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New Parameters Estimation Using Numerical Method and Steady State Performance for Convensional and Converter Fed Induction Motor

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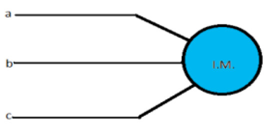
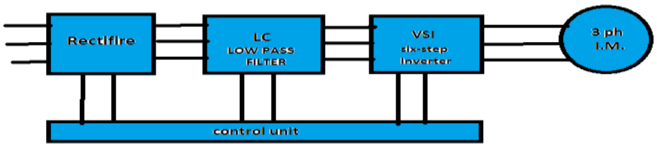
Abstract: ***The work proposes a method for parameter estimation of induction motor and steady state performance for conventional as well as converter fed induction motor, based on equivalent circuit method. The method, which requires a no-load and a blocked rotor test, is intended for steady state performance i.e. torque, efficiency, full load current, output power, power factor of three-phase squirrel cage induction motor within the rated range of operation.Data of the tests (No load test, Block rotor test, Full load test) taken from ERADA laboratory, and also simulate for conventional as well as converter fed induction motor using MATLAB-SIMULATION. Programming for estimation of parameter using numerical procedure Newton-Raphson method and determining steady state performance of induction motor algebraically and graphically(using circle diagram).***

Keywords: induction motor, matlab, newton raphson method, circle diagram, sensitivity analysis



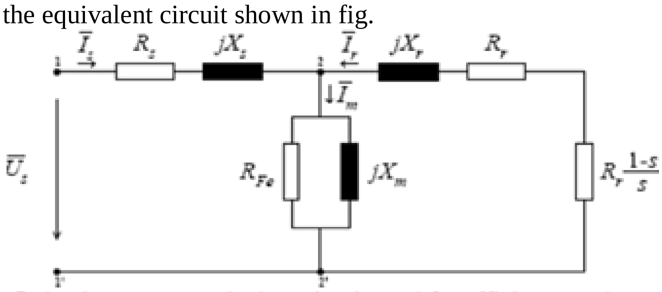
Conventional IM



Converter fed IM

1. Machine Model for conventional Induction Motor

The model required for the envisage performance analysis is the equivalent circuit shown in fig.



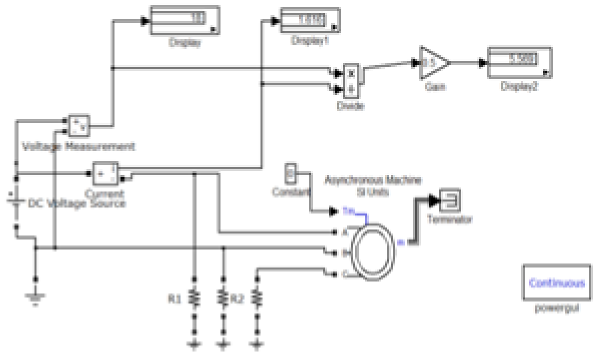
Induction motor equivalent circuit used for efficiency and torque calculations under or at rated conditions

Rs : Stator Resistance Xs : Stator Leakage Reactance Rfe : Magnetizing Resistance Us : Supply Voltage
Xm : Magnetizing Reactance Xr : Rotor Reactance Rr : Rotor Resistance s : Slip

2. Simulations of tests for conventional induction motor

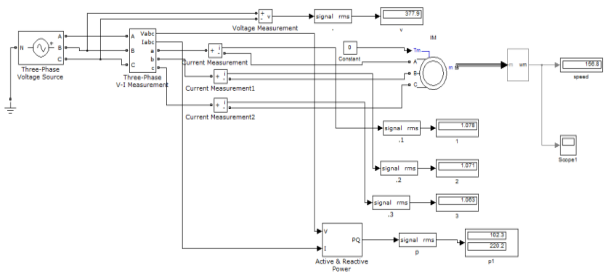
DC test

To perform dc test, the model shown in figure are built.
From this test, the stator resistance can be measured.



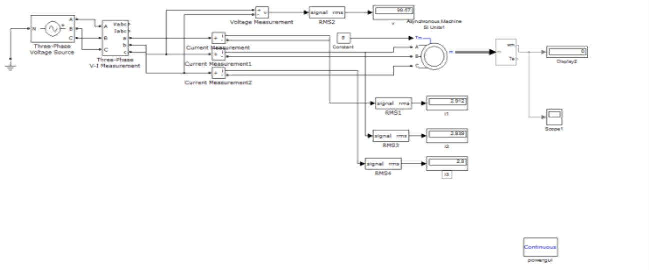
No Load test

The virtual no-load test can be carried out using this model, voltage, current, and power obtained. From this test Magnetizing parameters (Rfe, Xm) are determined.



Block Rotor Test

The virtual blocked-rotor test can be carried out using this model with infinite moment of inertia, voltage, current, and power obtained from these test rotor parameters (Rr,Xr) are determined.



Practical result from ERDA Lab and Simulation result obtain for conventional supply (50 Hz, 380V, 1.2Kw, 4 pole Induction Motor)

DC Test : Rs = 5.57Ω(From Practical) and Rs = 5.567Ω (From Simulation)

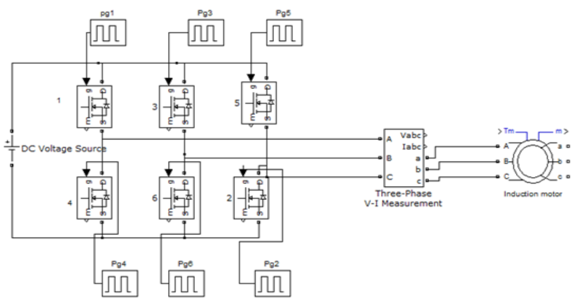
No Load Test

	V_o	I_o	P_o	$Cos\phi_o$	N
Practical	380	1.15	100	0.1321	1499
Simulation					
50 Hz	377.9	1.071	102.3	0.1459	1497.33
60 Hz	377.4	0.9061	101.7	0.1717	1799.2

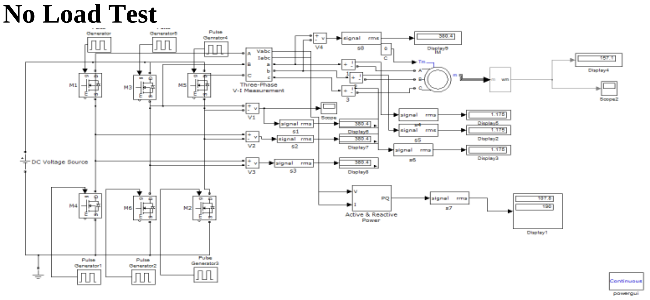
Block Rotor Test

	V_{br}	I_{br}	P_{br}	$Cos\phi_{br}$	N
Practical	99	2.8	230	0.479	0
Simulation					
50 Hz	98.57	2.847	240.7	0.4972	0
60 Hz	98.35	2.46	195.8	0.4672	0

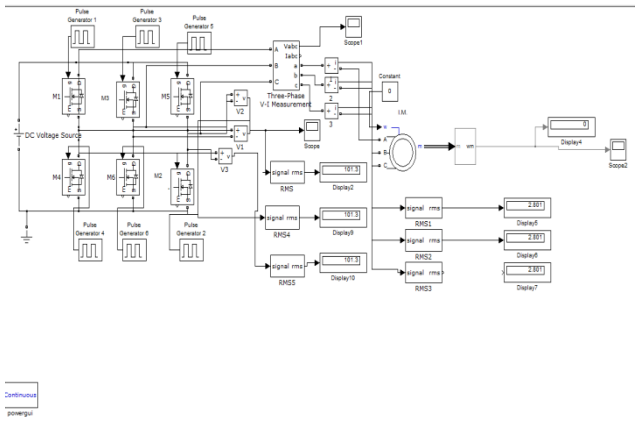
VSI – six step Inverter Fed Induction Motor



No Load Test



Block Rotor Test



3. Simulation result for Inverter fed Induction Motor

No load test

	Vo	Io	Po	Cosϕo	N
50Hz	380.4	1.175	107.8	0.1394	1499.23
60Hz	380.2	0.9803	79.68	0.1234	1795.2

Block Rotor Test

	Vbr	Ibr	Pbr	Cosϕbr	N
50 Hz	101.3	2.801	238.7	0.4858	0
60 Hz	101.3	2.379	205.9	0.5031	0

Equivalent Circuit Parameters from Results

From above tests for conventional and inverter fed induction motor, we have obtained magnetizing and rotor parameters.

	Rfe	Xm	Rr	Xr
Practical	1444.183	192.46	4.21	8.96
Simulation Conventional Im				
50 Hz	1395.98	205.92	4.3290	8.637
60 Hz	1400.54	244.09	5.2141	10.205
Inverter fed IM				
50 Hz	1341.96	188.91	4.57	9.123
60 Hz	1814.58	225.64	6.558	10.42

4. Mathematical Modelling of Induction Motor Based On Equivalent Circuit Method

There is a practical difficulty in the insertion of transducers for torque measuring on electro pumping groups related with mechanical disconnection of coupled machines, which is sometimes not fast or even not feasible. This fact motivated the search for an indirect torque observation method using measurement of electrical quantities and speed. This method used to find function equation of equivalent circuit parameters.

From the equivalent circuit we have,

$$\bar{Z} - \frac{Us}{Is} (\cos \theta + j \sin \theta) = 0$$

For finding equivalent impedance of circuit diagram,

$$Zeq = (Rs + jXs) * \left(\frac{jRfeXm}{Rfe + jXm}\right) \parallel \left(\frac{Rr}{s} + jXr\right)$$

After solving the equation we have,

$$Re\{\bar{z}\} = Rs + \frac{RfeXm^2 * \left(\left(\frac{Rr}{s}\right)^2 + Xr^2\right) * \left(\frac{Rr}{s}Rfe + \left(\frac{Rr}{s}\right)^2 + Xr^2\right)}{Xm^2 * \left(\frac{Rr}{s}Rfe + \left(\frac{Rr}{s}\right)^2 + Xr^2\right)^2 + Rfe^2 * \left(XrXm + \left(\frac{Rr}{s}\right)^2 + Xr^2\right)^2}$$

$$Im\{\bar{z}\} = Xs + \frac{Rfe^2Xm * \left(\left(\frac{Rr}{s}\right)^2 + Xr^2\right) * \left(XrXm + \left(\frac{Rr}{s}\right)^2 + Xr^2\right)}{Xm^2 * \left(\frac{Rr}{s}Rfe + \left(\frac{Rr}{s}\right)^2 + Xr^2\right)^2 + Rfe^2 * \left(XrXm + \left(\frac{Rr}{s}\right)^2 + Xr^2\right)^2}$$

The equations for **Current, Power factor, Output Power, Torque, Input Power, Efficiency** from equivalent circuit,

$Ieq = \frac{Us}{Zeq}$, PF = Cos($\tan^{-1}\{\frac{Re\{\bar{Z}\}}{Im\{\bar{Z}\}}\}$), Pout = 3 I_r^2 RL ,

where RL = Rr (1/s - 1)

Pout = 3 I_r^2 RL, Tg = Pg / ωm, Pin = 3*V*Ieq*Cosɵ, Eff =(Pout / Pin) *100

Once Rs is obtained from direct measurement and the stator and rotor reactance are assumed proportional as in IEEE std 112.

$Xs = K_{12}Xr$ Where K_{12} is ratio of Xs to Xr and is taken as 1.

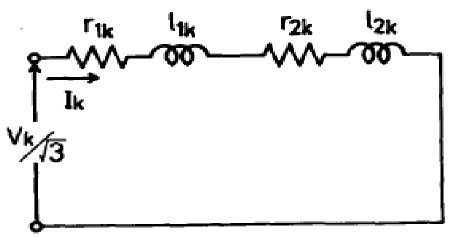
The no load and block rotor tests yield a system of four non linear equations (index B stands for 'Block-rotor' and index V for 'No Load')

F1= Re { $\bar{Z}_B$} - $\frac{Us_B}{Is_B}\cos\Phi_B$ F3 = Re { $\bar{Z}_V$} - $\frac{Us_V}{Is_V}\cos\phi_V$

F2 = Im { $\bar{Z}_B$} - $\frac{Us_B}{Is_B}\sin\Phi_B$ F4 = Im{ $\bar{Z}_V$} - $\frac{Us_V}{Is_V}\sin\phi_V$

From modeling induction motor, we have a determined the non linear functions, which are used to find out new modified parameters of equivalent circuit for conventional induction motor from numerical algorithm of Newton-Raphson method.

Machine model for inverter fed Induction Motor



r_{1k} and l_{1k} : stator resistance and leakage inductance for k-th harmonic

r_{2k} and l_{2k} : rotor resistance and leakage inductance for k-th harmonic

It is important to note that rotor parameters r_{2k} and l_{2k} are frequency dependent, due to skin effect in rotor bars. Since an inverter fed induction motor is usually started at low frequency, the values of r_{2k} and l_{2k}, should be those corresponding to the harmonic frequency k_f,where f is starting frequency and k is order of harmonic. Rfe is also frequency dependent. The stator parameters r_{1k} and l_{2k} are assumed, for simplicity, to be independent of frequency.

Functions for harmonic equivalent circuit,

Non linear equations of functions are:

$F_1 = Re\{\bar{z}\} - \frac{Us}{Is}\cos\emptyset$ $F_2 = Im\{\bar{z}\} - \frac{Us}{Is}\sin\emptyset$ $s_k = \frac{K+(1-s)}{K}$, Where, k = order of the harmonics

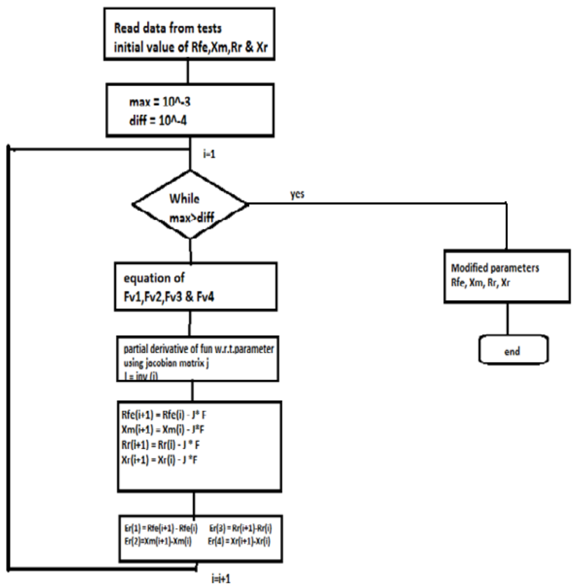
From modeling of induction motor, we have determined the non linear functions for new modified parameters of inverter fed Induction Motor from numerical algorithm of Newton – Raphson method.

5. Numerical Algorithm For Parameter Estimation

For getting better result of motor steady state performance in terms of efficiency, power factor, output power, load current, we have need to new parameter estimation of motor. For new estimation of motor, we have used Newton – Raphson method. Because the Newton Raphson mehod is a fast local convergence procedure used to solve non linear equations, f(x) = 0, using recurrence forulla and starting the iterative process with a value $x^{(0)}$ as first guess, as close as possible to the solution.

$$X^{(j+1)} = X^{(j)} - \frac{F(X)}{F'(X)}$$

- **Flow Chart for Newton – Raphson Method**



- **New Estimated Circuit Parameter After Newton – Raphson Programming**

	Rfe	Xm	Rr	Xr
Practical	1489	203.122	4.3504	9.1917
Simulation Conventional IM				
50 Hz	1462.4	215.7912	4.4583	8.8454
60 Hz	1817.3	232.8975	6.7380	10.7062

- **Results for harmonic equivalent circuit from NR Programming (Neglecting magnetizing parameter)**

	X_{rk} Ω	R_{rk} Ω	S_k
50 Hz	10.1163	4.8476	1.98
K=5	9.4484	4.7379	1.196
K=7	9.3658	4.6977	1.14
60 Hz	11.8735	7.1918	1.9973
K=5	10.8999	6.8130	1.995
K=7	10.7769	6.7521	1.1425

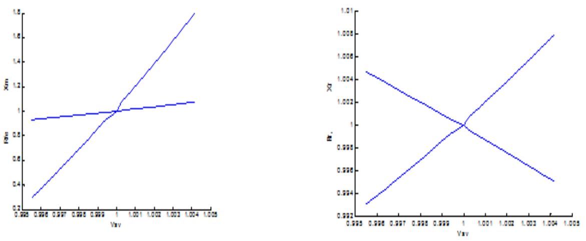
Effect of harmonic on parameter

- Parameter value of Rrk and Xrk decreases with order of the harmonic increases.
- Values of leakage inductance (Lm) decreases with increasing frequency.
- Harmonics are also increases with frequency increases.
- Parameter value Rrk and Xrk increases with frequency increases from 50 Hz to 60 Hz.

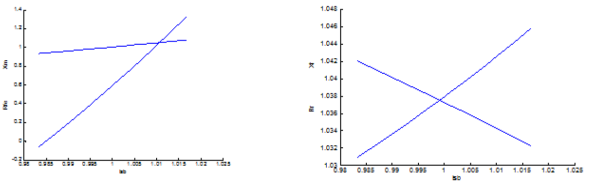
6. Sensitivity Analysis

Taking into account the dependence on measurements whose accuracy, among others, is related with the quality of instrumentation, the developed algorithm was also applied to study the influence of measurement errors on the calculation of parameters.

Sensitivity Analysis in terms are : Sensitivity of Parameter to errors in current measurement in a Block-Rotor Test :
a)Magnetizing branch Parameters b) Rotor Parameters



Sensitivity of parameters to errors in Voltage measurement in a No-Load Test :
a)Magnetizing branch Parameters b) Rotor Parameters



Graphs for Sensitivity Analysis are given in bellow results. In these graphs, both input (horizontal coordinate in terms voltage and current) and result (vertical coordinate in terms parameters of equivalent circuit of induction motor (Rfe, Xm, Rr, Xr)) are normalized to the values at the center of intervals (i.e.exact values).

Steady State Performance Of Induction Motor

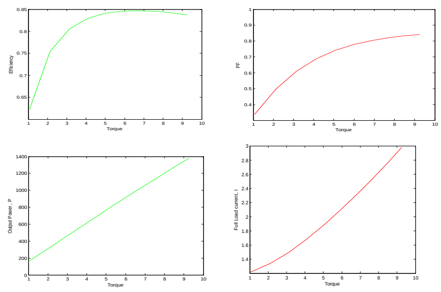
Algebraically steady state performance of IM,
Performances can be determined by following equations which are derived from power stages of the motor :
Stator input = Stator output + Stator losses
Rotor input = Stator output
Rotor Gross output = Rotor input – Rotor Cu Losses

$R_L = R_r(\frac{1}{s} - 1)$, $Z_{eq} = Z_o + Z_{ab}$, $Z_o = jRfeXm/Rfe + jXm$, $I_1 = {}^{V}/_{Z_{eq}} = I_o + I_2$

$P_{out} = 3I_2^2 R_L$, $T_g = P_g/\omega_m$, Rotor output = $T_g * 2\pi N$, Rotor input = $T_g * 2\pi N_s$

PF = $\mathrm{Cos}(\tan^{-1}\{\frac{IM\{Z_{eq}\}}{Re\{Z_{eq}\}}\})$, $P_{in} = 3VI_{eq}\cos\emptyset$, Efficiency = (P_{out} / P_{in}) *100

Graphs from algebraically equation for following motor (380V, 50 HZ, 1.2 Kw, 4-pole) : torque Vs Eff, PF, P, I.



Algebraically performance result for old and new estimated parameter obtained from ERDA Lab

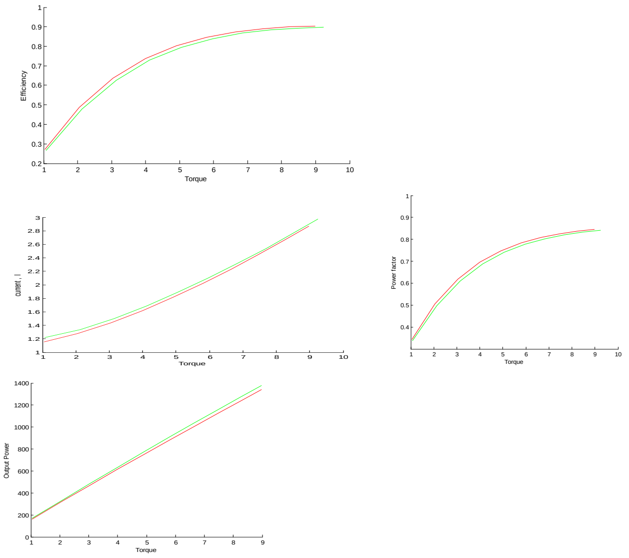
Performance result for old estimated parameters

Slip	0.01	0.02	0.03	0.04	0.05
Eff	75.39	82.97	84.62	84.52	83.70
PF	0.4970	0.6881	0.7773	0.8201	0.8411
Current	1.3386	1.6863	2.1012	2.5376	2.9749
Output Power	330.2	633.7	909.6	1157.7	1378.4
Torque	2.1232	4.1186	5.97	7.6776	9.2369
Speed	1485	1470	1455	1440	1425

Performance result for new estimated parameters from NR method

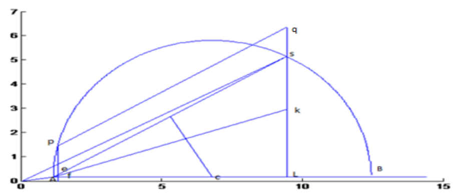
Slip	0.01	0.02	0.03	0.04	0.05
EFF	75.40	83.03	84.72	84.65	83.86
PF	0.5052	0.6957	0.7835	0.8253	0.8455
Current	1.2756	1.6158	2.0203	2.4452	2.8707
Output Power	319.8	614.3	882.6	1124.4	1339.8
Torque	2.0564	3.9907	5.7926	7.4561	8.9783
Speed	1485	1470	1455	1440	1425

- **Performance graph result for old and new estimated parameter.**

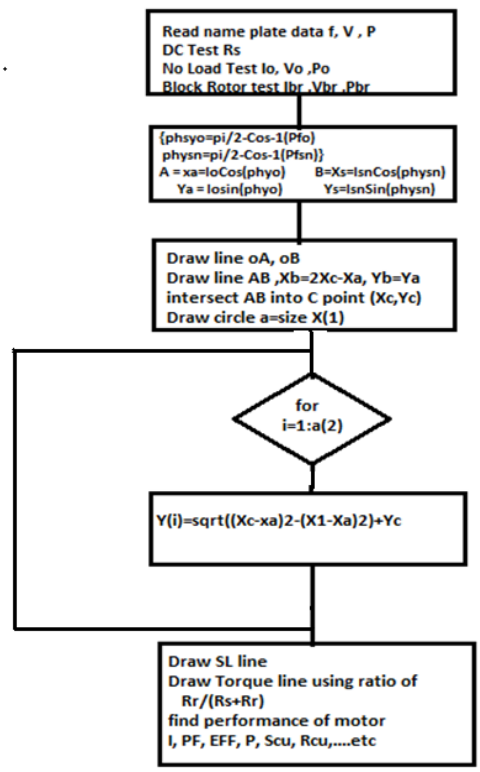


Where, Green line indicates performance for old parameter
Red line indicates performance for new estimate parameter

Performance obtained by circle diagram (Graphically)



7. Flow chart for the Circle Diagram



8. Result from Circle Diagram

For 50 Hz, 380V, 1.2Kw, 4 pole at Full load (100%)

	I_1	PF	N	T	Slip	P_1	Eff
Practical	1.9339	0.7455	1458.5	7.071	0.0312	1441.7	83.23
Simulink Conventional IM	1.8809	0.7688	1452.5	7.8893	0.0317	1456	82.40
Simulink Inverter fed IM	1.9641	0.7424	1448.6	7.910	0.0343	1458	82.30

For 60 Hz, 380V, 1.2Kw at Full load

	I1	PF	N	T	Slip	P1	Eff
Simulink Conventional	1.8039	0.8065	1730.8	6.6208	0.04	1454.8	82.48
Simulink Inverter fed IM	1.843	0.780	1710	6.7013	0.05	1437.8	83.46

Comparison of steady state performance for variable frequency IM at 50 and 60 Hz frequency.

- With increase the frequency, load current decrease
- Torque decrease with increase frequency
- Input power decrease with increase frequency
- Small percentage increase in efficiency
- Speed increases, as well as slip also increases.

9. Conclusion

In proposed method (Newton-Rapson) for determining the modified parameters of a three phase Induction Motor's Equivalent Circuit, has shown fast and univocal convergence Results. Equivalent circuit parameters will be used for determined steady state performance of IM. With frequency change, parameter of equivalent circuit of motor arechanged, so steady state performance of motor (Eff, PF,I,T…) are also changed.

10. Further Improvement

We will also estimated parameter of equivalent circuit using Annealing Method and Partical Swarm Optimizing Method.

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