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Electrical analogy for the solution of unidirectional heat transfer through star and delta configurations

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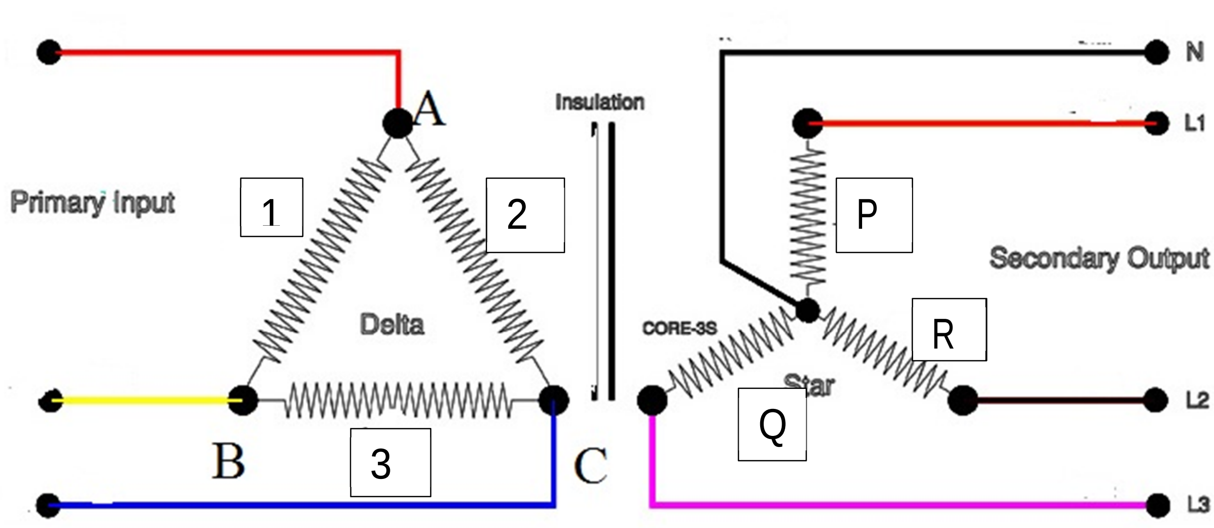
Abstract: - In the modern era the theory of relativity is the generic approach to resolve the problem of different field. Flux is the flow of energy form the transverse surface due to the difference in the energy potential between the two points. These fields can be of water, magnetic field, sound, light, heat etc. depending upon the parameters of interests. Every stream has its own energy field. In this, the analysis of the composite wall using star and delta configuration for the heat transfer through the composite wall is represented.

I. INTRODUCTION

The composite wall behaves like an electrical wire having its own material resistance. The walls of different materials are having different rates of the heat flow. The temperature gradient exists due to difference between the two points of the wall. This difference in temperature can be compared to the potential difference between two points of the wall. If the current of the heat is compared to the electricity the two configurations of the heat transfer are possible. Two basic configurations of three different propagations of thermal circuits are:-

Delta configuration:- In this configuration, the temperatures at the contact points of three different metallic slabs T_A, T_B and T_c are same. The unidirectional heat flow from the joins will be different.
Star configuration:- in this configuration the heat flow rate is constant through the common contact of the slab. Temperature can vary according to heat conductivity of the material.



Mathematical Formulation:- Let us consider a composite triangular wall slab of thickness L_1, L_2 and L_3 and joints A, B and C respectively. Considering unidirectional heat flow in the each slab from the star connection of common joint, the heat transfer can be expressed using the formulas' $Q = dT/R_{th}$ and $R_{th} = L/KA$. The formulation of the conversion is represented as under :-

A. Delta to star conversion

$$P = R_1.R_2/(R_1+R_2+R_3) = \frac{\left(\frac{L1L2}{K1K2A1A2}\right)}{\left(\frac{L1}{K1A1}+\frac{L2}{K2A2}+\frac{L3}{K3A3}\right)}$$

For the same cross-section and thickness;

$$P = \left(\frac{L}{K1K2A}\right) / \left(\frac{1}{K1}+\frac{1}{K2}+\frac{1}{K3}\right)$$

Similarly,

$$Q = R_1.R_3/(R_1+R_2+R_3) = \frac{\left(\frac{L1L3}{K1K3A1A3}\right)}{\left(\frac{L1}{K1A1}+\frac{L2}{K2A2}+\frac{L3}{K3A3}\right)} = \left(\frac{L}{K1K3A}\right) / \left(\frac{1}{K1}+\frac{1}{K2}+\frac{1}{K3}\right)$$

$$\text{And } R = R_2R_3/(R_1+R_2+R_3) = \frac{\left(\frac{L2L3}{K2K3A2A3}\right)}{\left(\frac{L1}{K1A1}+\frac{L2}{K2A2}+\frac{L3}{K3A3}\right)} = \left(\frac{L}{K2K3A}\right) / \left(\frac{1}{K1}+\frac{1}{K2}+\frac{1}{K3}\right)$$

B. Star to delta conversion

$$R_2 = \frac{PQ+QR+RP}{Q} = [(L_P/K_PA_P)x(L_Q/K_QA_Q)+(L_Q/K_QA_Q)(L_R/K_RA_R)+(L_R/K_RA_R)]/(L_Q/K_QA_Q)$$

For the slabs of same thickness and cross-section,

$$R_2 = (LK_Q/A)[(1/K_PK_Q)+(1/K_QK_R)+(1/K_RK_P)]$$

Similarly,

$$R_3 = \frac{PQ+QR+RP}{P} = [(L_P/K_PA_P)x(L_Q/K_QA_Q)+(L_Q/K_QA_Q)(L_R/K_RA_R)+(L_R/K_RA_R)]/(L_P/K_PA_P)$$

And for same length and thickness,

$$R_3 = (LK_P/A)[(1/K_PK_Q)+(1/K_QK_R)+(1/K_RK_P)]$$

And similarly,

$$R_1 = \frac{PQ+QR+RP}{R} = [(L_P/K_PA_P)x(L_Q/K_QA_Q)+(L_Q/K_QA_Q)(L_R/K_RA_R)+(L_R/K_RA_R)]/(L_R/K_RA_R)$$

For the same thickness and length

$$R_1 = (LK_R/A)[(1/K_PK_Q)+(1/K_QK_R)+(1/K_RK_P)]$$

1) *Applicability:* These formulae are applicable in various fields of energy transfer such as:-
   a) Flow of liquid from higher potential energy to the lower potential energy point.
   b) Flow of gas from the higher pressure to the lower pressure point.
   c) Flow of ions from the higher concentration to the lower concentration.
   d) Transformation of kinetic energy into potential energy and vice-versa of an object.
   e) Elastic stress and strains.
   f) Concept of heating of wire in a 3-Φ transformer is also possible.

g) Electric switches with the complex keyboard junctions and combinational thermocouples can also be developed.

II. NUMERICAL ANALYSIS

Consider an open line set of thermocouples connected with each-other. The wires are of different materials having thermal conductivity K_{Cu}=372 W/m-k, K_{Steel}=17W/m-k and K_{Lead}=35W/m-k having length 3cm, 8cm and 5cm respectively. Consider perfect insulation on the curved surface with no lateral heat transfer. The area of each wire section is equal and is 5cm^2. If the temperature at common junction of three thermocouples is 50° C and heat flow rate is equal 5watt for all free ends connected to different reservoirs. Find the temperature of source and find the temperature of the junction for the delta connection of thermocouple at each joint.

R_{Cu} = L/kA = 0.03/ (372x0.0005) = 0.1613 W/m-k,

R_{Steel} = L/kA = 9.4117,

R_{Lead}=2.857.

The temperature at the common junction

$T_{junction}$ = 50+273 = 323 k

Tempreture at the Cu interface

$Q_{Cu} = \frac{T1-323}{Rcu}$

T_1= Q_{Cu} R_{Cu} + 323

Or T_{Cu} = 5x0.1613+323 = 323.8 k.

And T_{Steel} = 370 k

And T_{Lead} = 337.28 k

If the thermocouples are connected in delta condition. The temperature at the joint position of two wires is:-

$R_{Cu\text{-}St} = \frac{\sum_{cu}^{pb} RCu.Rst}{RPb}$

$R_{Cu\text{-}St} = \frac{0.1613x9.4117+9.4117x2.857+2.857x0.1613}{2.857}$= 10.1

$R_{St\text{-}Pb} = \frac{0.1613x9.4117+9.4117x2.857+2.857x0.1613}{0.1613}$ = 179

$R_{Pb\text{-}Cu} = \frac{0.1613x9.4117+9.4117x2.857+2.857x0.1613}{9.4117}$ = 3.07

In this manner if the temperature of one joint is known then two others can be calculated simultaneously.

III. RESULT

The results of the numerical calculations of Dr. D. S. Kumar are exactly equal to the result of electrical analogy. Sometimes circuits are difficult to solve by star or delta. Then the transformation is required to evaluate the exact rate of the heat flowing from the particular section. For small space of conduction the law of Norton, Thevnin and superposition are also applicable for a perfectly insulated conduction beam.

IV. LIMITATIONS

A. The calculation is valid for small space heat transfer without convection and radiation.
B. The result is applicable for the metallic conductors.

C. This result is not applicable for heat generation process like curing, nuclear radiation, endothermic or exothermic reactions.

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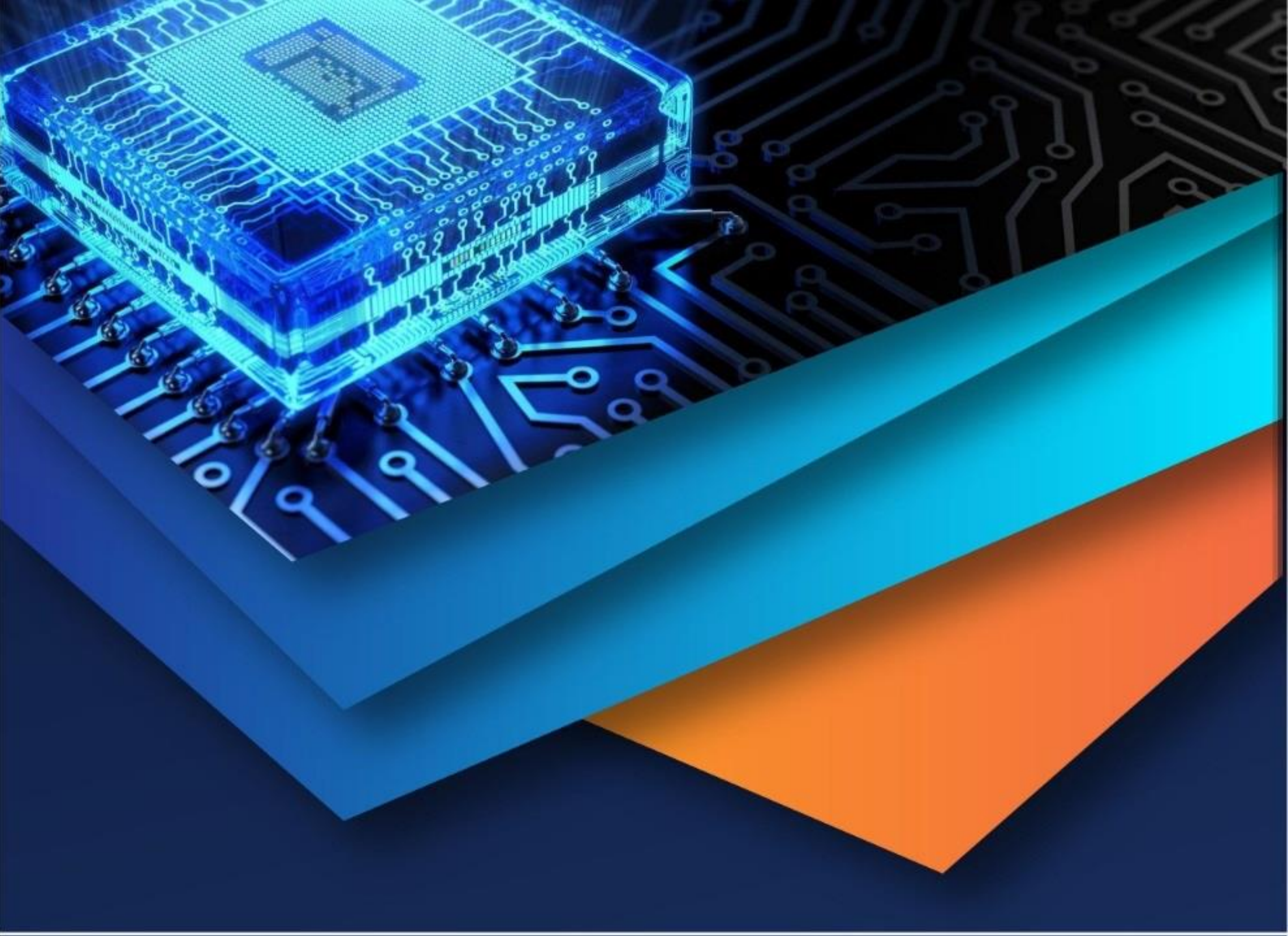

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