RESEARCH ARTICLE OPEN ACCESS

TNM Method Results Compared with Finite Element Analysis for a 30 KW SCIM Motor

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Abstract
The Thermal network model (TNM) of ten node 37 thermal resistances is considered as the highly detailed one for thermal distribution of all the TNM models. This model is reported to be the one that can take care of most of the complexities in geometry and estimation of convective heat transfer coefficients. Results obtained for the 30 KW motor using the above TNM model have been compared with that of Finite element Analysis using ANSYS. Listing of the MATLAB programs is presented as annexure.

I. INTRODUCTION

The standard 10 node thirty seven TNM by Mellor and Turner [7] has been used to model the 30 KW motor the details of which are given in the table 1.

II. THERMAL RESISTANCE ESTIMATION OF MOTOR COMPONENTS

Thermal network model consist of 10 nodes such as 1-Frame, 2-Stator Yoke,3-Stator Teeth,4-Stator Winding,5-Air Gap,6-End Winding,7-End Cap Air,8-Rotor Winding,9-Rotor Iron,10-Shaft

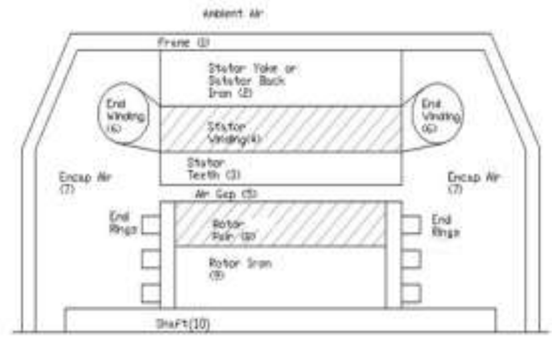


Fig. 1 – The 10 node TNM model of SCIM motor

TABLE I
DETAILS OF 30 KW MOTOR [1]

Power	30 KW	Connection	delta	Core length	207
Air gap	0.80	Rotor diameter	213	Stator diameter	334
η	0.927	Rated speed	1450 rpm	Rated torque	98.8 Nm
Rotor slots	43	Stator slots	48	Voltage (Line/Ph)	660/398.3 V
Location of loss	Stator core	Stator teeth	Stator winding	Rotor bar	Rotor core
Loss (Watts)	467	165.40	738.2	563	89.4

A. FRAME

$$R_1 = \frac{1}{A_{frame}\ h_1} \quad (1)$$

$$R_2 = \frac{1}{\pi\ h_{conv}\ \ L r_1} \quad (2)$$

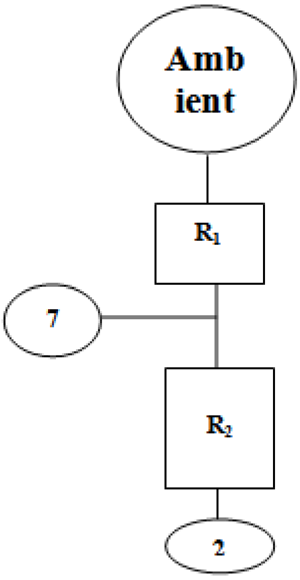


Fig.2 Frame

B. STATOR YOKE / STATOR BACK IRON

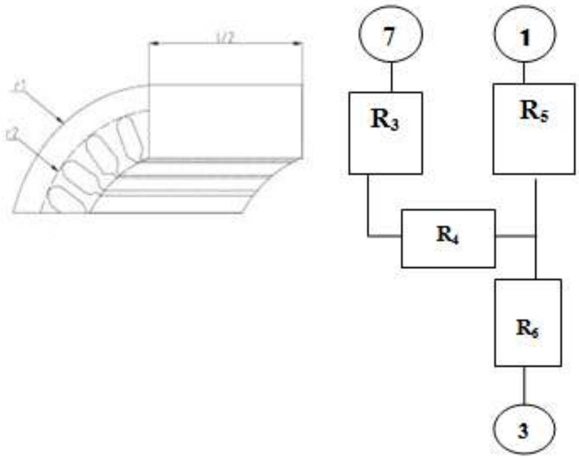


FIG. 3 STATOR BACK IRON

$$R_3 = \frac{L}{6*\pi*k_{la}*(r_1^2 - r_2^2)} \quad \text{……... (3)}$$

$$R_4 = (-1)*\left[\frac{r_1^2 + r_2^2 - \dfrac{[4*r_1^2*r_2^2*\ln(\frac{r_1}{r_2})]}{(r_1^2 - r_2^2)}}{4*\pi*k_{lr}*s*L*(r_1^2 - r_2^2)}\right] \quad \text{……(4)}$$

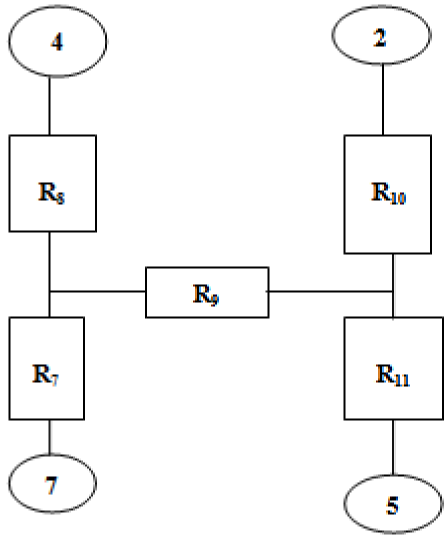
$$R_5 = \frac{1}{(2*\pi*k_{lr}*s*L)}\left[1 - \left[\frac{[2*r_2^2*\ln(r_1/r_2)]}{(r_1^2 - r_2^2)}\right]\right]$$

……..(5)

$$R_6 = \frac{1}{(2*\pi*k_{lr}*s*L)}\left[\left[\frac{[2*r_1^2*\ln(r_1/r_2)]}{(r_1^2 - r_2^2)}\right] - 1\right]$$

……..(6)

C. STATOR TEETH



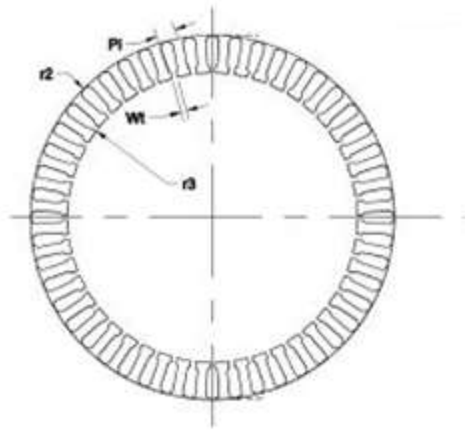


FIGURE – 4 STATOR TEETH

$$R_7 = \frac{L*P_t}{6*\pi*k_{la}*W_t*(r_2^2 - r_3^2)} \quad \text{….(7)}$$

$$R_8 = \frac{\pi*W_t*(r_2^2 - r_3^2)}{k_{lr}*L*s*p_t*(r_2 - r_3)^2*n^2} \quad \text{…..(8)}$$

$$R_9 = (-1)*\left[\frac{r_2^2 + r_3^2 - \frac{[4*r_2^2*r_3^2*\ln(\frac{r_2}{r_3})]}{(r_2^2 - r_3^2)}}{4*\pi*k_{lr}*L*s*W_t*(r_2^2 - r_3^2)}\right] \quad \text{......(9)}$$

$$R_{10} = \frac{P_t}{(2*\pi*k_{lr}*s*L*W_t)}\left[1 - \left[\frac{[2*r_3^2*\ln(r_2/r_3)]}{(r_2^2 - r_3^2)}\right]\right] \quad \text{....(10)}$$

$$R_{11} = \frac{P_t}{(2*\pi*k_{lr}*s*L*W_t)}\left[\left[\frac{[2*r_2^2*\ln(r_2/r_3)]}{(r_2^2 - r_3^2)}\right] - 1\right] \quad \text{......(11)}$$

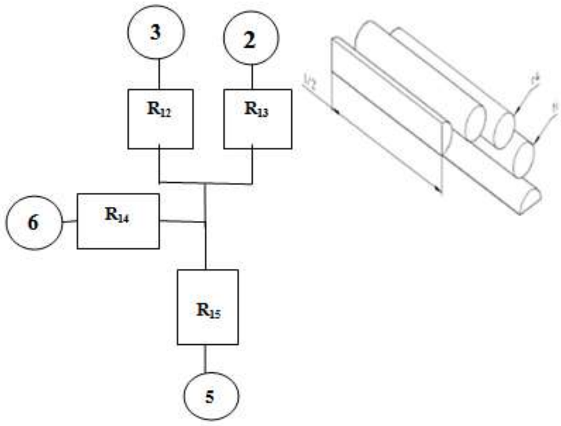


FIG. 5 STATOR WINDING

$$R_{12} = \frac{2*t_i}{(\pi*k_i*L*r_4*n)} + \frac{1}{(2*\pi*k_v*L*f_r*n)} \quad \text{...(12)}$$

$$R_{13} = \frac{L}{(6*k_c*A_{sc}*n)} \quad \text{.......(13)}$$

$$R_{14} = \frac{4*t_i}{(\pi*k_i*L*r_4*n)} + \frac{1}{(\pi*k_v*L*f_r*n)} \quad \text{....(14)}$$

$$R_{15} = \frac{1}{(\pi*k_v*L*f_r*n)} \quad \text{........(15)}$$

E. AIR GAP

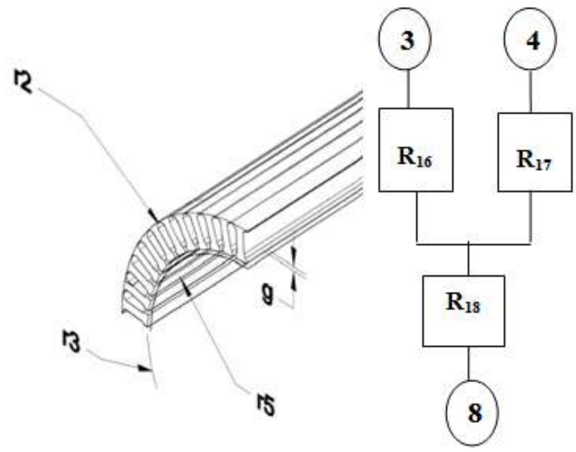


Fig. 6 AIR GAP

$$R_{16} = \frac{P_t}{W_t*\pi*r_3*l*h_{2r}*[h_{2s}]} \quad \text{............(16)}$$

$$R_{17} = \frac{P_t}{(P_t\text{-}W_t)\ \pi*r_3*l*h_{2r}*[h_{2s}]} \quad \text{............(17)}$$

$$R_{18} = \frac{1}{\pi*r_5*l*h_{2r}*[h_{2s}]} \quad \text{............(18)}$$

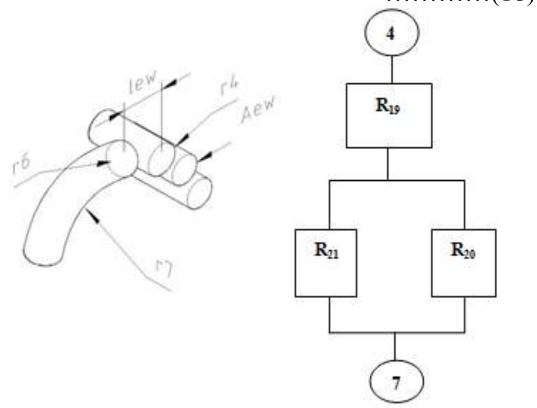


FIGURE – 7 END WINDING

$$R_{19} = \frac{l_o*w}{(n*A_{sc}*k_c)} \quad \text{...........(19)}$$

$$R_{20} = \frac{w}{(16*\pi^2*r_t*fr*k_v)} \quad \text{...........(20)}$$

$$R_{21} = \frac{w*r_6^2}{(8*\pi*r_4^2*l_o*f_r*k_v*n)} \quad \text{...........(21)}$$

G. END CAP AIR

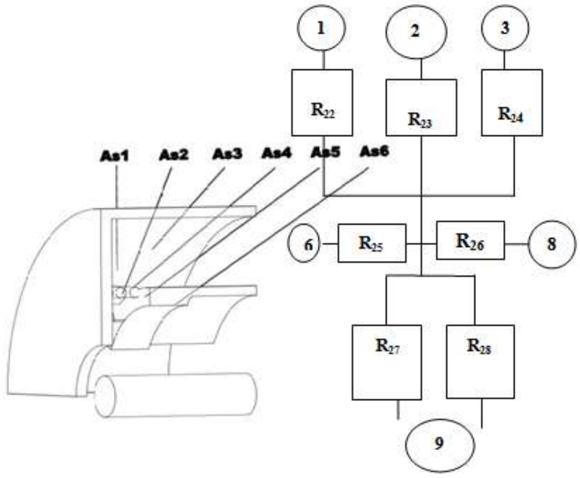


Fig. 8 END CAP AIR

The circulating air in the end cap is assumed to have a uniform temperature. A single film coefficient is used to describe the convective heat transfer from all surfaces.

The contact area offered by the end winding toroidal model is increased by 50% to allow for surface irregularities and the greater area of the flatter structure of a true end winding.

$$R_{22} = \frac{1}{A_{s1}*h_{3r}[*h_{3s}]} \quad ....(22)$$

$$R_{23} = \frac{1}{A_{s2}*h_{3r}[*h_{3s}]} \quad ....(23)$$

$$R_{24} = \frac{1}{A_{s3}*h_{3r}[*h_{3s}]} \quad ....(24)$$

$$R_{25} = \frac{1}{1.5*A_{s4}*h_{3r}[*h_{3s}]} \quad ....(25)$$

$$R_{26} = \frac{1}{A_{s5}*h_{3r}[*h_{3s}]} \quad ....(26)$$

$$R_{27} = \frac{1}{A_{s6}*h_{3r}[*h_{3s}]} \quad ....(27)$$

H. ROTOR WINDING

$$R_{28} = \frac{L}{[6*\pi*k_a*(r_5^2 - r_8^2)]} + \frac{l_e}{[\pi*k_a*(r_5^2 - r_7^2)]} \quad ...(28)$$

$$R_{29} = (-1)*\left[\frac{r_5^2 + r_8^2 - \dfrac{[4*r_5^2*r_8^2*\ln(\frac{r_5}{r_8})]}{(r_5^2 - r_8^2)}}{4*\pi*k_a*L*(r_5^2 - r_8^2)}\right] \quad .(29)$$

$$R_{30} = \frac{1}{(2*\pi*k_a*L)}\left[1 - \left[\frac{[2*r_8^2*\ln(r_5/r_8)]}{(r_5^2 - r_8^2)}\right]\right] \quad .(30)$$

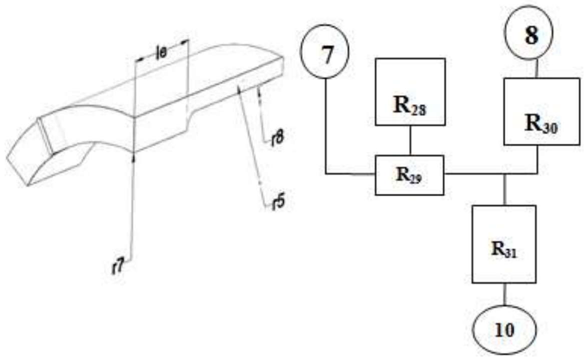


FIG. 9 ROTOR WINDING

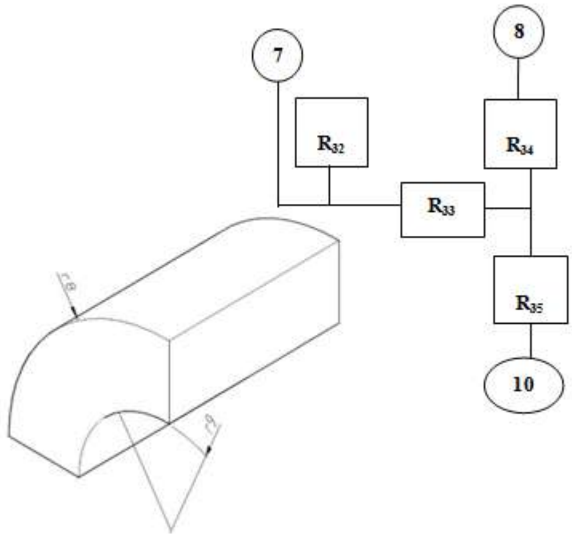


Fig. 10 ROTOR IRON

$$R_{31} = \frac{1}{(2*\pi*k_a*L)}\left[\left[\frac{[2*r_5^2*\ln(r_5/r_8)]}{(r_5^2 - r_8^2)}\right] - 1\right] \quad ...(31)$$

$$R_{32} = \frac{L}{6*\pi*k_a(r_8^2 - r_9^2)} \quad ....(32)$$

$$R_{33} = (-1) * \left[\frac{r_8^2 + r_9^2 - \frac{[4 * r_8^2 * r_9^2 * \ln(\frac{r_8}{r_9})]}{(r_8^2 - r_9^2)}}{4 * \pi * k_{lr} * s * L * (r_8^2 - r_9^2)} \right]$$

…..(33)

$$R_{34} = \frac{1}{(2 * \pi * k_{lr} * s * L)} \left[1 - \left[\frac{[2 * r_9^2 * \ln(r_8 / r_9)]}{(r_8^2 - r_9^2)} \right] \right] \quad \text{…..(34)}$$

$$R_{35} = \frac{1}{(2 * \pi * k_{lr} * L * s)} \left[\left[\frac{[2 * r_8^2 * \ln(r_8 / r_9)]}{(r_8^2 - r_9^2)} \right] - 1 \right] \quad \text{…..(35)}$$

I. SHAFT

$$R_{36} = \frac{1}{(2 * \pi * k_s * L)} + \frac{l_m}{(2 * \pi * k_s * r_9^2)} \quad \text{……(36)}$$

$$R_{37} = \frac{1}{(4 * \pi * k_s * l_b)} + \frac{l_m}{(2 * \pi * k_s * r_9^2)} \quad \text{………(37)}$$

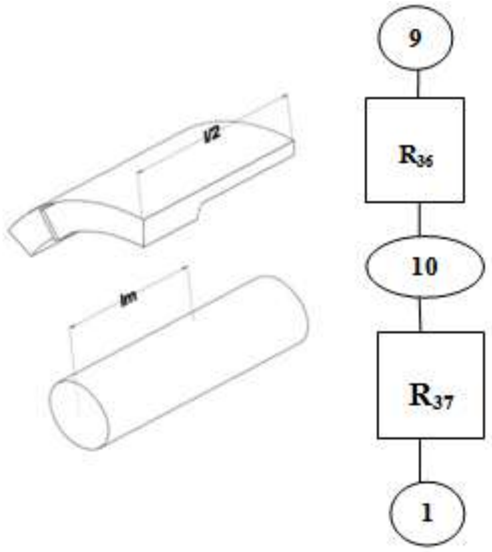


FIG. 11 SHAFT

TABLE II
LIST OF SYMBOLS

Symbols		Name
R_e	Ohm	Electrical Resistance (suffix s for stator and r for rotor)
I	Amp.	Current
	W/(m^2.K)	Free convection heat transfer coefficient between frame and ambient
h_{2r}	W/(m^2.K)	Rotating air-gap film coefficient
h_{2s}	W/(m^2.K)	stationary air-gap film coefficient
h_{3r}	W/(m^2.K)	Rotating end cap film coefficient
h_{3s}	W/(m^2.K)	Stationary end cap film coefficient
k_{la}	W/(m.K)	Lamination axial conductivity
k_{lr}	W/(m.K)	Lamination radial iron conductivity
k’	W/(m.K)	Equivalent thermal conductivity
k_c	W/(m.K)	Copper conductivity
k_i	W/(m.K)	Slot liner conductivity
k_v	W/(m.K)	Varnish conductivity
k_a	W/(m.K)	Aluminium conductivity
K_s	W/(m.K)	Shaft steel conductivity.
A_{frame}	mm^2	Half of frame area
A_s	mm^2	Slot Area
A_{sc}	mm^2	Copper wire area
A_v	mm^2	Varnish area
A_{Sc}	mm^2	Copper cross- section in slots
L	m	Stator length
l_0	m	Slot winding overhang
h_{cont}	m	Frame-core contact coefficient
r_1	m	Stator outer radius
r_2	m	Tooth outer radius
r_3	m	Tooth inner radius
r_4	m	Equivalent winding radius
r_5	m	Rotor outer radius
r_6	m	End winding cross section radius
r_7	m	End ring inner radius
r_8	m	Equivalent rotor winding radius
r_t	m	End winding toroid radius
t_i	m	Insulation thickness
P_t	m	Tooth pitch
W_t	m	Stator tooth width
n	--	Number of slots
w	--	Hot spot to mean temperature ratio
f_r	--	Radial conductivity factor
l_e	mm	End ring width
l_b	mm	Bearing housing width
l_m	mm	Distance of the bearing centre to rotor mean
A_{s1}	mm^2	Surface area of end cap
A_{S2}	mm^2	Surface area of stator iron
A_{S3}	mm^2	Surface area of stator teeth,
A_{S4}	mm^2	Surface area of end winding
A_{S5}	mm^2	Surface area of rotor end-

		ring
A_{S6}	mm^2	Surface area of rotor iron

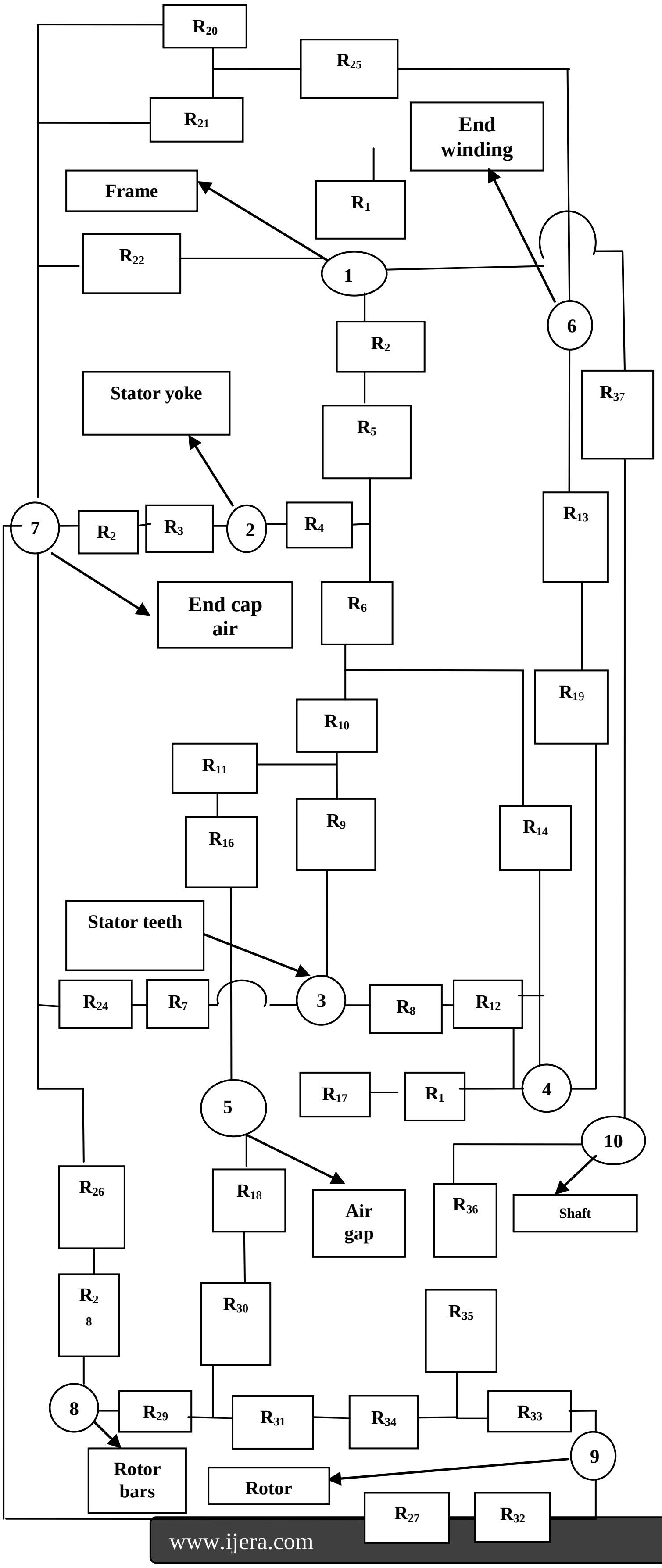


FIG. 11 - TNM MODEL OF 10 NODES

TABLE III
Thermal Resistance Description of 10 Node TNM Model

Resist-ance	**(K/W)**	**Description**
1-	**FRAME**	
R1	0.0567	Thermal resistance from frame to ambient
R2	0.0228	Radial thermal resistance from frame to stator yoke
2-	**STATOR BACK IRON/CORE**	
R3	0.2658	Axial thermal resistance from stator yoke to end cap air
R4	-0.0015	Radial interconnecting thermal resistance of the stator yoke
R5	0.0042	Radial thermal resistance from the stator yoke to frame
R6	0.0049	Radial thermal resistance from the stator yoke to stator teeth
3-	**STATOR TEETH**	
R7	0.8185	Axial thermal resistance from stator teeth to end cap air
R8	0.0008	Radial/circumferential thermal resistance from stator teeth to stator winding
R9	-0.003	Radial interconnecting thermal resistance of the stator teeth
R10	0.0086	Radial thermal resistance from the stator teeth to stator yoke
R11	0.0100	Radial thermal resistance from the stator teeth to air gap
4-	**STATOR WINDING**	
R12	0.0127	Radial/circumferential thermal resistance from the stator coils to stator teeth
R13	0.0094	Axial thermal resistance from the stator coils to end-winding
R14	0.0254	Radial thermal resistance from the stator coils to stator yoke
R15	0.0160	Radial thermal resistance from the stator coils to air gap
5-	**AIR GAP**	
R16	0.2958	Radial thermal resistance from the air gap to stator teeth
R17	0.2958	Radial thermal resistance from the air gap to stator coils
R18	0.1490	Radial thermal resistance from the air gap to rotor bars
6-	**END WINDING**	
R19	0.0102	Axial thermal resistance from the end-winding to stator coils
R20	0.0392	Thermal resistance from the end-

		winding to end cap air
R21	0.2522	Thermal resistance from the end-winding to end cap air
7-	**END CAP AIR**	
R22	0.0455	Axial thermal resistance from the end cap air to frame
R23	0.3716	Axial thermal resistance from the end cap air to stator yoke
R24	1.2088	Thermal resistance from the end cap air to stator teeth
R25	0.0614	Thermal resistance from the end cap air to end-winding
R26	1.1002	Thermal resistance from the end cap air to rotor end-rings
R27	0.7870	Thermal resistance from the end cap air to rotor iron
8-	**ROTOR WINDING**	
R28	0.0387	Axial thermal resistance from the rotor bars to end cap air
R29	-0.0001	Radial interconnecting thermal resistance of the rotor bars
R30	0.0003	Radial thermal resistance from the rotor bars to air gap
R31	0.0003	Radial thermal resistance from the rotor bars to rotor iron
9-	**ROTOR IRON**	
R32	0.4235	Axial thermal resistance from the rotor iron to end cap air
R33	-0.0037	Radial interconnecting thermal resistance of the rotor iron
R34	0.0095	Radial thermal resistance from the rotor iron to rotor bars
R35	0.0138	Radial thermal resistance from the rotor iron to shaft
10-	**SHAFT**	
R36	0.2158	Radial thermal resistance from the shaft to rotor iron
R37	0.2760	Axial thermal resistance from the shaft to frame through bearings

TABLE IV
TEMPERATURE DISTRIBUTION AND HEAT FLOWS - 10 NODE TNM MODEL

Heat input values: Watts			
		Additional loss	298.0
Stator yoke loss	467.0	Mechanical loss	76.0
Stator copper loss	619.0	Rotor copper loss	563.0
Temperatures at all the nodes are given in brackets			
NODE 1: Frame (57.39)		**NODE 2: Stator yoke (74.50)**	
HEAT FLOWS FROM			
Node 10 to node 1	116.41	Heat flows from node 3 to Node 2	290.18
Node 2 to node 1	670.28	Heat flows from node 4 to Node 2	157.36
Node 10 to node 1	224.81	Heat flows from node 5 to Node 2	72.56
No heat generation at node 1		Heat generation at node 2	233.50
		HEAT GOES OUT TO	
All these heat quantities go to ambient	-993.85	Node 7	-10.76
		Node 1	-670.28
NODE 3: Stator teeth (77.11)		**NODE 4:Stator winding (79.13)**	
HEAT FLOWS FROM		HEAT FLOWS FROM	
Heat flows from node 4	144.51	From node 6	34.29
Heat flows from node 5	67.63	From node 5	59.41
Heat flows out to		Heat flows out to	
To Node 2	-290.18	Flows out to node 3	-144.51
To Node 7	-4.66	Flows out to node 2	-157.36
Heat generated	82.70	Heat generated at node 4	208.16
NODE 5: Air gap (97.32)		**Node 6: End winding (**79.75)	
flows out to node 3	-67.63	Heat generated at node 6	160.94
flows out to node 4	-59.41	Flow to node 4	-34.29
Heat flows from node 8	127.05	Flows to node 7	-126.65
NODE 7: End cap air (67.66)		**NODE 8:Rotor bars (**116.42)	
Heat flow from node 8	42.914	Heat flow out to node 5	-127.05
Heat flow from node 2	10.76	Heat flow out to node 7	-42.914
Heat flow from node 3	4.66	Heat flow out to node 9	-111.54
Heat flow from node 6	126.65	Heat generated	281.50
Heat flow from node 9	39.83		
Heat flow out to node 1	-224.81		
Heat generated	0.0		

NODE 9: Rotor Iron (115.75)			
Heat flow from node 8	42.914	Heat flow from node 9	39.83
Heat flow from node 2	10.76	Heat flow out to node 1	-224.81
Heat flow from node 3	4.66	Heat generated	0.0
Heat flow from node 6	126.65		
NODE 10: Shaft (89.49)			
Heat to node 1	116.41	Heat from node 9	-116.41
No heat generation			

REFERENCES

[1] PH Mellor, D Roberts, DR Turner, Lumped parameter thermal model for electrical IEE PROCEEDINGS-B/ *Vol. 138, No. 5, 1/*205-218/machines of TEFC design 1991 *SEPTEMBER* 1991
[2] Popove Lyudmila, Combined electromagnetic and thermal design platform for totally enclosed induction motors, MASTER'S THESIS
[3] ANSYS manual

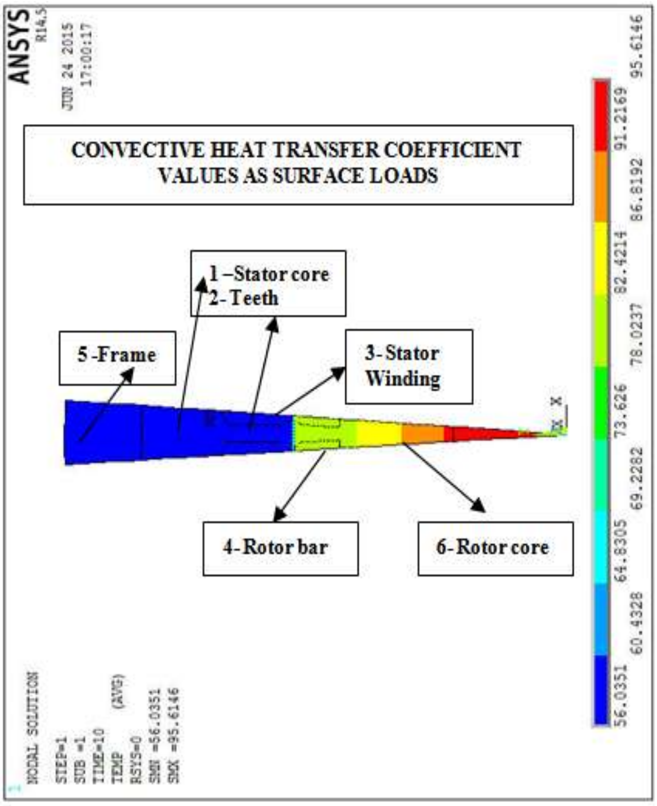


Fig. 13 Thermal Distribution of 30 kw Motor

```
% ANNEXTURE – MATLAB program
f2 = fopen('motor10nodes.txt','w');
%%All dimensions are in meter %%
%% Stator length and Stator outer radius %%
length=0.2066;    ra1 = 0.169
%%  Tooth outer radius and Tooth inner radius %%
ra2 = 0.1351;      ra3 = 0.1075
%% Winding radius and Rotor outer radius %%
ra4 = 0.0085718;   ra5 = 0.1067
%% End winding cross section radius %%
ra6 = 0.0273
%% End disk inner radius %%
ra7 = 0.0889
%% Equivalent rotor winding radius %%
ra8 = 0.0975
%% Shaft radius and Frame radius %%
ra9 = 0.05510;   raframe = ra1 + 0.02
%% End-winding toroid radius and No. of Slots %%
rat = (ra2+ra3)/2;     n = 48
%% Tooth pitch and Insulation Thickness %%
pt = 0.0106;    ti = 0.0005
%% End Winding length or Slot winding over hang
lew = 0.025;lo=lew
%% distance of rotor centre to bearing centre %%
lm = 0.15;
%% Bearing length and End cap length %%
lb = 0.025;     lendcap = 0.1281;
%% Length of Frame %%
lframe = 0.23140;
%% Surface area of copper  and Slot area %%
Asc= 0.00019066; Aslot = ra4^2*pi;
%% Endcap contact area %%
As1 = (2*pi*raframe*lendcap) + (pi*raframe^2);
%% End length %%
le = 0.0365;
%% Short terms
ra12= ra1^2-ra2^2;   ra23= ra2^2-ra3^2;
ra57= ra5^2-ra7^2;   ra58= ra5^2-ra8^2;
ra89= ra8^2-ra9^2;
%% Contact Area of stator iron %%
As2 = pi*(ra12);
%% Contact area of stator teeth %%
As3 = pi*(ra23) -  Aslot*n;
%% Contact area of endwinding %%
As4 = 2*pi*ra6*2*pi*rat;
% As4 = 2*pi*ra6;
hsum = (((ra5*2) - ra7*2 )/(2));
%% Contact area of rotor end winding %%
As5 = pi*(ra5^2 -((2*ra5-2*(hsum))/2)^2);
%% Contact area of rotor %%
As6 = pi*(((2*ra5-2*(hsum))/2)^2-(ra9^2));
%% Contact area of end ring %%
As7 = (2*pi*(ra57)+2*pi*ra5*le);
%% Surface area of frame %%
Aframe = pi*raframe^2 + 2*pi*raframe*lframe;
%% Heat transfer coefficient %%
%% Frame core contact coffi %%
hcont = 400;
%% Lamination stacking factor %%
s = 0.97;
%% Radial conductivity factor %%
```

```
fr = 2.5;
%% Hotspot to mean temp %%
w = 1.5;
%% Lamination axial and iron conductivities %%
kla = 4;    klr = 39;
%% Shaft steel and copper conductivities %%
ks = 40;    kc = 400;
%% Slot liner and varnish conductivities %%
ki = 0.8;     kv = 0.8;
%% Aluminium and air conductivities  %%
ka = 237; kair = 0.026;
%% Convection bt frame and ambient %%
h1 = 15.0952;
%% rotating airgap film %%
h2r = 96.8975;
%% Stationary airgap and end cap films %%
h2s = 65;    h3s = 15.5;
%% rotating endcap air film %%
h3r = 83.0951;
%losses %%
pfys = 467.00;                   pfes = 76.00;
pad = 298.00;       pcus = 619.00;     pcur = 563.00;
%% Resistance %%
r1 = 1/(2*h1*1.51*Aframe);
r2 = 1/(pi*hcont*length*ra1);
r3 = length/(6*pi*kla*ra12);
r4_c= 4*ra1^2*ra2^2*log(ra1/ra2)/ra12;
r4_d= 4*pi*klr*length*s*ra12;
r4 = -1*(ra1^2 + ra2^2 -r4_c)/r4_d;
r5_a= 2*ra2^2*log(ra1/ra2)/ra12;
r5_b = (1-r5_a);
r5= r5_b/(2*pi*klr*length*s);
r6_a = 2*ra1^2*log(ra1/ra2)/ra12;
r6= (r6_a -1)/(2*pi*klr*length*s);Wt = 0.0053;
r7 = length*pt/(6*pi*kla*Wt*ra23);
r8 = pi*Wt*ra23/(klr*length*s*pt*(ra2-ra3)^2*n^2);
r9_a= 4*ra2^2*ra3^2*log(ra2/ra3)/ra23 ;
r9_b = -pt*(ra2^2 + ra3^2 -r9_a);
r9= r9_b/ (4*pi*klr*length*s*Wt*ra23);
r10_a= 2*ra3^2*log(ra2/ra3)/ra23;
r10_b= 2*pi*klr*length*s*Wt;
r10 = pt*(1-r10_a)/r10_b;
r11_a= 2*ra2^2*log(ra2/ra3)/ra23;
r11_b= 2*pi*klr*length*s*Wt;
r11 = pt*(r11_a -1)/r11_b;
r12_a = 2*ti/(pi*ki*length*ra4*n);
 r12_b = 1/(2*pi*kv*length*fr*n);
r12 = r12_a + r12_b;
r13 = length/(6*kc*Asc*n);
r14_a = 4*ti/(pi*ki*length*ra4*n);
 r14_b= 1/(pi*kv*length*fr*n);
r14 = r14_a + r14_b;
r15 = 1/(pi*kv*length*fr*n);
r16 = pt/(Wt*pi*ra3*length*h2r);
r17 = pt/((pt-Wt)*pi*ra3*length*h2r);
r18 = 1/(pi*ra5*length*h2r);
r19 = lo*w/(n*Asc*kc);
r20 = w/(16*pi^2*rat*fr*kv);
r21 = w*ra6^2/(8*pi*ra4^2*lo*fr*kv*n);
r22 = 1/(As1*h3r);           r23 = 1/(As2*h3r);
r24 = 1/(As3*h3r);           r25 = 1/(1.5*As4*h3r);
r26 = 1/(As5*h3r);           r27 = 1/(As6*h3r);
r28_a = length/(6*pi*ka*(ra58));
r28_b= le/(pi*ka*(ra57));  r28= r28_a + r28_b;
r29_a=  4*ra5^2*ra8^2*log(ra5/ra8)/ra58;
r29_b = 4*pi*ka*length*ra58;
r29 = -1*(ra5^2 + ra8^2 -r29_a)/r29_b;
r30_a= 2*ra8^2*log(ra5/ra8)/ra58;
r30_b= 2*pi*ka*length;
r30 = (1-r30_a)/r30_b;
r31_a= 2*ra5^2*log(ra5/ra8)/ra58;
r31_b= 2*pi*ka*length;
r31 = (r31_a -1)/r31_b;
r32 = length/(6*pi*kla*ra89);
r33_a= 4*ra8^2*ra9^2*log(ra8/ra9)/ra89;
r33_b= 4*pi*klr*length*s*ra89;
r33 = -1*(ra8^2 + ra9^2 -r33_a)/r33_b;
r34_a= 2*ra9^2*log(ra8/ra9)/ra89;
r34_b= 2*pi*klr*length*s;
r34 = (1-r34_a)/r34_b;
r35_a= 2*ra8^2*log(ra8/ra9)/ra89;
r35_b= 2*pi*klr*length*s;
r35 =  (r35_a-1)/r35_b;
r36_a=1/(2*pi*ks*length);r36_b= /(2*pi*ks*ra9^2);
r36 = r36_a + r36_b;
r37_a = 1/(4*pi*ks*lb);     r37_b= /(2*pi*ks*ra9^2);
r37 = r37_a + r37_b;
%% Thermal conductances %%
g12 = 1/(r2+r4+r5);   g17 = 1/ r22;    g110 = 1/r37;
g11 = g12 +g110 + g17+(1/r1);
g23 = 1/(r4+r6+r9+r10);     g24 = 1/(r14+r6+r4);
g25 = 1/(r4+r6+r10+r11+r16);
g27 = 1/(r3+r23);              g22 = g12 +g23+g27+g24;
            g34 = 1/(r8+r12);
g35 = 1/(r9+r11+r16);       g37 = 1/(r7+r24);
g33 = g23 + g34 +g37 + g35;
g45 = 1/(r15+r17);             g46 = 1/(r13+r19);
g44 = g24 + g34 +g45 +g46;
g58 = 1/(r18+r29+r30);     g55 = g35 +g45 + g58 ;
r67_a  = r20*r21/(r20+r21);
g67 = 1/(r67_a + r25);       g66 = g46 + g67;
g78 = 1/(r26 +r28);            g79 = 1/(r32+r27);
g77 = g17 + g27 + g37 + g67 + g78 + g79 ;
g89 = 1/(r29+r31+r33+r34);
g88 = g58+g78+g89;g910 = 1/(r33+r35+r36);
g99 = g89 + g79 + g910;   g1010= g910+g110;
%% Matrix %%
g = [g11    -g12    0   0   0    0    -g17    0    0     -g110;
    -g12    g22  -g23   -g24    0    0    -g27    0    0     0;
    0   -g23  g33  -g34  -g35  0  -g37    0    0     0    ;
    0     -g24 -g34    g44  -g45  -g46    0     0    0     0  ;
    0      0  -g35   -g45   g55    0     0    -g58  0    0;
    0      0     0   -g46    0   g66   -g67    0    0     0  ;
    -g17    -g27  -g37   0   0   -g67   g77   -g78 -g79  0 ;
    0      0   0      0   -g58    0   -g78   g88  -g89     0 ;
    0      0   0      0     0      0   -g79  -g89   g99  -g910 ;
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  -g110   0   0     0    0   0  0      0  -g910 g1010  ];
p = [0;       pfys/2;    (pfes+0.3*pad)/2;
((pcus*0.48+0.4*pad)/2);     0;
  pcus*0.52/2;        0;   pcur/2;   0.3*pad/2;      0];
t=g\p;
f_Row= [g11   -g12   0  0   0  0   -g17   0   0   -g110 ];
s_Row= [ -g12 g22 -g23   -g24    0  0   -g27  0  0   0] ;
t_Row= [ 0  -g23  g33  -g34  -g35   0   -g37  0  0   0 ];
fo_Row=[0   -g24 -g34    g44  -g45  -g46   0  0  0  0 ];
fi_Row=[ 0  0  -g35  -g45  g55    0    0  -g58  0  0;    ];
si_Row=[ 0   0   0   -g46   0  g66  -g67    0    0     0  ];
se_Row=[-g17 -g27 -g37 0 0  -g67 g77 -g78 -g79  0];
ei_Row=[ 0   0   0   0   -g58   0   -g78   g88  -g89  0  ];
ni_Row=[  0  0  0  0   0  0   -g79  -g89   g99  -g910 ] ;
te_Row=[ -g110  0    0    0  0   0  0  0  -g910 g1010  ];
fprintf(f2,'\n    r1    r2     r3    r4        r5      r6   \n');
fprintf(f2,'%9.3f',r1,r2,r3,r4,r5,r6);
fprintf(f2,'\n    r7     r8       r9    r10   r11    r12   \n');
fprintf(f2,'%9.3f',r7,r8,r9,r10,r11,r12);
fprintf(f2,'\n    r13    r14      r15    r16    r17   r18  \n');
fprintf(f2,'%9.3f',r13,r14,r15,r16,r17,r18);
fprintf(f2,'\n    r19   r20     r21     r22   r23      r24  \n');
fprintf(f2,'%9.3f',r19,r20,r21,r22,r23,r24);
fprintf(f2,'\n    r25   r26  r27   r28      r29       r30  \n');
fprintf(f2,'%9.3f',r25,r26,r27,r28,r29,r30);
fprintf(f2,'\n    r31   r32   r33   r34   r35   r36   r37 \n');
fprintf(f2,'%9.3f',r31,r32,r33,r34,r35,r36,r37);
fprintf(f2, '30KW,440V,50HZ,3-Ph SCIM\n');
fprintf(f2, **********************************');
fprintf(f2, '\nOutput Data:');
fprintf(f2, '\n-----------');
fprintf(f2, '\n heat input values:');
fprintf(f2,'stator yoke loss %5.1f, iron loss=%5.1f,additional loss%5.1f',pfys,pfes,pad);
fprintf(f2,'stator copper loss=%5.1f, rotor copper loss=%5.1f',pcus,pcur);
fprintf(f2, '\n--------------conductivity matrix ');
fprintf(f2,'\n-------conductivitymatrix ');fprintf(f2,'\n');
fprintf(f2,'%6.1f',f_Row);fprintf(f2,'\n');
fprintf(f2,'%6.1f',s_Row);fprintf(f2,'\n');
fprintf(f2, '%6.1f',t_Row);fprintf(f2,'\n');
fprintf(f2, '%6.1f',fo_Row);fprintf(f2,'\n');
fprintf(f2, '%6.1f',fi_Row);fprintf(f2,'\n');
fprintf(f2, '%6.1f',si_Row);fprintf(f2,'\n');
fprintf(f2, '%6.1f',se_Row);fprintf(f2,'\n');
fprintf(f2, '%6.1f',ei_Row);fprintf(f2,'\n');
fprintf(f2, '%6.1f',ni_Row);fprintf(f2,'\n');
fprintf(f2, '%6.1f',te_Row);fprintf(f2,'\n');
fprintf(f2, '\nTemperature rise in the nodes');
fprintf(f2,'%7.2f',t);
fprintf(f2, '\nHeat in puts in the nodes');
fprintf(f2,'%7.2f',p);
%Heat flows around node 1
ht12 = (t(1)-t(2))/(r2+r4+r5);
ht17 = (t(1)-t(7))/ r22;
ht110 = (t(1)-t(10))/r37;
ht11 = ht12 +ht110 + ht17+(1/r1);
fprintf(f2,'\n    ht12        ht17      ht110     ht11      \n');
fprintf(f2,'%9.3f',ht12,ht17,ht110,ht11);
%Heat flows around node 2 (ht12 is already defined)
ht23 = (t(2)-t(3))/(r4+r6+r9+r10);
ht24 = (t(2)-t(4))/(r14+r6+r4);
ht25 = (t(2)-t(5))/(r4+r6+r10+r11+r16);
ht27 = (t(2)-t(7))/(r3+r23);
ht22 = ht12 +ht23+ht27+ht24;
fprintf(f2,'\n ht12  ht23   ht24   ht25  ht27  ht22    \n');
fprintf(f2,'%9.3f',ht12,ht23,ht24,ht25,ht27,ht22);
%Heat flows arnd node 3 ( ht23 is already defined)
ht34 = (t(3)-t(4))/(r8+r12);
ht35 = (t(3)-t(5))/(r9+r11+r16);
ht37 = (t(3)-t(7))/(r7+r24);
ht33 = ht23 + ht34 +ht37 + ht35;
fprintf(f2,'\n    ht23   ht34      ht35    ht37   ht33     \n');
fprintf(f2,'%9.3f',ht23,ht34,ht35,ht37,ht33);
%Heat flows arn node 4 (ht24 and ht34 defined)
ht45 = (t(4)-t(5))/(r15+r17);
ht46 = (t(4)-t(6))/(r13+r19);
ht44 = ht24 + ht34 +ht45 +ht46;
fprintf(f2,'\n    ht24   ht34  ht45    ht46       ht44     \n');
fprintf(f2,'%9.3f',ht24,ht34,ht45,ht46,ht44);
%Heat flows arnd node 5 (ht35 and ht45 are defined)
ht58 = (t(5)-t(8))/(r18+r29+r30);
ht55 = ht35 +ht45 + ht58 ;
fprintf(f2,'\n    ht35    ht45  ht58   ht55     \n');
fprintf(f2,'%9.3f',ht35,ht45,ht58,ht55);
%Heat flows around node 6 (ht46 is already defined);
r67_a  = r20*r21/(r20+r21);
ht67 = (t(6)-t(7))/(r67_a + r25);
ht66 = ht46 + ht67;
fprintf(f2,'\n    ht46  ht67  ht66     \n');
fprintf(f2,'%9.3f',ht46,ht67,ht66);
%Heat flows around node 7 (ht17, ht27, ht37,ht67 are
%already defined)
ht78 = (t(7)-t(8))/(r26 +r28);
ht79 = (t(7)-t(9))/(r32+r27);
ht77 = ht17 + ht27 + ht37 + ht67 + ht78 + ht79 ;
fprintf(f2,'\n ht17 ht27ht37 ht67 ht78 ht79 ht77    \n');
fprintf(f2,'%9.3f',ht17,ht27,ht37,ht67,ht78,ht79,ht77);
%Heat flows around node 8 (ht58, ht78 are defined)
ht89 = (t(8)-t(9))/(r29+r31+r33+r34);
ht88 = ht58+ht78+ht89;
fprintf(f2,'\n    ht58  ht78  ht89 ht88  \n');
fprintf(f2,'%9.3f',ht58,ht78,ht89,ht88);
%Heat flows around node 9 (ht89, ht79 are  defined)
ht910 = (t(9)-t(10))/(r33+r35+r36);
ht99 = ht89 + ht79 + ht910;
fprintf(f2,'\n    ht89  ht79  ht910 ht99  \n');
            fprintf(f2,'%9.3f',ht89,ht79,ht910,ht99);
%Heat flows around node 9
ht1010= ht910+ht110;
fprintf(f2,'\n    ht910 ht110  ht1010  \n');
fprintf(f2,'%9.3f',ht910,ht110,ht1010);
fclose(f2);
```