Estimation of Equivalent Circuit Parameters of Transformer and Induction Motor from Load Data

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***Abstract* – In this paper, a simple and robust technique is proposed for estimation of parameters characterizing electrical machine based on experimentally obtained load data under running condition. The equivalent circuit parameters of three phase induction motor and single-phase transformer have been estimated from load data obtained from the experiments. Data was analyzed employing particle swarm optimization technique and H-G diagram based resistance estimation technique. Estimated parameters have been compared with the corresponding values obtained through classical test procedure recommended by IEEE. Comparative study shows that, the proposed technique can reliably be used to estimate the parameters of electrical machines.**

***Index Terms*— Equivalent Circuit, Induction Motor, Parameter Estimation, Particle Swarm Optimization, Transformer,**

I. NOMENCLATURE

$I_{1_{trans}}$ and $I_{2_{trans}}$ = Measured primary and secondary current of transformer

$I_{0_{trans}}$ = Calculated no-load current of transformer

$V_{2_{trans}}$ = Measured secondary voltage of transformer

$P_{in_{trans}}$ and $P_{out_{trans}}$ = Measured primary input power and secondary output power of transformer

$I_{1_{ind}}$ = Measured stator current of induction motor

$I_{0_{ind}}$ = No-load current of induction motor

pf_{ind} = Measured input power factor of induction motor

$P_{in_{ind}}$ and $P_{out_{ind}}$ = Measured stator input power and rotor output power of induction motor

R_1 = Primary side resistance for transformer / Stator side resistance of Induction motor

X_1 = Primary side reactance for transformer / Stator side reactance of Induction motor

R_2' = Secondary side resistance for transformer referred to primary / Rotor side resistance of Induction motor referred to stator

X_2' = Secondary side reactance for transformer referred to primary / Rotor side reactance of induction motor referred to stator

$R_{eq} = R_1 + R_2'$

$X_{eq} = X_1 + X_2'$

R_c = Core loss resistance for both transformer and Induction motor

X_m = Magnetizing reactance for both transformer and Induction motor

s = Slip of induction motor

J = Objective function

$\overline{V_s}$ = Complex stator voltage

$\overline{I_s}(\overline{I_r})$ = Complex stator (rotor) current of induction motor

$\overline{R_s}(\overline{R_r})$ = Stator (rotor) resistance of induction motor

L_s = Stator self-inductance = $L_{1s} + L_m$

L_r = Rotor self-inductance = $L_{1r} + L_m$

L_m = Stator – rotor mutual inductance

ω_s = Synchronous speed

$\omega_{sl} = \omega_s - \omega_r$ = Slip frequency

II. INTRODUCTION

Reliable operation of critical power system components like transformers is essential for uninterrupted power supply to the consumer end whereas consistent functionality of induction motors ensure the smooth and uninterrupted industrial operations. However, performances of the critical components decline due to various environmental factors. Therefore, continuous assessment of these components is required to ensure their satisfactory performance. Equivalent circuit parameters characterize the behavior and performance of electrical machines. Hence estimation of equivalent circuit parameters can provide significant information about the condition and performance of the machine.

Machine modeling is very important for state of the art modern ac drive systems, for example vector control of induction motor. In vector control of induction motors, determination of rotor flux linkage estimation is essential, which requires accurate estimation of motor equivalent circuit parameters

The equivalent circuit parameters of electrical machines can be determined from the standard test procedures, as per IEEE guidelines [22]. However, being offline, the technique cannot be employed for the machines which are in operation. Besides, deviation of environmental conditions (like temperature, humidity etc.) can lead to the change of the equivalent circuit parameters. Therefore, the present research work is oriented towards assessing the condition of those components on-line.

Several research works have been done on estimation of equivalent circuit parameters of transformers and induction motors. In paper [1], M. Reza Feyzi and M. Sabahi have proposed an online dynamic parameter estimation technique using recursive least square (RLS) algorithm. Koubaa [2] also proposed a recursive least square algorithm based parameter estimation scheme for induction motor. Zhang Hu, Gong Shu-juan, Dong Zi-zhao [3] also proposed an on-line parameter identification scheme of induction motor based on Recursive Least Square (RLS) algorithm. They have solved the Butterworth digital filtering equation with improved Euler's numerical solution to increase the accuracy of the scheme.

In [4], Bigdeli and Rahimpour proposed a scheme to estimate transformer parameters for fault detection and power network analysis based on geometrical dimension. But this method suffers from dimensional data unavailability for old machines.

Use of soft computing method for diagnosis of electrical devices was first proposed by Szczepaniak and Rudnicki in [5]. Mehdi Bigdeli, Ebrahim Rahimpour [6] proposed another model for transient analysis of transformer using genetic algorithm (GA). S. Subramanian and S. Padma [7] proposed a method for parameter estimation of three winding transformer based on bacterial foraging algorithm.

In [8], Mohamed I. Mossad, Mohamed Azab, and A. Abu-Siada used particle swarm optimization (PSO) for estimation of the transformer parameters from name plate data without conducting any offline tests. They also provided comparative study of the proposed method with GA and showed significant improvement with PSO. Keun Lee, Stephen Frank, Pankaj K. Sen, Luigi Gentile Polese, Mahmoud Alahmad, Clarence Waters [9] proposed a parameter estimation scheme of three phase induction motor from available name-plate data only using Gauss-Seidel algorithm. But these methods suffer from selection of proper boundary conditions, as well as change of parameters with environmental condition, ageing and rewinding.

Nangsue, Pillay and Conry [10] proposed a parameter estimation technique of induction motor using genetic algorithm (GA). In [11], authors presented a scheme for induction motor parameter estimation using chaotic ant swarm algorithm and showed that the errors are minimized than that of GA. Burak Tekgun, Yilmaz Sozer and Igor Tsukerman [14] have proposed a technique to estimate the parameters of split phase induction motor by Levenberg–Marquardt (LM) algorithm.

In [12], the authors proposed a PSO based evolutionary optimization technique for parameter identification of induction motor. They added a constriction factor with classical PSO to identify the parameters of induction motor. In [13], Hassan M. Emara, Wesam Elshamy and A. Bahgat proposed a modified PSO technique named Clubs-based PSO technique to identify the parameters of induction motor. In paper [21], a parameter estimation methodology for single phase transformer and three phase induction motor was proposed using particle swarm optimization (PSO) technique. Here the equivalent circuit parameters and losses of a single-phase transformer and a three-phase induction motor were obtained using PSO technique.

In this paper, an improved technique for estimation of equivalent circuit parameters and losses of transformer and induction motor is proposed from performance data of these machines under running condition. Tests were performed on a 3kVA single phase transformer and a 2 hp three phase induction motor. The result shows that the proposed scheme can estimate the equivalent circuit parameters accurately and reliably.

III. Overview of PSO

Particle swarm optimization technique was first proposed by Kennedy and Eberhart [16]. This method is based on two fundamental concepts: social concept and swarm intelligence concept. It consists of swarm of particles, where each particle symbolizes a potential solution. The swarm is defined as a set [21]:

$$s = \{x_1, x_2, ..., x_N\} \quad ...... (1)$$

N is number of particles (candidates' solution).

Each particle has a unique position vector and velocity in the search space. Position of particle can be shifted by adding velocity to the current position. Position vector and velocity of each particle is defined as:

$$x_i = \{x_{i1}, x_{i2}, ..., x_{in}\}^T \subseteq A \quad \text{where } i = 1,2,...,N \quad .... (2)$$

$$v_i = (v_{i1,} v_{i2}, ..., v_{in})^T \subseteq A \quad \text{where } i = 1,2,...,N \quad .... (3)$$

Velocity of particle can be updated using the information obtained from previous step. This is implemented in terms of memory where the particle's best position is stored. This memory can be defined [21]:

$$P_i = (P_{i1}, P_{i2}, ..., P_{in})^T \subseteq A \quad ...... (4)$$

After each iteration position and velocity should be updated using following two equations.

$$v_i(t+1) = \chi\{v_i(t) + c_1 r_1(p_i(t) - x_i(t)) + c_2 r_2(p_g(t) - x_i(t))\} \quad ... (5)$$

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad ...... (6)$$

Here 't' is iteration counter, c_1 and c_2 are cognitive and social acceleration constant, r_1 and r_2 are uniformly distributed random number within 0 and 1, $p_i(t)$ and $p_g(t)$ are local and global best position in the search space . After getting the new position and velocity memory should be updated by the new best position of particle [21]

$$P_i(t+1) = \begin{cases} x_i(t+1) \\ P_i(t) \end{cases} \quad \ldots\ldots (7)$$

TABLE I. PSEUDOCODE OF THE OPERATION OF PSO [16]

Input	No. of particles: N , Swarm: S **,** Best particle: P
Step 1	**Set** $t \leftarrow 0$
Step 2	**Initialize** S and set $P \equiv S$.
Step 3	**Evaluate** S and P , and define index g of the best position.
Step 4	**While** (termination criterion not met)
Step 5	**Update** S using equations (1) and (2).
Step 6	**Evaluate** S .
Step 7	**Update** P and redefine index g .
Step 8	**Set** $t \leftarrow (t+1)$.
Step 9	**End While**
Step 10	**Print** best position.

IV. PARAMETER ESTIMATION OF INDUCTION MOTOR

It was found that if the parameters of the equivalent circuit were estimated using PSO only, the accuracy was low. In the equivalent circuit, the output of three phase induction motor is defined as $R_2 \times \frac{(1-s)}{s}$. As in this case, speed is a measured quantity, hence slip is known. Therefore, estimation of rotor resistance is quite accurate when the load current is dominant. But under no load condition or lightly loaded condition, magnetizing current is predominant. This introduces error in the estimation using particle swarm optimization technique. Hence H-G diagram based resistance estimation technique [15], [17] was utilized to determine the stator and rotor resistances. The leakage reactance (X_{eq}), core loss resistance (R_c)and the magnetizing reactance (X_m) was estimated with PSO.

A. *Stator and rotor resistance estimation*

The equivalent circuit of an induction motor is shown in Fig. 1. The complex input impedance of the machine is given by (8):

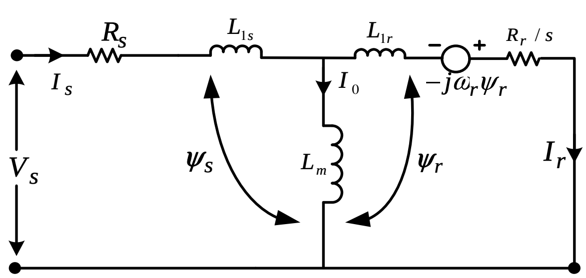


Fig 1: complex static reference frame induction motor equivalent circuit

$$Z_{in} = \frac{\overline{V_s}}{\overline{I_s}} = (R_s + j\omega_s L_s) + (\frac{R_r}{s} + j\omega_s L_r) \,||\, (j\omega_s L_m) \quad \ldots (8)$$

Equation (8) can be written as [17]

$$Z_{in} = \frac{\overline{V_s}}{\overline{I_s}} = R_s + \omega_s G(\omega_{sl}) + j\omega_s H(\omega_{sl}) \quad \ldots\ldots\ldots\ldots (9)$$

Where,

$$G(\omega_{sl}) = \frac{L_m{}^2 \omega_{sl} R_r}{R_r{}^2 + L_r{}^2 \omega_{sl}{}^2} \quad \ldots\ldots\ldots\ldots (10)$$

$$H(\omega_{sl}) = L_s - \frac{L_m{}^2 \omega_{sl}{}^2}{R_r{}^2 + L_r{}^2 \omega_{sl}{}^2} L_r \quad \ldots\ldots\ldots\ldots (11)$$

The $G(\omega_{sl})$ and $H(\omega_{sl})$ have dimension of inductance and they represent the active power consumption generating the motor torque and reactive power consumption generating the magnetizing flux. The active power and reactive power consumed by the motor given by the following equation [17].

$$P = \overline{V_s} \bullet \overline{I_s} = u_{s\alpha} i_{s\alpha} + u_{s\beta} i_{s\beta} \quad \ldots\ldots\ldots\ldots (12)$$

$$Q = \overline{V_s} \times \overline{I_s} = u_{s\alpha} i_{s\beta} + u_{s\beta} i_{s\alpha} \quad \ldots\ldots\ldots\ldots (13)$$

It can be shown that for each induction motor operating point $'i'$, $G(\omega_{sl})$ and $H(\omega_{sl})$ are given by

$$G_i = G(\omega_{sl}) = \frac{1}{\omega_s}(\frac{P}{I_s{}^2} - R_s) \quad \ldots\ldots\ldots\ldots (14)$$

$$H_i = H(\omega_{sl}) = \frac{Q}{\omega_s I_s{}^2} \quad \ldots\ldots\ldots\ldots (15)$$

$$I_s{}^2 = I_{s\alpha}{}^2 + I_{s\beta}{}^2 \quad \ldots\ldots\ldots\ldots (16)$$

From equation (12) and (13), we can compute the rotor time constant τ_r as [17]

$$\tau_r = \frac{L_r}{R_r} = \frac{L_s - H(\omega_{sl})}{\omega_{sl} G(\omega_{sl})} = \frac{H_0 - H_i}{\omega_{sl} G_i} \quad \ldots\ldots\ldots.. (17)$$

Considering an equitable share of the flux leakage, the rotor resistance could be deduced from the following equation [17].

$$R_r = \frac{G_i}{1 - \frac{H_i}{H_0}} \omega_{sl} \quad \ldots\ldots\ldots.. (18)$$

The stator resistance can be given by

$$R_s = kR_r \quad \ldots\ldots\ldots\ldots (19)$$

Where,

$$k = \frac{R_{sn}}{R_{rn}}$$

R_{sn} & R_{rn} are the rated values of stator and rotor resistance respectively given by the manufacturer.

B. *Formulation of objective function for PSO*

For the estimation of equivalent leakage reactance (X_{eq}), core loss resistance (R_c), and magnetizing reactance (X_m), the objective function was formulated based on the minimization of square error technique as given in equation (20). From the experimental observations, it can be concluded that, a large number of set of parameter values satisfies same nameplate data (i.e., magnitude of current, voltage and efficiency remain near rated value whereas the parameter values are changing a lot). There are various reasons for this. For example, induction motors designed with same current density and flux density, but with different values of actual number of primary and secondary turns (turns ratio being same) will have different parameters. Parameters also depend on the number of stator and rotor slots and their dimension. Even the parameters will differ if the winding arrangement varies, with every other consideration remaining same. Therefore, here all the measurable quantities such as stator current ($I_{1_{ind}}$), input power ($P_{in_{ind}}$), input power factor (pf_{ind}), output power ($P_{out_{ind}}$) are considered in formation of the objective function. The above-mentioned quantities are taken into consideration as they change with load and defines machine behavior. No load current ($I_{0_{ind}}$) is taken into consideration to estimate the core loss resistance and magnetizing reactance accurately.

$$J = min[(\frac{(I_{1_{ind}} - I_{1_{indest}})}{I_{1_{ind}}})^2 + (\frac{(P_{in_{ind}} - P_{in_{indest}})}{P_{in_{ind}}})^2 + (\frac{(P_{out_{ind}} - P_{out_{indest}})}{P_{out_{ind}}})^2 + (\frac{(pf_{ind} - pf_{indest})}{pf_{ind}})^2 + (\frac{(I_{0_{ind}} - I_{0_{indest}})}{I_{0_{ind}}})^2] \qquad \text{............ (20)}$$

NEMA guideline has been followed here for considering the no load current.

C. Experimental setup

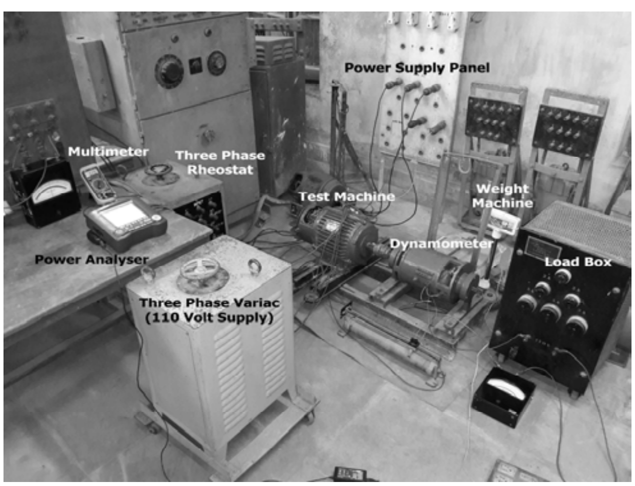


Fig 2. Photograph of the experimental setup of induction motor used in the laboratory

The experiment was performed on a 110 volt 2 hp three phase induction motor. The induction motor was coupled with an eddy current dynamometer for loading as well as to measure the output power of the motor. On the stator side, clamp on power meter was used for measuring input voltage, current, power and power factor. Both armature and field winding of eddy current dynamometer was supplied from a separate 110-volt DC supply. The load on the induction motor was varied by varying the armature current of the eddy current dynamometer keeping the field current constant. The complete experimental setup is shown in Fig: 2

Fig 3 shows the complete equivalent circuit of a three phase induction motor. The following tests were performed on the machine as par IEEE Standard test procedures [22] for determining equivalent circuit parameters.

- DC resistance test
- No-load test for induction motor
- Blocked rotor test for induction motor

The obtained results are given in the next section.

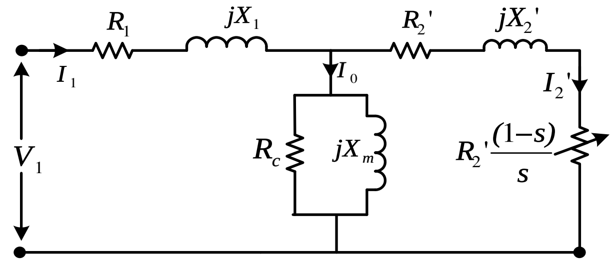


Fig 3: Three phase Induction motor equivalent circuit referred to stator side

D. Experimental results

The dc cold resistance was measured at the beginning of the test and after two hours of experiment, dc hot resistance was measured. These dc resistances, obtained from the test was then converted into ac resistances by multiplying a factor of 1.2.

Our proposed algorithm employs H-G diagram based resistance estimation technique [17] to estimate the stator and rotor resistances of the induction motor. The measured cold resistances were used as the initial resistance value and from that the hot resistances were estimated using the above-mentioned algorithm. Using these estimated resistances, the leakage reactance, core loss resistance and magnetizing reactance were estimated employing particle swarm optimization. In Table II, a comparison of estimated parameters and parameters obtained from the tests is given. This comparison shows that the estimation algorithm is capable of estimating the parameters without much error.

Parameters of equivalent circuit were estimated from measured data for different loading condition. The variation of the parameters with load, are shown in fig 4(a), 4(b), 4(c) and 4(d). From the figures, it is evident that the estimated parameters are within acceptable limit.

TABLE II. COMPARISON OF ESTIMATED AND EXPERIMENTALLY OBTAINED PARAMETER VALUES FROM NO LOAD AND BLOCKED ROTOR TEST FOR 2 HP INDUCTION MOTOR

Parameter	Experimentally obtained Value (Ω)	Estimated value under full load condition (Ω)	% Error
R_1 (Ω)	0.81	0.8027	0.9
R_2' (Ω)	1.33	1.3336	-0.27
X_{eq} (Ω)	2.87	2.868	0.0697
R_c (Ω)	158.19	160.028	-1.162
X_m (Ω)	27.61	27.917	-1.111

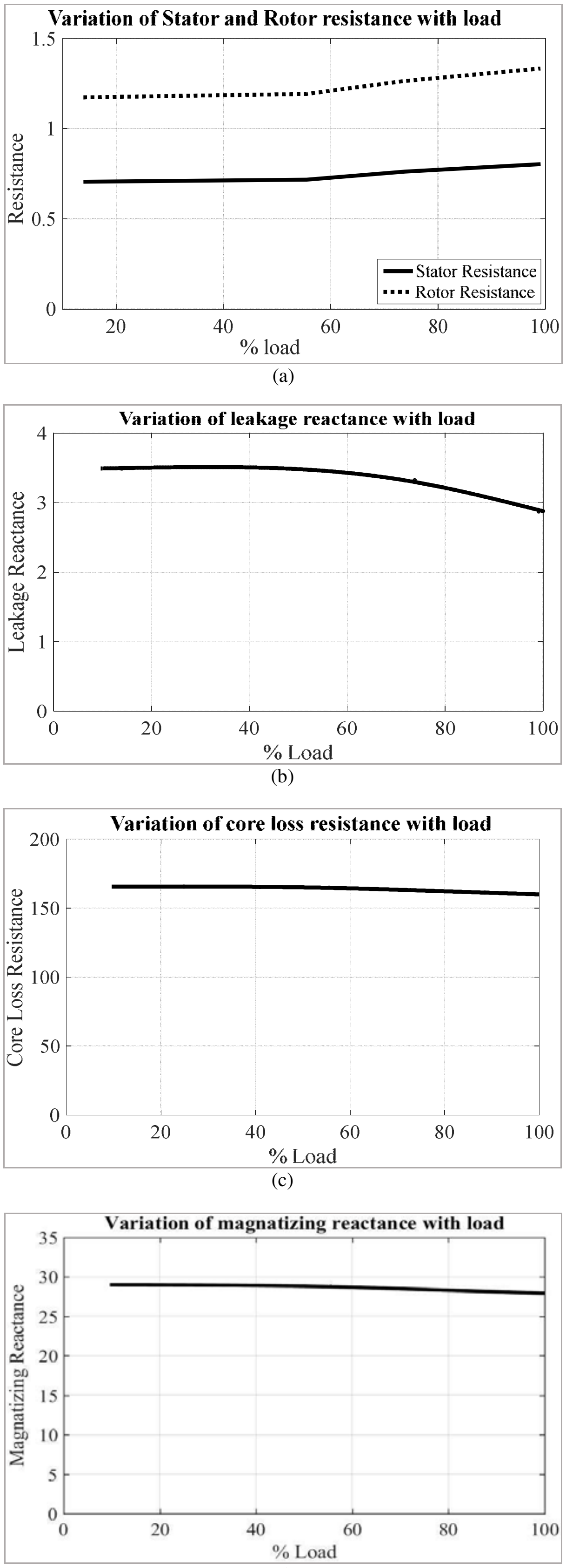


Fig 4. Variation of estimated parameters with load

Graphical representation of variation of different losses with load is shown in Fig. 5.

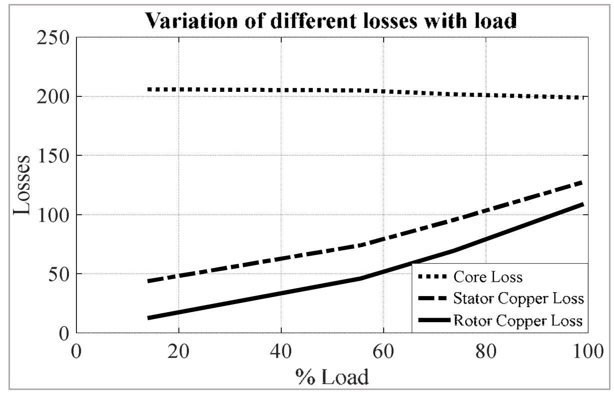


Fig 5. Variation of different losses with load

V. Parameter Estimation of Transformer

A. Formulation of objective function

Particle swarm optimization technique was used for estimation of equivalent circuit parameters of single phase transformer by solving the circuit equations. The objective function formulated here based on the available measured data, using the minimization of square error technique is given in equation (21).

It is observed from experiments that, a large number of set of parameter values satisfies same nameplate data (as discussed in section IV (B)). The main reasons behind this are, transformers designed with same current density and flux density, but with different values of actual number of primary and secondary turns (turns ratio being same) will have different parameters. Even the parameters will differ if the winding arrangement varies, every other consideration remaining same. Therefore, here all the measurable quantities such as input current ($I_{1_{trans}}$), output current ($I_{2_{trans}}$), input power ($P_{in_{trans}}$), output power ($P_{out_{trans}}$), output voltage ($V_{2_{trans}}$) are considered in formation of the objective function. These above-mentioned quantities define the characteristics of the machine. No load current ($I_{0_{trans}}$) is taken into consideration to estimate the core loss resistance and magnetizing reactance accurately.:

$$J = min[(\frac{(I_{1_{trans}} - I_{1_{transest}})}{I_{1_{trans}}})^2 + (\frac{(I_{2_{trans}} - I_{2_{transest}})}{I_{2_{trans}}})^2 + (\frac{(I_{0_{trans}} - I_{0_{transest}})}{I_{0_{trans}}})^2 + (\frac{(V_{2_{trans}} - V_{2_{transest}})}{V_{2_{trans}}})^2 + (\frac{(P_{in_{trans}} - P_{in_{transest}})}{P_{in_{trans}}})^2 + (\frac{(P_{out_{trans}} - P_{out_{transest}})}{P_{out_{trans}}})^2] \quad \ldots\ldots\ldots\ldots (21)$$

No load current, $I_{0_{trans}}$ was calculated by taking the difference between measured $I_{1_{trans}}$ and $I_{2_{trans}}$. both primary and secondary power factors could also be calculated from the measured data.

No load current, $I_{0_{trans}}$ plays a very important role in accurate determination of the equivalent circuit parameters of transformer. Exclusion of no load current from the objective function introduce large error in estimation of parameters whereas, estimated current, voltage and power data remains almost same. The objective function excluding the no load current is given below in equation (22).

$$J = min[(\frac{I_{1_{trans}} - I_{1_{transest}}}{I_{1_{trans}}})^2 + (\frac{I_{2_{trans}} - I_{2_{transest}}}{I_{2_{trans}}})^2 + (\frac{V_{2_{trans}} - V_{2_{transest}}}{V_{2_{trans}}})^2 + (\frac{P_{in_{trans}} - P_{in_{transest}}}{P_{in_{trans}}})^2 + (\frac{P_{out_{trans}} - P_{out_{transest}}}{P_{out_{trans}}})^2] \quad \ldots\ldots\ldots\ldots (22)$$

The comparison of estimated parameters with experimentally obtained parameter values is given below in table III.

TABLE III. COMPARISON OF ESTIMATED AND OBTAINED PARAMETERS FOR 3 KVA TRANSFORMER UNDER FULL LOAD CONDITION CONSIDERING OBJECTIVE FUNCTION (22)

Parameter	Experimentally Obtained Value (Ω)	Estimated values under full load condition (Ω)	% Error
R_{eq} (Ω)	0.1148	0.1189	-3.57143
X_{eq} (Ω)	0.0872	0.0172	80.27523
R_c (Ω)	192.06	202.1782	-5.26825
X_m (Ω)	41.69	35.3296	15.25642

The comparison of estimated load data obtained using the estimated parameters and measured load data is tabulated below in table IV.

TABLE IV. COMPARISON OF MEASURED AND ESTIMATED LOAD DATA FOR 3 KVA TRANSFORMER UNDER FULL LOAD CONDITION CONSIDERING OBJECTIVE FUNCTION GIVEN IN (22)

Parameter	Experimentally Obtained Value (Ω)	Estimated values under full load condition (Ω)	% Error
$I_{1_{trans}}$ (A)	27.4063	27.4063	0
$I_{2_{trans}}$ (A)	26.6917	26.6918	-0.0003
$V_{2_{trans}}$ (V)	106.7667	106.7670	-0.0002
$P_{in_{trans}}$ (W)	2994.9	2994.9	0
$P_{out_{trans}}$ (W)	2849.8	2849.8	0

From table III and table IV, it is clear that though there is a large error in estimation of parameter (especially the leakage reactance), though estimated load data can track the measured data quite accurately. Hence consideration of $I_{0_{trans}}$ has immense importance from the aspect of accurate estimation of equivalent circuit parameters.

B. *Experimental setup*

The experiment was performed on a 110-volt 3 kVA transformer. 110 volts single phase ac supply was provided to the low voltage side of the transformer connected with a variable load-box at the high voltage side for varying the load. Voltmeters, ammeters and wattmeters were used to measure the voltage, current and power at both high voltage and low voltage side of the transformer. Photograph of the experimental setup is given in Fig 6

The equivalent circuit of a transformer is shown in Fig 7. Following tests were performed on the above-mentioned machine to determine the equivalent circuit parameters as per IEEE guideline [22].

- DC resistance test
- Open circuit test for transformer
- Short circuit test for transformer

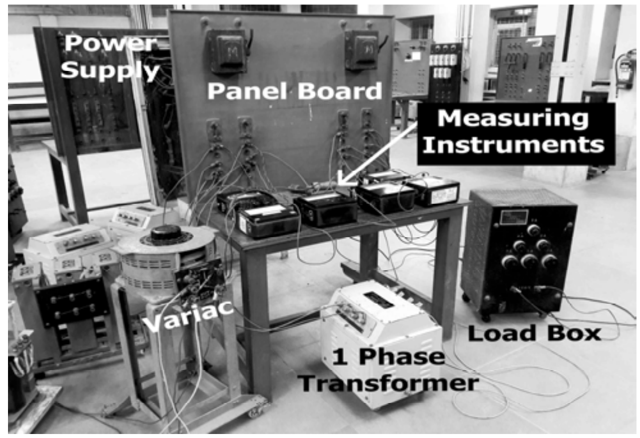


Fig 6. Photograph of the experimental setup of transformer used in the laboratory

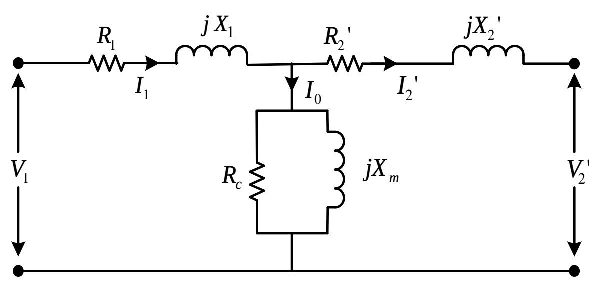


Fig 7: Transformer equivalent circuit referred to primary side

C. *Experimental results*

The equivalent circuit parameters of the single-phase transformer were obtained from the tests. Equivalent circuit parameters were estimated by the developed algorithm employing particle swarm optimization technique as the tool.

TABLE V. COMPARISON OF ESTIMATED AND OBTAINED PARAMETERS FOR 3 KVA TRANSFORMER UNDER FULL LOAD CONDITION CONSIDERING OBJECTIVE FUNCTION GIVEN IN (21)

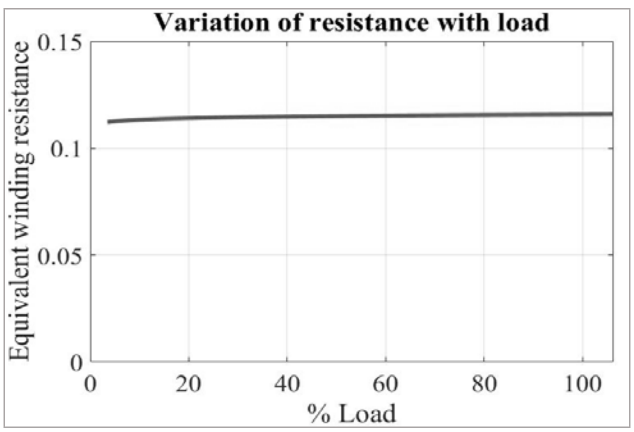
Parameter	Experimentally Obtained Value (Ω)	Estimated values under full load condition (Ω)	% Error
R_{eq} (Ω)	0.1148	0.1148	0
X_{eq} (Ω)	0.0872	0.0869	0.344
R_c (Ω)	192.06	192.0905	-0.016
X_m (Ω)	41.69	41.69	0

TABLE VI. COMPARISON OF MEASURED AND ESTIMATED LOAD DATA FOR 3 KVA TRANSFORMER UNDER FULL LOAD CONDITION CONSIDERING OBJECTIVE FUNCTION GIVEN IN (22)

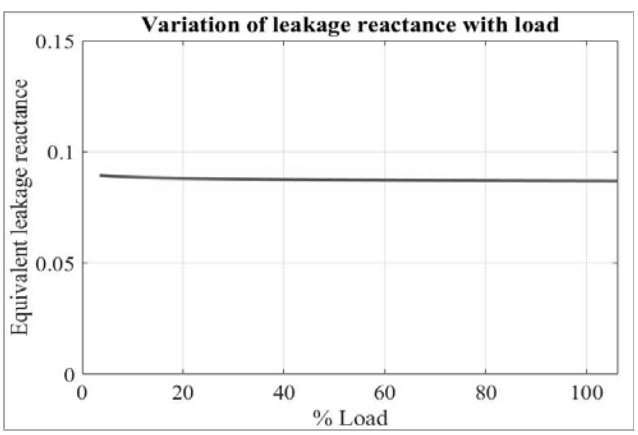
Parameter	Experimentally Obtained Value (Ω)	Estimated values under full load condition (Ω)	% Error
$I_{1_{trans}}$ (A)	27.4063	27.4065	-0.0007
$I_{2_{trans}}$ (A)	26.6917	26.6918	-0.0003
$V_{2_{trans}}$ (V)	106.7667	106.7670	-0.0002
$P_{in_{trans}}$ (W)	2994.9	2994.9	0
$P_{out_{trans}}$ (W)	2849.8	2849.8	0

Table V and VI clearly shows the comparison between the experimentally obtained and estimated parameters which leads to the conclusion that our developed estimation technique can estimate the equivalent circuit parameters quite accurately, with precisely tracking the measured load data.

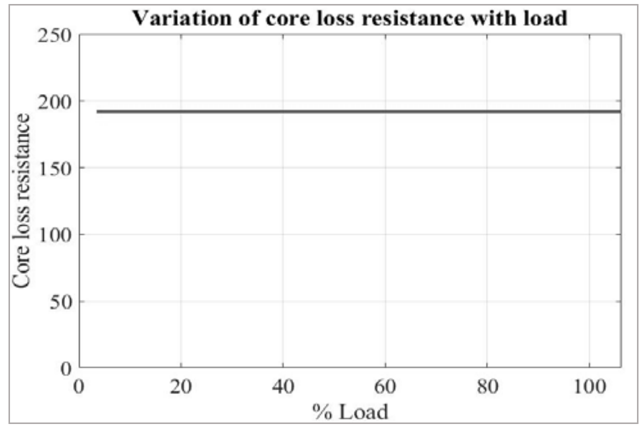
Fig 8 shows the variation of parameters estimated from measured data at different loading condition.



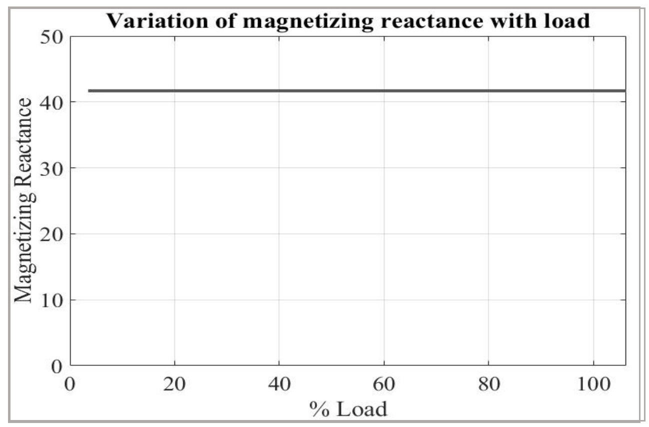
(a)



(b)



(c)



(d)

Fig 8. Variation of estimated parameters with load

Variation of different transformer losses with load is shown below.

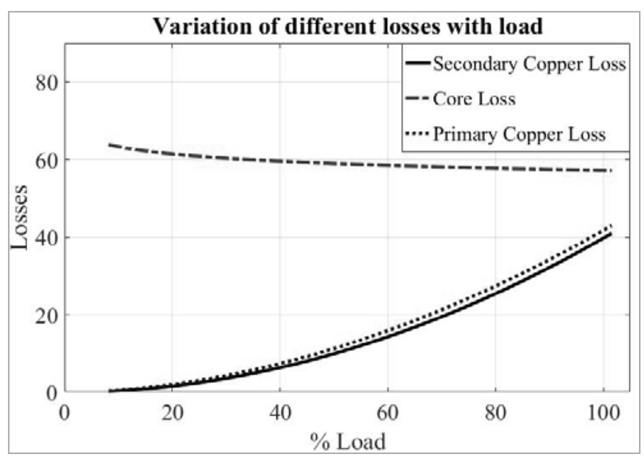


Fig 9. Variation of different losses with load

VI. SCOPE OF FUTURE WORK

Except PSO, newly developed nature inspired algorithm like Firefly Algorithm (FA), Bat Algorithm (BA) Cuckoo Search (CS), can be further applied to validate the result and to identify the best optimization method for estimation of the parameters. The losses estimated, can be utilized in thermal model of these machines for temperature prediction so that the machines can be protected from thermal failure too.

VII. Conclusion

Accurate parameter estimation is essential for vector controlled drives and fault detection of electrical machines. A simple, and effective technique to estimate the equivalent circuit parameters of a single-phase transformer and three phase induction motor from load data has been proposed in this paper. The identification process is carried out using a very simple method, which is very easy to understand and gives sufficiently good accuracy. Compared to other optimization methods PSO occupies the biggest optimization ability. The simulation result shows a reasonable degree of accuracy. This method is easy to implement and with little modifications it can be adopted for parameter estimation of other machines also. This method can be improved by validating it for Variable Voltage Variable Frequency (VVVF) drive induction motors with different load condition

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