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Ampacity of bundled PVC house wiring cables in a conduit pipe based on experimental and theoretical considerations

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Flexible PVC Cables form the major part of Power distribution system within residential buildings, industrial buildings, and other commercial institutions. The ampacity of power cable depends upon the cross sectional area of conductor and the laying and installation of the cable in service. Generally two or more number of PVC cables are bundled together and inserted as a bundle in a conduit pipe for connecting to various load points. As the bundling of cables produce more heat than a single PVC Cable, and dissipation of heat is poor, the ampacity of these cables reduces considerably. Hence the exact selection of sizes and no. of cables are essential to avoid overheating of those cables and the resulting fire havocs.

PVC House wiring cables consists of copper conductor extruded with PVC insulation and are installed generally through a conduit pipe in a bundled manner. The steady state current rating of these cables depends on the way the heat generated in the cable due to current and the heat transmitted to the cable surface & then dissipated to the surroundings. The maximum conductor temperature is limited by the type of insulating material used. In this paper theoretical and experimental results of steady state ampacity ratings of bundles of house wiring PVC Cables laid in conduit pipes are compared.

Keywords: *Ampacity, house wiring cables,*

1.0 INTRODUCTION

The ampacity of the house wiring cables depends upon the following factors

- Size of the conductor
- Installation of the cable
- Type of insulation
- Type of conductor material

An increase in the diameter, or cross section, of a cable conductor decreases its resistance and increases its capacity to carry current. An increase in the specific resistance of a conductor increases its resistance and decreases its capacity to carry current.

The installation of a cable in a circuit determines the temperature under which the cable is operating. A cable may be located in a conduit or placed with other wires in a cable. Because it is confined, the wire operates at a higher temperature than if it were open to the free air. The higher the temperature under which a wire is operating, the greater will be its resistance. Its capacity to carry current is also lowered. In both the above cases the resistance of a wire determines its current-carrying capacity. The greater the resistance, the more power it dissipates in the form of

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heat energy. Conductors may also be installed in locations where the ambient (surrounding) temperature is relatively high.

When this is the case, the heat generated by external sources is an important part of the total conductor heating. This heating factor will be explained further when we discuss temperature coefficient. We must understand how external heating influences how much current a conductor can carry. It varies with the type of conductor insulation being used. The insulation of a wire does not affect the resistance of the wire. As current flows through an insulated conductor, the limit of current that the conductor can withstand depends on how hot the conductor can get before it burns the insulation. Different types of insulation will burn at different temperatures. Therefore, the type of insulation used is the third factor that determines the current rating of a conductor.

2.0 CURRENT RATING OF HOUSING CABLES

The ampacity or current carrying capacity of a cable is decided by the maximum current which the cable can carry continuously without the temperature at any point in the insulation exceeding the temperature limits specified for the respective insulation material. The Table 1 shows the maximum working temperature of various insulation materials of cables.

TABLE 1

MAXIMUM OPERATING TEMPERATURES OF VARIOUS INSULATION MATERIALS

Insulation	**Max Conductor Temperature (^{O}C)**
Paper	65-70
PVC	70
EPR	90
XLPE	90

The amount of current that can be safely carried by a cable is affected by the cross section of the cable. A variety of factors like the nature of the insulating material wrapped around the wire, the temperature of the surroundings, the number of nearby wires, etc affect the ampacity of Cables. The current rating depends upon the rate of heat generation within the cable as well as the rate of heat dissipation from the cable to the surroundings. The heat sources of a general Power Cables are heat generated in the conductor due to passage of current, dielectric losses and sheath losses. For a house wiring cable, the dielectric losses are negligible and sheath losses are not applicable due to absence of metallic sheath.

3.0 THERMAL RESISTANCE

The heat dissipation for a cable from conductor to ambient depends on the thermal resistance of the non metallic materials with in the cable and in the environment around the cable. Thermal resistance is defined as the difference in temperature in Kelvin between opposite faces of a meter cube of material caused by the transference of One Watt of heat and the unit is given as Km/ W. The thermal resistance of various insulating materials used for Power Cables are given in Table 2.

TABLE 2

THERMAL RESISTIVITY OF VARIOUS INSULATING MATERIALS

Material	**Thermal Resistivity km/W**
PE & XLPE	3.5
PVC	5.0—6.0
EPR	3.5—5.0

The thermal resistivity of the materials used for cable ducts are given in Table 3.

TABLE 3

THERMAL RESISTIVITY OF VARIOUS CABLE DUCTING MATERIALS

Material	**Thermal Resistivity km/W**
Concrete	1.0
Fibre	4.8
Asbestos	2.0
Earthenware	1.2

4.0 THEORETICAL CALCULATION OF CURRENT RATING

A MATLAB program for calculation of current rating based up on the IEC 60287 with some variations in the empirical formulas were made and compared with experimental investigation.

The general guidelines for calculating current rating is provided in IC 60287, which gives the current rating equations at steady state operations. IEC 60287 consists of three parts, with part I giving the formulas for rating, part II giving the formulas for thermal resistance and part III section on operating conditions. [2]

As per IEC 60287 the current rating is given by

$$I=\left\{\frac{\Delta\theta - Wd\,(0.5T1+n(T2+T3+T4)}{RT1+nR(1+\lambda 1)T2+nR(1+1\lambda+\lambda 2)(T3+T4)}\right\}^{0.5} \quad ....(1)$$

Where

$\Delta\theta$-Conductor temperature rise above the ambient temperature

R-Alternating current resistance in Ω /m

Wd-Dielectric loss per unit length in W/m

T1-Thermal Resistance of insulation(K.m/W)

T2-Thermal Resistance of bedding (K.m/W)

T3-Thermal Resistance of outer Sheath(K.m/W)

T4-Thermal Resistance per unit length between the cable surface and the surrounding medium(K.m/W)

n- number of load carrying conductors

$\lambda 1$= Ratio of losses in the metal sheath to the losses in the conductor

$\lambda 2$= Ratio of losses in the armour to the losses in the conductor

As the house wiring PVC cables do not contain metallic sheath, armour, bedding and Outer sheath, the thermal resistance factors of bedding, outer sheath will not appear in the calculation of current. However the current equation will have the losses due to the factors of thermal resistance of air between cable surface and conduit pipe, thermal resistance of pipe and thermal resistance of pipe to the external atmosphere. Hence the current equation is as follows

$$I=\left\{\frac{\Delta\theta}{RT1+nR(T4'+T4''+T4''')}\right\}^{0.5} \quad ....(2)$$

Where

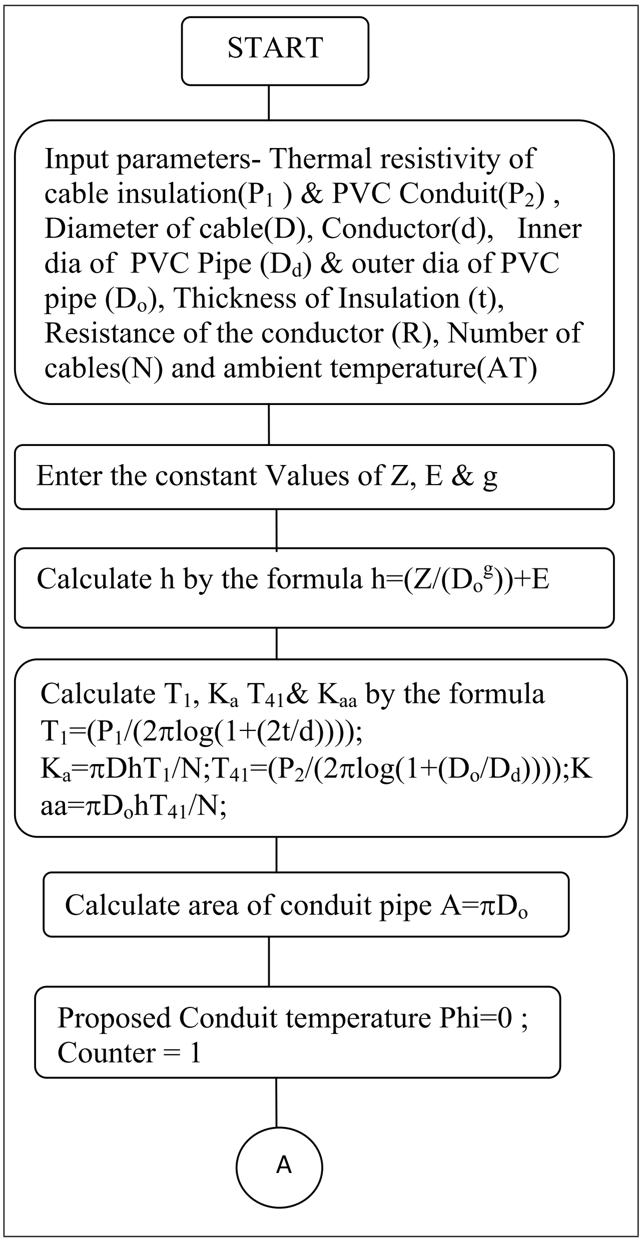
T4'- Thermal resistance of the air space between the cable surface and pipe internal surface

T4''= Thermal resistance of the pipe

T4''' = External Thermal resistance of the Pipe

The MATLAB program for calculation of current rating was developed based up on the guidelines of IEC 60287 with slight variations in certain empirical formulae for heat developed in the conduit pipes with time. The flowchart is presented in Figure 1. It has provision to calculate current carrying capacity with multiple wires in same conduit. [1]

Since the most important part in this calculation is the steady state temperature of the Conduit Pipe, It is proposed an array of temperatures staring from 0 to 70 ºC (Maximum operating temperature of PVC insulated cables). After that, the program will calculate the maximum current that can pass through the cables system according to the proposed conduit temperature, Conduit dimensions and number of cables which is as shown in Figure 2.



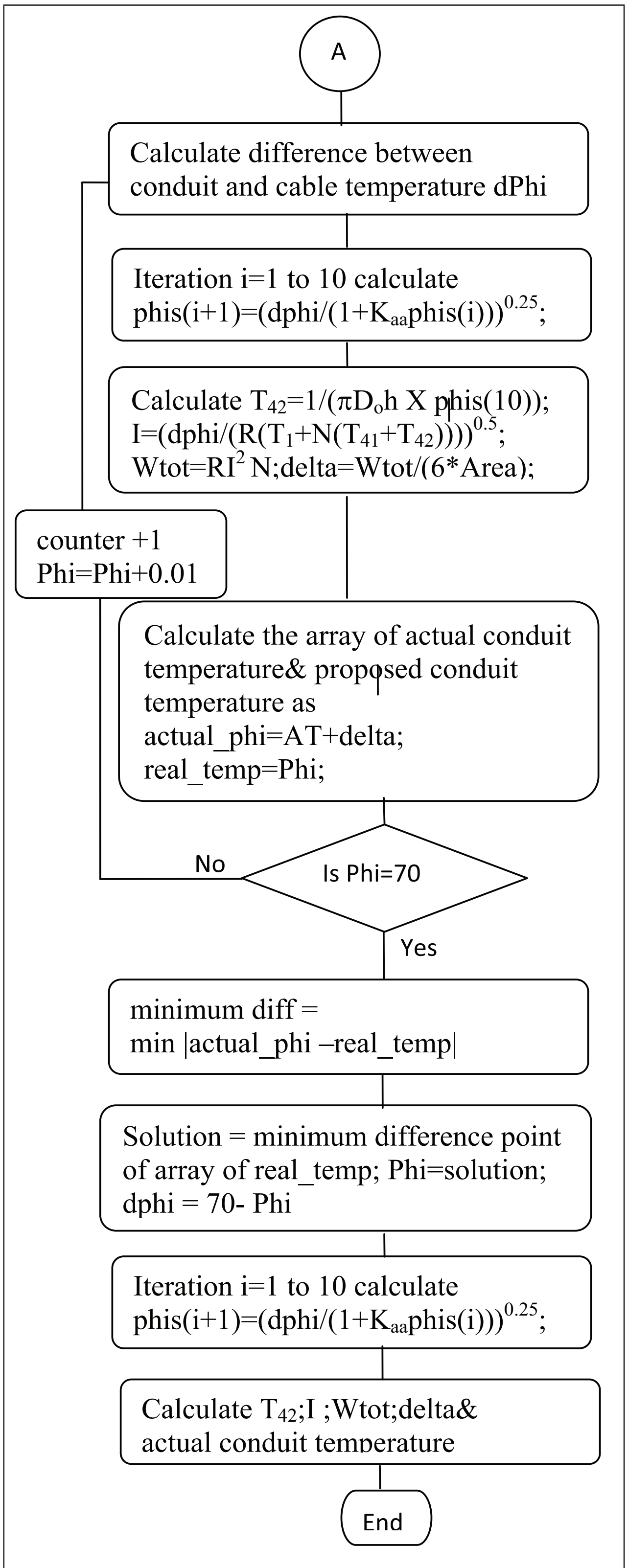


FIG. 1 FLOW CHART FOR CALCULATION OF CONDUIT TEMPERATURE

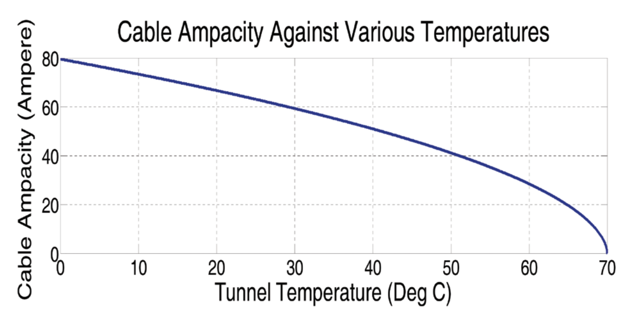


FIG. 2 CABLE AMAPACITY VS PROPOSED CONDUIT TEMPERATURE

Then the program starts to calculate, the maximum heat dissipation from the cables system that will increase the ambient temperature of the conduit for the corresponding calculated current passage through the cable. Now the program has virtual (proposed) temperatures against Ampacity & Ampacity against temperature.

Final stage of the program will be plotting the two curves at the same figure (Temperature vs. Ampacity & Ampacity vs. Temperature which is as shown in Figure 3. The intersection point between the two curves will be the steady state temperature inside the conduit. Hence it is easy to calculate the maximum current that can pass through the cable for this steady state temperature of the conduit.

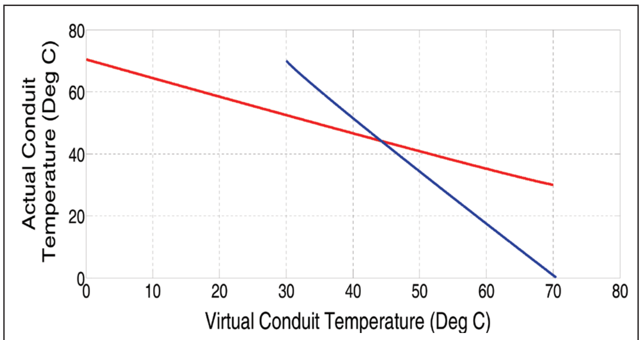


FIG. 3 PROPOSED CONDUIT TEMPERATURE VS AMPACITY & AMPACITY VS ACTUAL CONDUIT TEMPERATURE

5.0 EXPERIMENTAL INVESTIGATION

The house wiring cables of different cross sections were evaluated for their current rating by inserting the cables in a PVC conduit pipe of 35 mm diameter and length of 3 metres [3]. The both ends of the pipe were sealed with a suitable thermal insulating material so that no heat is radiated out from the ends of the PVC Conduit pipe. The temperature of the conductor was checked by removing the insulation over a small portion of the conductor and thermocouple was fixed on to it. One thermocouple was inserted into the conduit to measure the conduit temperature. The ac current was passed through the cable and steady state conductor temperature and conduit temperature were measured. The currents were slowly increased till the steady state conductor temperature reaches the stabilized conductor temperature of 70 Deg.C i.e the maximum working temperature of PVC insulation.The steady state temperature inside the conduit pipe was also measured. The investigations were carried out with multiple wires to check the effect of additional loading.

The comparison of results of experimental and theoretical investigations on current density of cables at 30 Deg.C are given in Table 4.

TABLE 4

Sample	No. of Cable / Conduit	Current density (A/Sq.mm)		
		Lab Results	Theoretical Results	
			As per IEC formula	As per proposed formula
1X 1.0 mm^2 PVC Cable	1	19.9	17.3	20.6
1X 1.5 mm^2 PVC Cable	1	16.7	13.9	16.5
1X 2.5 mm^2 PVC Cable	1	13.2	10.7	12.7
1X 4.0 mm^2 PVC Cable	1	10.2	8.4	9.9
1X 6.0 mm^2 PVC Cable	1	7.7	6.7	7.8

The results of theoretical and laboratory investigations are presented in Table 3. The slight variations in the results may be due to the variations in ambient temperatures during evaluation and variations in conductor resistance values. For theoretical calculations, the maximum specified values as per IEC 60228 were considered. The evaluations were carried out with class 2 conductors.

6.0 ANALYSIS

The current density for different cables with no. of cables in conduit & current density with respect to various ambient temperatures are shown in Figures 4 & 5. The current density of 1 sq.mm cable varies from 21.3 to 13.9 whereas for 6 sq.mm cable the current density variations are from 6.2 to 4.2 , With increase in no. of cables from 1 to 3. As the cross section increases the current density reduces. However the percentage variations in current density for no. of cables from 1 to 3 remains in the same rate of around 32 to 34 %, for all cross sections.

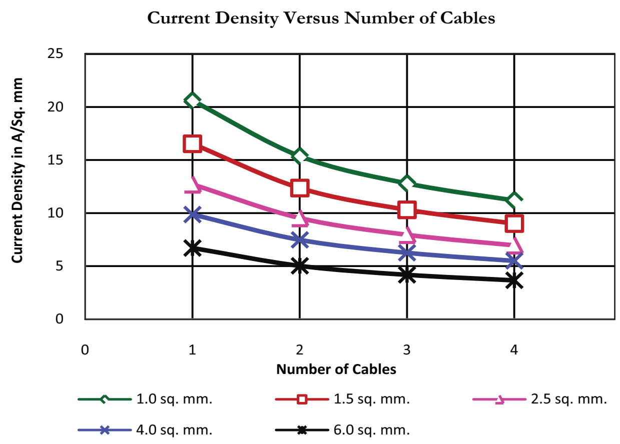


FIG. 4 VARIATION OF CURRENT DENSITY WITH THE NO. OF CABLE

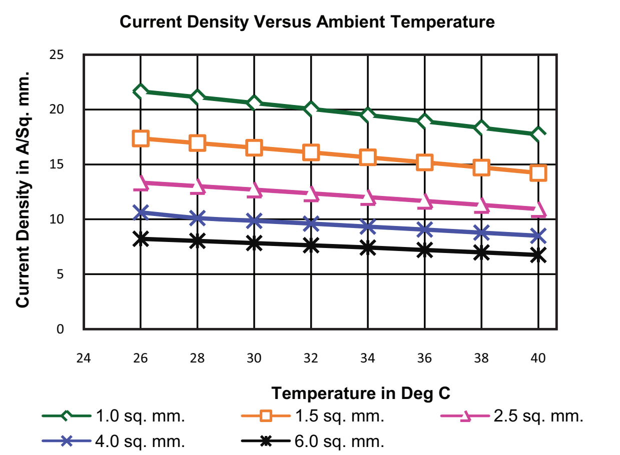


FIG. 5 VARIATION OF CURRENT DENSITY WITH AMBIENT TEMPERATURE

Similarly the temperature inside the conduit increases with increase in no. of cables due to increase in heat generation as well as with the increase in the ambient temperature.

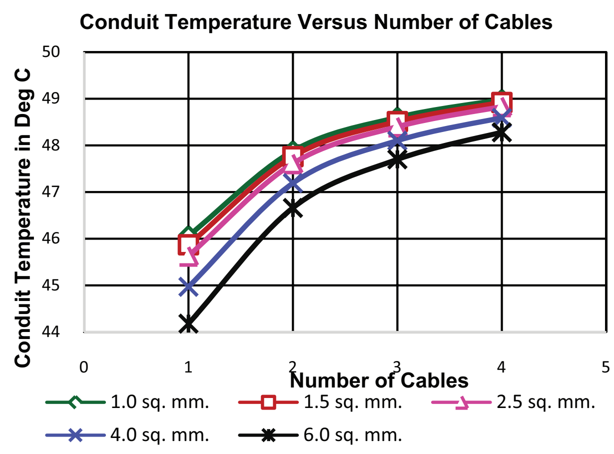


FIG. 6 VARIATION OF CONDUIT TEMPERATURE WITH THE NO OF CABLES

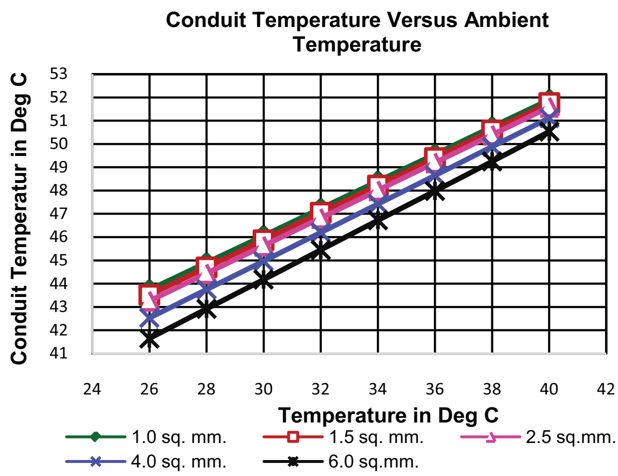


FIG. 7 VARIATION OF CONDUIT TEMPERATURE WITH AMBIENT TEMPERATURE

7.0 EMPIRICAL FORMULAE FOR CONDUIT TEMPERATURE RISE

After calculating the current rating at ambient temperature , the temperature inside the conduit raises due to the generation of heat with in the cable conductor. The actual rating of cable depends on the stabilized conductor temperature and the temperature with in the conduit. As per IEC 60287, the empirical formulae for increase in temperature due to the current has to be calculated using the formula delta=tot / (3 x Area) ....(3)

where

Wtot= I^2 R x N ....(4)

Area= Surface Area of the conduit

However , it is seen that this empirical formula needs some correction for exact calculation of temperature rise in case of flexible cables . As per the suggestion the formula to be used for flexible cables will be

delta= Wtot / (6 x Area) ....(5)

The change in the empirical relation can be attributed to the higher dissipation of heat due to reduced thickness of flexible cables.

8.0 CONCLUSION

The current rating of PVC flexible cables depends on several factors such as ambient temperature , no. of cables per conduit, resistance of conductor, thermal resistivity of insulating material, thermal resistivity of conduit and thermal resistivity of surrounding medium. An attempt is made to evaluate the current density of flexible cables through experimental and theoretical evaluations. Based up on the experimental verifications and theoretical calculation as per IEC 60287, it is found that the increase in temperature of insulation due to current is almost half for flexible cables compared to normal power cables.This reduction in temperature can be attributed to lower volume insulation available with the flexible cables.

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