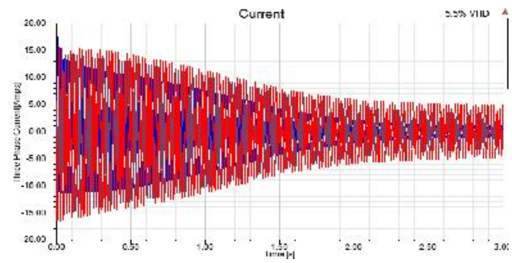
P Sethupathi[1], P Pranesh[2], D Sandhiya[3]

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 5- Issue 2, Paper 16 August 2022



(a)



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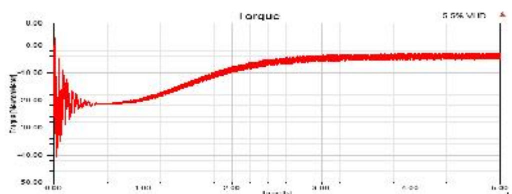

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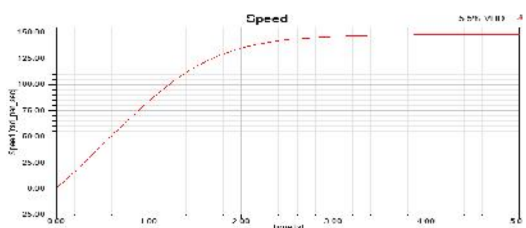

(d)

Fig.2.3 (a),(b),(c),(d) represents the voltage, current, torque and speed waveform for 5.5% VUF

3.TESTING OF INDUCTION MOTOR

The efficiency of small motors can be determined by direct load testing and by measuring their parameters like input power, output power, torque by using this parameters we find the efficiency of an induction motor. But for a larger motors it may be difficult to arrange loads for them. Moreover power loss will be large with direct loading tests. The cost for conducting load test on induction motor is high. Thus no load and blocked rotor tests are performed on the motors.

3.1. PERFORMANCE TEST

Journal of Current Research in Engineering and Science
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Volume 5- Issue 2, Paper 16 August 2022

Need for load testing on athree-phase induction motor are discussed as follows:

- The load test on an induction motor is conducted to compute the motor performance completely
- Torque, Slip, Efficiency, Power factor can be accurately obtained by performance test
- This will reduce the energy consumption and losses of an induction motor in working atmosphere

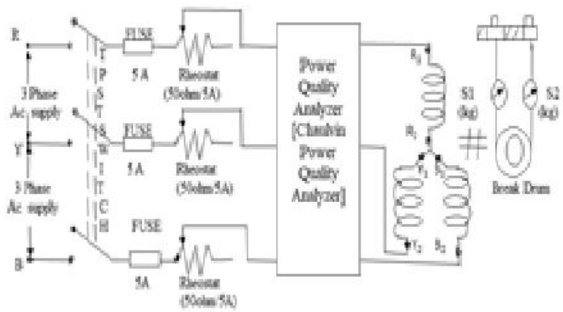


Fig 3.1(a) Circuit diagram for a performance test of an induction motor.

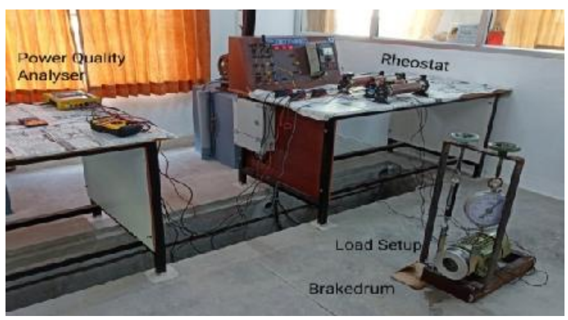


Fig. 3.1(b) Experimental setup for load testing of three phase induction motor

Table 1 Showing the experimental data of an three phase induction motor

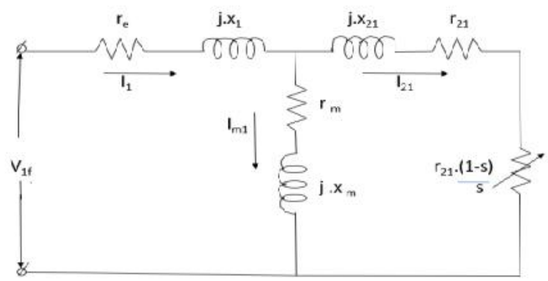
% VUF	V_R	V_Y	V_B	I_R	I_Y	I_B	INPUT POWER (W)	SPEED (RPM)	TORQUE	
									S1	S2
0	233.9	233	234	2	2	2	804.5	1358	11	4.6
2.5	220.4	226.1	232	2.2	2	1.9	802.1	1330	11	4.5
5.5	207.2	221.5	229.5	2.4	2.1	1.8	829.5	1308	11	4.6

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)

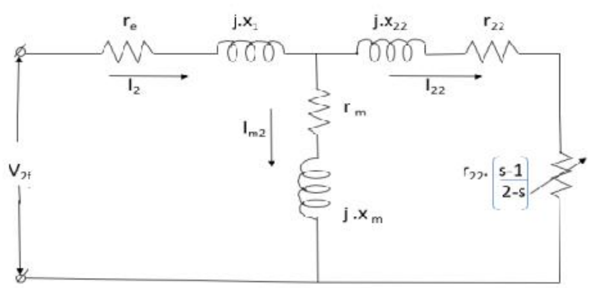
Volume 5- Issue 2, Paper 16 August 2022

4.ANALYTICALMETHOD

The operation of induction motor subjected with unbalanced voltages can be analyzed by applying the theory of rotating fields by the equivalent circuits. Figure 4.1(a) represents the positive sequence component corresponding to the flow that rotates in the direction of the motor shaft rotation. Figure 4.1(b) represents the negative sequence component corresponding to the flow that opposes to motor shaft rotation.



(a)



(b)

Figure 4.1 Equivalent circuits of (a) positive and (b) negative sequence of motors operating with voltage unbalanced conditions

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)

In the above figures , V_{1f} and V_{2f} are voltage of positive and negative sequence per phase respectively in (V),I_1 and I_2 are input current of positive and negative sequence respectively in (A),I_{m1} and I_{m2} are magnetization current of positive and negative sequence respectively in (A),I_{21} and I_{22} are rotor current of positive and negative sequence respectively in (A),r_e is stator resistance in (Ω),x_1 is stator leakage reactance in (Ω) ,r_m is core loss resistance in (Ω),a_m is magnetizing reactance in (Ω) ,x_{21} and x_{22} are rotor leakage reactance of positive and negative sequence respectively in (Ω),r_{21} and r_{22} are rotor resistance of positive and negative sequence respectively in (Ω), s is slip in (p.u).

For calculations, first the positive and negative sequence line voltages are calculated by using

$$\begin{bmatrix} 0 \\ V_1 \\ V_2 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix}$$

Where α is known as Fortescue operator

Then, using the positive and negative sequence phase voltages, the positive and negative sequence currents are calculated as follows:

$$I_1 = \frac{V_{1f}}{Z_1} \qquad I_2 = \frac{V_{2f}}{Z_2} \quad (1)$$

The equations of Z1 and Z2 are described below:

$$Z_1 = (r \ + j_{x1}) + \frac{\left((r_m + jx_m)\ r_{21} + r_{21}\left(\frac{1-s}{s}\right) + jx_{21}\right)}{(r_m + jx_m) + r_{21} + r_{21}\left(\frac{1-s}{s}\right) + jx_{21}} \quad (2)$$

$$Z_2 = (r \ + jx_1) + \frac{(r_m + jx_m)\left(r_{22} + r_{22}\left(\frac{s-1}{2-s}\right) + jx_{22}\right)}{(r_m + jx_m) + r_{22} + r_{22}\left(\frac{s-1}{2-s}\right) + jx_{22}} \quad (3)$$

The motor output power or shaft power P_{out}, can be calculated as the sum of positive sequence output power P_{out1} and negative sequence output power P_{out2} as describe the following.

$$P_{out} = P_{out1} + P_{out2} - P_{fw} \quad (4)$$

$$P_{out} = 3r_{21}\left(\frac{1-s}{s}\right) I_{21}^2 + 3r_{22}\left(\frac{s-1}{2-s}\right) I_{22}^2 - P_{fw} \quad (5)$$

Where P_{out}, P_{out1} and P_{out2} are the total, positive sequence and negative sequence of output power respectively in (W), P_{fw} is the friction and windage losses in (W).

The positive sequence and negative sequence rotor current can be calculated by using the following formula.

$$I_{21} = I_1 \frac{jX_m}{r_{21}\left(\frac{1-s}{s}\right) + (jX_m + X_{21})} \quad (6)$$

$$I_{22} = I_2 \frac{jX_m}{r_{22}\left(\frac{s-1}{2-s}\right) + (jX_m + x_{22})} \quad (7)$$

Where I_{21} and I_{22} are rotor positive sequence and negative sequence currents in Ampere.

In steady state operation, the slip varies between 0.01 and 0.05.

Copper loss is occurred by both positive sequence and negative sequence components but effect of copper loss is more in negative sequence components

$$P_{cu2} = P_{ag2} - P_{mec2} \quad (8)$$

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 5- Issue 2, Paper 16 August 2022

$P_{cu2} = 3\left(\frac{r_{22}}{2-s}\right) I_{22}^2 - 3\left(\frac{s-1}{2-s}\right) r_{22} I_{22}^2$ (9)

$P_{cu2} = 3.\ r_{22}.\ I^2_{22}$(10)

Where Pcu2 is the copper loss of negative sequence in (W), Pag2 is air gap power of negative sequence in (W) and Pmec2 is the mechanical power expended corresponding to negative sequence in (W)

Total losses in induction motor under voltage unbalanced can be calculated by using the following formula

$P_{tot\text{-}loss} = 3(r_e I^2_1 + r_m I^2_{ml} + r_{21} I^2_{21} + r_e I^2_2 + r_m I^2_{m2} + r_{22} I^2_{22}) + P_{fw}$ (11)

where $P_{tot\text{-}loss}$ is total losses in W

Input power of induction motor can be calculated by the sum of output power and total loss of an machine

$P_{in} = P_{out} + P_{tot\text{-}loss}$ (12)

where P_{in} is input power in W

Motor efficiency is:

$\eta = \frac{Pout}{P1+P2} * 100$(13)

$\eta = \frac{Pout}{Pout+Ptot-loss} * 100$(14)

η is the efficiency in (%)

4.4 RESULT ANALYSIS

Table 2 Showing the result comparison:

%VUF	Ansys simulation $\eta(\%)$	Experimental testing $\eta(\%)$	Analytical method $\eta(\%)$
0	79	78.9	78
2.5	78	77.4	76.4
5.5	74	72.5	73.3

In this paper the performance of an induction motor is analysed in three methods, analytical method, experimental method and ansys simulation. For this three methods we are taking three sets of voltage unbalance factor (0%, 2.5% and 5.5%) .Here 0% means there is no unbalance in the machine then we are giving 2.5% and 5.5% of unbalance to the motor and observer the performance of the motor. In the analytical method, the efficiency of an motor for 0% VUF is 78, for 2.5%VUF is 76.4 and for 5.5%VUF the efficiency is 73.3. In the experimental method the efficiency of an induction motor for 0% VUF is 78.9, for 2.5%VUF the efficiency is 77.4 and for 5.5% efficiency is 72.5. In the ansys simulation the efficiency for 0% VUF is 79,for 2.5% VUF is 78 and for 5.5% VUF is 74. Comparing with this three methods, we got an higher efficiency in ansys simulation because in this software each and every components of an motors is measured accurate.

5.CONCLUSION

Three phase induction motor is widely used in industrial and commercial applications. In this paper we analysed the effect of induction motor under voltage unbalance conditions. For this, we find out the input power, output power, losses, efficiency of an induction motor by analytical way. To validate the analytical result we conducted an load test on induction motor under three different voltage conditions. For zero percent unbalance by testing the efficiency is 78.9%, for 2.5% VUF the efficiency is 77.4% and for 5.5% VUF the efficiency is 72.5%.By using the co-simulation method we verified the

Volume 5- Issue 2, Paper 16 August 2022

motor performance under various voltage unbalance conditions. Analytical machine design software is the most powerful tool for analysis of the motor. IN our proposed method while designing of the motor itself if possible, we change the motor parameters the effect of voltage unbalance is reduced.

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