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A Study on Induced Voltages in Control Cables and their Mitigation

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Abstract

The induced voltage, apart from being a concern for human safety, also becomes a concern for the continuous operation of plants, where the electrical equipment is connected via numerous wires and cables for control purposes. The induced voltage beyond permissible limits may intervene with the proper functioning of the signalling and controlling devices of the plant and result in unscheduled interruptions. It is a well-known phenomenon of electromagnetism, that when the static conductor is situated within a changing magnetic field or a conductor moves within a static magnetic field, a voltage is induced in the conductor and thus, induced voltage is inevitable in conductors in alternating current fields. In this paper, we have attempted to study induced voltage considering variations in cable constructions aiming to derive a solution to mitigate or minimize induced voltage in control cables. We have come across enquiries from cement plants towards the requirement of control cables limiting induced voltage up to 50V to prevent malfunctioning of their signalling and sensing equipment which sometimes may be catastrophic, which has triggered this study.

Keywords: Control Cables, Electrostatic, Induced Voltage, Magnetic Field, Power Cables

1. Introduction

Control cables are used in process industries, to send and receive low voltage signals, between types of equipment like Potential Transformers (PT), circuit breakers, disconnection switches, Current Transformers (CT) etc, and protection, control and monitoring devices like timers' relays and control switches, status lights, alarms, etc.

These control cables usually have standard construction as, 1100 V, core Cu conductor, PVC Insulated, GS armored and PVC Outer sheath as per IS 1554-1, IS 7098-1, IEC 60502-1 etc.

In these multi-core control cables sometimes, a few cores are kept as spare cores given future demand,

During our study, we visited a cement plant where various automated process controllers relate to MCC and I/O stations through control cables to monitor and control the process for better throughput and zero downtime.

LV Power cables (>600 volts) used in cement plants which carry relatively large currents, laid together in the same cable tray; hence voltage may get induced in the control cable due to electromagnetic interference from outside.

In the process industries I/O station sends control signals through the Control cables to process controllers and receives feedback signals through the same control cables, during this process induced voltage is experienced in the return phase unless it is suitably mitigated.

Hence, experiencing voltage induced in control cables which is quite a common issue in cement industries results in malfunctioning of the system and hence cannot be left unattended, otherwise, it may lead to failure of communication devices and relay and could cause a serious threat of interruption of the continuous manufacturing process.

In this study, analysis was done as below:

i) Inception of induced voltage by lab testing experiences.
ii) Impact of induced voltage on the system and cables.
iii) Improved methods in cable construction to mitigate/ minimize induced voltage.

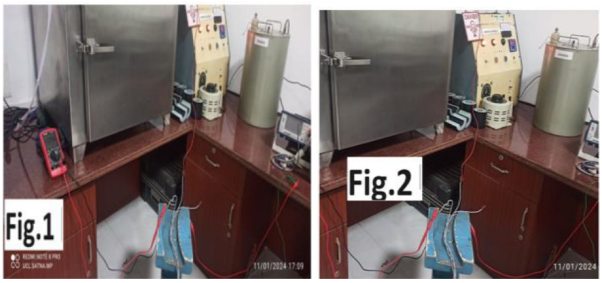
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iv) Spacing between power and control cable to reduce the induced voltage

1.1 Inception of Induced Voltage by Lab Testing Experiences

Various experiments on induced voltage were performed at the in-house RandD laboratory on different control cable samples (Figures 1 and 2), and observations are tabulated in Table 1.



Figures 1 and 2. Experiments on samples.

Table 1. Observation Table

Apparatus used: Hi-POT and Multi-meter.

Sample length: 3.6 meters, Supply Voltage: 250V, Screen and armour are earthed and Induced voltage measured on the spare cores.					
Sample No:1	**Set-up**	**Number of live cores**	**Number of the earth's core**	**Induced voltage (Volts)**	**Observation**
7CX 1.5 Sq.mm, PVC Insulated, Overall Screened, Un-armored cable	1	One	---	5.8	Induced voltage increased w.r.t number of live cores.
	2	Three	---	15.8	
	3	Four	---	24.5	
Sample No:2					
4Core X 1.5 Sq.mm, PVC Insulated, Un-Screened, un-armored cable	1	One	---	23.8	Induced voltage measured in the unearthed spare core is lower, when the rest spare cores are earthed.
	2	One	Two	17.6	
Sample No:3					
2Pair X 1.5 Sq.mm, PVC Insulated, Twisted, Un-Screened cable	1	One	---	9	The induced voltage is lower compared to the sample.
Sample No:4					
2P X 1.5 Sq.mm, PVC Insulated, Twisted individual Screened cable	**1**	One	---	0.11	The induced voltage is lower compared to sample 1 and sample 2
Sample No:5					
7C X 2.5 Sq.mm, PVC Insulated, Un Screened, armoured cable	**1**	Six	---	50	Induced voltage is lower, when all spare cores are earthed
	2	Six	One	0.04	
Sample No:6					
1P X 1.5 Sq.mm, PVC Insulated, Overall Screened, Un-armored twisted cores	1	One		20.5	The induced voltage is comparatively LESS in the case of XLPE insulated cable.
Sample No:7					
1P X 1.5 Sq.mm, XLPE Insulated, Overall Screened, Un-armoured twisted cores	1	One		11	

Based on the above observation, Electromagnetic Theory (EMT) and improper earthing are found behind the initiation of Induced voltage. The basic component of EMT consists of capacitive and inductive coupling phenomena between two or more circuits or current-carrying components as described below:

1.1.1 Capacitive Coupling

This phenomenon is initiated due to the presence of distributed capacitance which helps to transmit the signal from one current-carrying component to another through the electrical field[1].

Theoretically, in capacitive coupling, if the voltage is increased, the charge accumulates gradually and when the voltage is reduced, the charge that accumulates due to the applied voltage will be released and vice versa.

From basic circuit theory, we know that capacitance (C) is related to the area (A) of parallel plates and distance (d) between plates and relative permittivity of medium (ε_r) in the following manner.

$C = \varepsilon_r A/d$ ----- (1)

Thus, the coupling distance is inversely proportional to the capacitance, as the coupling distance increases, the coupling capacitance will decrease, and the intensity of the output signal will be reduced.

Similarly, coupling area (A) is also proportional to the capacitance, as the coupling area increases, the coupling capacitance increases, and the coupling will be intensified (Figure 3).

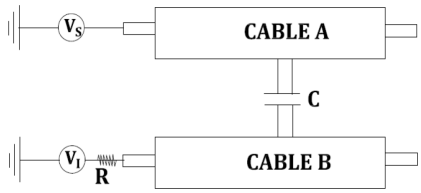


Figure 3. Capacitive coupling between two cables.

1.1.2 Inductive Coupling

Two conductors are inductively coupled or magnetically coupled when they are configured in a way such that change in current through one wire induces a voltage across the ends of the other wire through electromagnetic induction".

This principle works on following the laws as stated below.

As per Faraday's law of Electromagnetic Induction "when a conductor is placed in a varying magnetic field, an electromotive force is induced in the circuit" (Figure 4).

The voltage V_I induced in a closed loop area A resulting from a magnetic field of flux density B, and the angle between them θ, can be derived from Faraday's law[2].

Induced Voltage (V_I) = ωB.Acosθ ……(2)

From the basic electromagnetic theory,

$\phi = B.A \cos\theta$ --------- (3)

and

$\phi = MI_1$--------- (4)

Where, ϕ: Magnetic flux, M: Mutual inductance and I: is the current passing through the conductor.

Hence from the above Equations 2, 3 and 4, we can say Induced voltage in terms of mutual inductance (M) between two cables can be expressed as

Induced voltage (V_I) = $\omega MI1$-------- ***(5)***

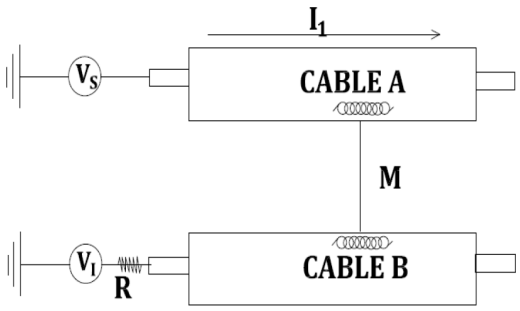


Figure 4. Inductive coupling between two cables.

From the above equation, Induced Voltage is directly proportional to the surface of the cross-sectional area linked with magnetic flux lines of varying fields. Hence, an increase in magnetic field will induce higher induced voltage.

Further, an increase in mutual inductance or Current rating in the live conductor will cause an increase in induced voltage.

Biot Savart's law states that "magnetic field due to a current-carrying conductor at a distance point is inversely proportional to the square of the distance between the conductor and point and directly proportional to the length of the conductor"

If, we presume magnetic flux density (B) at a distance 'd' from a current-carrying conductor and μ_0 is the permeability in free space and l is the length of the conductor, then

$B = \mu_0 I / 2 \pi d^2$ ---------- (6)

From the above equation, by increasing the distance between two current-carrying components, magnetic flux density can be reduced, and this will cause a reduction in induced voltage.

1.1.3 Improper Earthing of Metallic Shield

During laboratory experiments, we observed that armour or metallic shielding of control cables required to be properly earthed at both ends or at least to one end.

For unarmoured unshielded control cables, spare cores are to be earthed.

These methods will cause lower induced voltages when compared with cables without earthing arrangement.

The below figure (Figure 5) for the Proper earthing method shows armour and spare cores (which are not in use) to be joined together and earthed at one end.

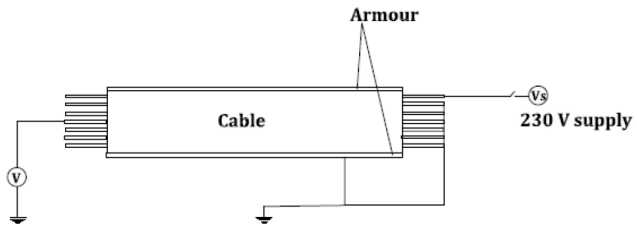


Figure 5. Proper earthing method.

1.2 Impact of Induced Voltage on The System and Cables

In processing industries, control cables are connected at various locations as depicted in the below figure (Figure 6).

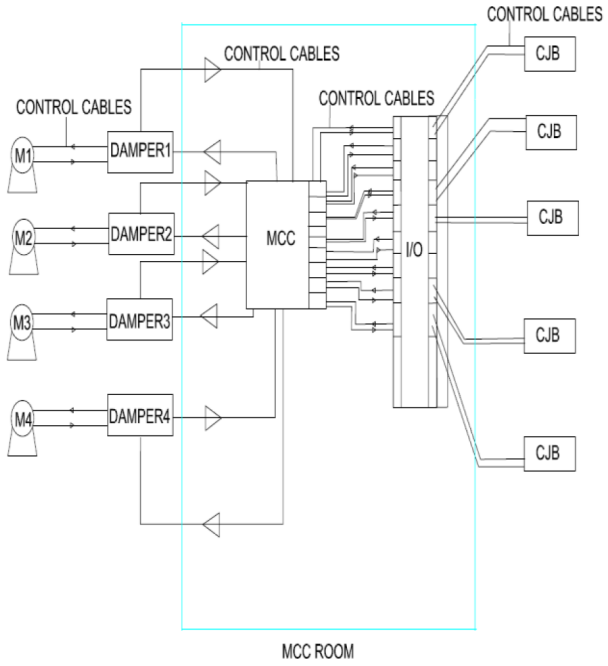


Figure 6. Laying of control cables.

Motor Control Centers (MCCs) play a critical role in industrial facilities because they provide control and protection for electrical motors and associated systems.

Electric motors are installed in processing plants, and it is quite necessary to control all of them from a central place, so the MCC is designed for this function.

MCC consists of multiple enclosed sections with common bus bars. Each section houses power contactors, isolators, protection relays, and control and indication devices.

So, when induced voltage appears (generally more than 50 V) in control cables associated with the MCC and I/O panel there will be the possibility of malfunction of the relay or other communication devices.

Malfunctioning of relay results in trippage and nuisance trips leading to unwanted process interruption and therefore, major continuous processes of various industries get shut down.

Moreover, a high magnitude of power-frequency fault current flows in the power cable which lies in the vicinity of control cables due to a line-to-ground fault. Incidences involving erroneous operation of relay circuits may happen under these conditions.

1.3 Improved Method in Cable Construction to Minimize Induced Voltage

1.3.1 Twisting of Two Cores

From the above experiments, it has been observed that multi-core cables with twisted pair formation generate lower induced voltage when compared with multi-core cables without twisted pair formation.

Typically twisted pair cables come with the following construction:

UTP-Unshielded Twisted Pair

STP-Shielded Twisted Pair

In the case of UTP, both the insulated cores are twisted together to form a pair without any shielding, while in the case of a shielded twisted pair generally shielding of aluminium-backed Mylar tape with drain wire is provided.

Twisting has the advantage of pulling the wires tightly together and maintaining their separation at a uniform distance, twice the thickness of the wire insulation.

The electromagnetic field coupling between two wires is directly proportional to the distance between the wires.

As we know "when two similar conductors placed nearly in an electrical circuit generate equal and opposite magnetic fields, the two opposite magnetic fields cancel or nullify each other as well as any external magnetic fields". So, when two wires are twisted, it enhances this cancellation effect and provides self-shielding for the pair of wires as shown in below Figure 7.

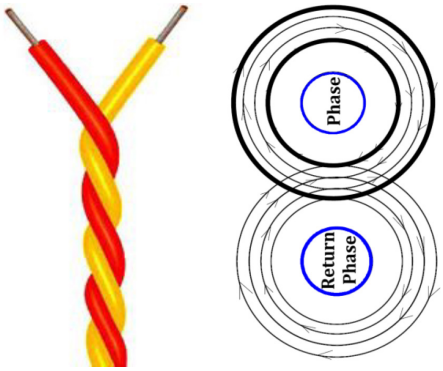


Figure 7. Twisted pair and magnetic field cancellation.

Going one step further, as per the experiments on shielded pairs, we observed that individual shielded pair cables are a better solution to reduce the induced voltage from adjacent cables where shielding is connected to the ground from at least one end. The grounding of the shield helps minimise the effect of the magnetic field as the voltage induced in the shield of pairs, originating due to electromagnetic induction, is already connected with the zero potential.

The above perspective indicates that control cable can be used with unshielded or shielded twisted pairs to overcome the problem of electromagnetic field interference to some extent, although shielded twisted pairs give better results in the long run.

1.3.2 Use of XLPE Control Cables in Place of PVC Cables

Experiments indicate that voltage induced is lower in the case of XLPE cables than PVC cables due to the low relative permittivity of XLPE insulation. Hence, XLPE insulated control cables are preferred, if there is no specific purpose for the use of PVC cable.

1.4 Spacing Between Power and Control Cables to Reduce the Induced Voltage

Proper spacing of cables for all the premises is not possible in most of the situations below figure (Figure 8: Improper spacing between cables and Figure 9: Proper spacing between cables) shows some similar laying conditions of improper and proper spacing of cables.



Figure 8. Improper space between cables.

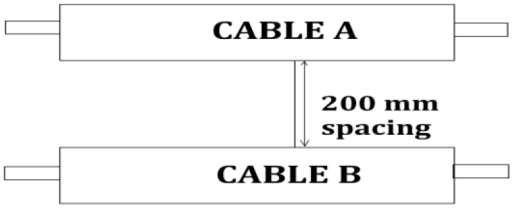


Figure 9. Proper spacing between cables.

Minimum clearance between control (Cable A) and power cables (Cable B) (see Figure 9) is recommended as 200 mm as per IS 1255[3] for low inductive influence on sensitive control cables.

As far as possible control cables should be laid through separate ducts or trays (with spacing 200 mm between racks).

2. Conclusion

Efforts have been made to find possible solutions for mitigating induced voltage on control cables used in various process industries. Cables samples have been tested with various set-ups to measure the induced voltage. These samples include Armoured, unarmoured, screened, and unscreened multi-core PVC/XLPE cables.

As per the observations, Induced voltage is less in unscreened twisted pair cores, when compared with multi-core cables, and more reduction is observed in screened pair cables. Further, proper earthing also plays a role in mitigating the induced voltage, apart from ensuring human safety.

Some of these experiments show that XLPE insulated cables give better results, compared to those with PVC insulation.

Apart from the above observations on different cable constructions, proper spacing between cables also plays an important role.

From the study, we observed that complete elimination of induced voltage may not be possible. However, the selection and use of XLPE insulated individual shielded twisted pair cable construction may be helpful where there is a necessity to restrict the induced voltage to a limit.

3. References

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