THE USE OF THE ARMOUR OF STEEL WIRE ARMOURED CABLES AS A PROTECTIVE CONDUCTOR

The Problem Encountered

In my daily work as an electrical surveyor inspecting and testing electrical installations in domestic, commercial and industrial premises I find Steel Wire Armoured Cables (SWA) with the following arrangements for the provision of the circuit protective conductor (CPC).

1. The use of the steel armouring as a CPC with the cable terminated at each end in brass glands.
2. The use of an internal core as a CPC in addition to the SWA with both ends terminated in brass glands.
3. The use of an external green/yellow single core PVC CPC run in parallel with the SWA cable with the cable terminated in brass glands.
4. The use of an internal core of the SWA cable as a CPC with no cable glands and the cable ends inserted in to enclosures.
5. The use of the steel wire armouring as a CPC with no brass glands and “Tenby” type bonding clamps on to the exposed steel armouring with a green/yellow single core PVC CPC on to the clamp.
6. The brass glands terminated with and without the earthing ring (Banjo).

Information Requested

I have asked experienced electricians in the field and students at the college where I teach why external CPCs are used and why cable cores are used for a CPC. The answers varied wildly both with and without logical reasoning. I have particularly probed the respondents with the question of the use of 3 core cable on single phase circuits. The cable is manufactured in both old and new harmonised colours for 3 phase. The use of this cable requires the over sleeving of cable cores to single phase colours and green/yellow for the CPC. Often this over sleeving is not provided. I have tested the advocates of the use of 3 core cables on single phase as to why they think 2 core cable is correctly coloured for single phase use.

The responses to questions can be reduced to those listed below or a combination of these.

1. The steel wire armouring cannot be relied on as a CPC.
2. The use of the armouring is as a CPC is not allowed in the “regs” (BS7671).
3. An external CPC is needed as the SWA is not big enough.
4. An internal core is needed as a CPC as the SWA is not big enough.
5. The SWA does not need to be earthed as it is not an exposed conductive part.

6. It is not good workmanship to use the SWA as a CPC.
7. I have always done it that way.
8. Banjos are not needed as the brass gland is the same as terminating conduit or MICC cable.
9. You cannot use the SWA as a bonding conductor.
10. It is dangerous to terminate both ends of the SWA.

Defining Protective Conductor

Protective Conductor is defined in BS7671 under Part 2 Definitions as:-

A conductor used for some measure of protection against electric shock and intended for connecting together any of the following parts:

1. Exposed conductive parts.
2. Extraneous-conductive parts.
3. The main earthing terminal.
4. Earth electrodes.
5. The earthed point of the source, or an artificial neutral.

Protective Conductors are divided in to 4 main categories in BS7671

1. Earthing conductor.
2. Main equipotential bonding conductor.
3. Supplementary bonding conductor.
4. Circuit Protective Conductor.

Sizing of Protective Conductors BS7671

543 -01-01 states that the cross sectional area of every protective conductor, other than an equipotential conductor, shall be:

1. Calculated in accordance with Regulation 543 – 01 – 03, or
2. Selected in accordance with Regulation 543 – 01 – 04.

So if the SWA were to be used as a protective conductor, other than an equipotential bonding conductor, it would have to be suitably sized using either the adiabatic equation in 541-01-03 or selected from the appropriate tables.

The use of SWA as a Protective Conductor BS7671

The permitted types of protective conductor are listed in 543-02-02 and SWA is identified in sub section (v) as:

A metal covering, for example, the sheath, screen, or armouring of a cable.

It can therefore be verified that the SWA can be used as a protective conductor in compliance with BS7671.

However there are conditions on the use of SWA as a protective conductor defined in BS7671.

1. It must be adequately sized to meet the requirements of section 543-01-01.
2. If the armour is used as a CPC then any accessories have to be connected to the associated enclosure's earth terminal by a separate CPC (flying lead) to comply with 543-02-07.
3. If the SWA is used as a main equipotential conductor other than on a PME system it must have a CSA of not less than half the cross sectional area of the associated earthing conductor and not less than $6mm^2$ to comply with 547-02-01. If the installation is PME then the CSA of the SWA must comply with table 54H. If the conductor material is other than copper the material has to have the equivalent conductance to copper.
4. Where a number of installations have separate earthing arrangements any protective conductors common to these have to be suitably sized to carry the maximum current likely to flow through them OR insulated from the other installation at one end to comply with 542-01-09.
5. If the SWA is to be used as a combined CPC and main bonding conductor it must meet the requirements of both 547-02-01 and 543-01.

Is the wire armouring an exposed conductive part?

The wire armouring is steel and therefore is conductive. However the steel is covered by an exposed oversheath of insulation so is not exposed. The cable is terminated on most installations with brass glands which are conductive. These parts are therefore exposed conductive parts but these may also be covered with PVC shrouds.

The function of the armouring is to protect the cable against mechanical damage and to allow the cable to be run out of safe zones. Should a sharp conductive object such as a drill bit or garden fork penetrate the cable it is critical that the armouring is connected to earth to enable the supply to be automatically disconnected by the circuit protective device under this fault condition.

The use of bonding clamps as an alternative to glands.

Bonding clamps are designed for clamping on to solid pipes. The force required to make a reliable tight joint on to a SWA cable would effectively deform the cable and may loosen over time due the continued deformation of the cable.

Cross sectional area and conductivity of SWA.

The CSA of the armouring of various SWA cables is set out in tables D9, D10A and D10B of IEE GN1. These are for thermoplastic PVC cables operating at 70^0C, 90^0C thermosetting cables operating at 90^0C and 90^0C thermosetting cables operating at 70^0C respectively. These tables also very usefully indicate where these cables meet with the requirement of table 54G of BS7671 for the adequacy of the CPC CSA.

I have produced below the information for thermoplastic and thermosetting cables operating at 70^0C.

The figures shown in brackets do not meet the requirements of table 54G however if the adiabatic equation for the prospective fault current and the circuit protection device used is calculated then the armour might comply with 543-01-03. If the armour is found to be undersized then a full sized separate CPC must be provided.

Table for 70^0C Thermoplastic PVC SWA cables.

Conductor CSA	Minimum CSA of SWA to meet 54G	CSA of armour 2 core	CSA of armour 3 core	CSA of armour 4 core
1.5	3.4	15	16	17
2.5	5.7	17	19	20
4	9.0	21	23	35
6	13.6	24	36	40
10	22.6	41	44	49
16	36.1	46	50	72
25	36.1	60	66	76
35	36.1	66	74	84
50	56.4	74	84	122
70	79.0	84	119	138
95	107.2	122	138	160
120	135.3	(131)	150	220
150	169.2	(144)	211	240
185	208.6	(201)	230	265
240	270.6	(225)	(260)	299
300	338.3	(250)	(289)	(333)
400	403.9	(279)	(319)	(467)

Table for 90^{0}C Thermosetting SWA cables operating at 70^{0}C.

Conductor CSA	Minimum CSA of SWA to meet 54G	CSA of armour 2 core	CSA of armour 3 core	CSA of armour 4 core
1.5	3.4	16	17	18
2.5	5.7	17	19	20
4	9.0	19	21	23
6	13.6	22	23	36
10	22.6	26	39	43
16	36.1	41	44	49
25	36.1	42	62	70
35	36.1	62	70	80
50	56.4	68	78	90
70	79.0	80	90	131
95	107.2	113	128	147
120	135.3	(125)	141	206
150	169.2	(138	201	230
185	208.6	(191)	220	255
240	270.6	(215)	(250)	289
300	338.3	(235)	(269)	(319)
400	451.0	(265)	(304)	(452)

Terminating the cable ends of SWA cables.

BS7671 has a fundamental requirement set out in regulation 133-01-04 for every electrical joint and connection shall be of proper construction as regards conductance, insulation, mechanical strength and protection.

This requirement would preclude the termination of the cable ends of SWA with bonding clamps for the reason given above. It would also preclude the termination of the cable by inserting it into an enclosure without a gland as the steel armouring earth continuity could not be reliable.

Cable manufacturers supply and recommend the termination of their SWA cables in glands correctly selected for the individual size of the particular cable. These glands are supplied for internal use and alternative exterior glands rated at IP66 for external use.

The manufacturer’s gland kits are provided with suitably sized earth rings which are commonly known as “Banjos”. These earth rings are used to enhance the contact surface area of the gland and are also provided with a bolt hole for connection of an auxiliary CPC.

The cable glands can be directly used without the earth ring in the same manner as conduits and MICC cables are terminated in metal enclosures. As with conduits and MICC cables the paint around the enclosure hole must be removed to expose bare metal. The gland lock nuts must then be suitably tightened to maintain conductivity.

Some enclosures are provided with removable gland plates and in these circumstances the earth continuity relies on the gland plate fixing screws. It is recommended in these circumstances that the earth ring is used with a suitably sized CPC connected to the main earth bar. This is never done with conduit or MICC in my experience which also relies on these fixing screws for earth continuity. An alternative would be to drill the gland plate and bolt a CPC to it connected to the main earth bar.

Where an SWA cable enters a plastic enclosure then an earth ring would be needed to maintain earth continuity.

It goes without saying that the steel wires of the armouring should all enter the tapered socket of the cable gland and the gland nut should be adequately tightened.

In the same way as the regulations do not require a separate CPC to be used with metal conduits it would seem good practice to always use an earth ring. This ring to be separately bolted to the enclosure and a CPC with a crimped eyelet connected to this bolt. The CPC then connected to the earth terminal of the enclosure. If the enclosure is outside or exposed to moisture then it would be preferable to place the earth ring on the inside of the enclosure. This will permit the paint or other coating to be removed under the ring without compromising the environmental protection for the enclosure.

Environmental Conditions

There is a general requirement for all electrical equipment to be suitable for the environmental conditions prevailing for that installation set out in BS7671. There is also an additional requirement for earthing systems set out in 542-01-07 which requires, " they are adequately robust or have additional mechanical protection appropriate to the assessed conditions of external influence".

I have found one reference in IEE GN7 that would preclude the use of the armouring as a CPC when SWA cables are used. This is in marinas and the guidance states, "Due to the possibility of corrosion, the galvanised steel armouring of cables must not be used wholly or in part as a circuit protective conductor (cpc) for the floating section of marinas. A separate protective conductor should be used which, when in accordance with Regulation 543-01-02 can be common to several circuits if necessary. The armour must still, however, be connected to protective earth".

If the SWA cable ends are terminated outside or in areas where water is present then the exterior IP66 glands should be used.

TNCS (PME) Installations

Where the supply company will not permit the export of the means of earthing to the supplied premises outside of those premises then special precautions will need to be taken for SWAs supplying remote buildings or equipment outside the supplied premises.

The reason for this restriction is to prevent the danger of exposed conductive parts and extraneous conductive parts connected to the installation outside the main equipotential zone becoming live in the event of the loss of the neutral under fault conditions. Also with long cable runs their will be a potential difference between the supplied earth from the neutral terminal and the general mass of earth.

In these circumstances it is preferred to connect the steel armouring of the SWA to earth at the main supplied premises and insulate the armouring at the remote end of the cable. This allows the SWA cable to be protected by the circuit protection device that is protecting the phase conductor(s) of the cable. At the remote building the SWA is terminated in a plastic box and only the live conductors are then connected to the remote installation. The remote installation is converted to a TT system with a suitably selected RCD main switch and the provision of an earth electrode.

It may also be possible with the consent of the supply company to extend the main equipotential zone to the remote building. This can be done by using the SWA armouring as a combined CPC and main bonding conductor. All extraneous metal work in the remote building is connected to a common terminal known as the Building Earth Marshalling Terminal (BEMT). The armouring must be sized to comply both with Regulations 547-02-01 and 543-01. In addition with a PME system there may be currents flowing normally in the protective conductors which may raise the temperature of the SWA cable. In these circumstances the cable will need to be derated to accommodate this temperature rise. An alternative may be to run a parallel PVC green/yellow cable of suitable size with the SWA. If this parallel CPC is buries then it would need to be a minimum of $16mm^2$ to comply with Regulation 542-03-01 unless it is mechanically protected.

If the remote building has an alternative means of earthing then the SWA armour or separate CPC would need to be rated to permit the maximum current flow likely to comply with Regulation 542-01-09.

Earth Loop Impedance

Where the measured value of earth loop impedance (Zs) at the end of a final circuit is found to be to high to achieve automatic disconnection by the circuit protection device in the required disconnection time Regulation 413-02-04 permits the use of supplementary bonding to achieve an acceptable measured value of Zs. This in my view is a compensatory measure for poor initial design of the circuit and incorrect selection of the cable. If the cable was correctly selected at the design stage with due regard to the required value of Zs for the final circuit, the Zs of the distribution board, the R1 + R2 calculated value for the size and length of cable and any temperature correction then compensatory measures would not be required. If supplementary bonding is required then the use of a spare core of an SWA cable could be used or an additional CPC run in parallel with the cable.

The vales of R1 + R2 for copper cables at 20^0 C are shown below.

CSA mm	2 CORE SWA	3 CORE SWA	4 CORE SWA
1.5	0.02280	0.02230	0.02160
2.5	0.01638	0.01608	0.01518
4	0.01211	0.01161	0.00921
6	0.00988	0.00768	0.00718
10	0.00663	0.00563	0.00523
16	0.00495	0.00475	0.00435
25	0.00442	0.00322	0.00302
35	0.00302	0.00282	0.00252
50	0.00268	0.00238	0.00218
70	0.00226	0.00206	0.00146
95	0.00159	0.00149	0.00129
120	0.00145	0.00125	0.00091
150	0.00132	0.00090	0.00080
185	0.00091	0.00080	0.00070
240	0.00080	0.00070	0.00061
300	0.00073	0.00064	0.00055

Supplementary CPCs.

Where it is determined that a selected cable size will not provide sufficient CSA for the CPC a supplementary CPC can be run in parallel with the SWA cable. This CPC should be adequately sized to handle the full potential earth fault current not just to provide sufficient additional capacity to the SWA armour to meet the required CSA. This is required as the currents flowing under fault conditions would not be equally distributed over the cables due to differences in impedance.

Conclusion

The use of internal cores, of both thermoplastic and thermosetting SWA cables, as a CPC and/or the use of separate parallel CPCs are not required for SWA cables to comply with BS7671 provided.

1. The operating temperature of the cable does not exceed 70^0C.
2. The CSA of conductor cores does not exceed $95mm^2$.
3. The cable is not installed in the floating section of any marina.
4. The cable is correctly selected for the correct value of R1 + R2 for the circuit protection device protecting the cable.
5. The cable does not connect different installations together which have separate means of earthing unless sized for the potential earth fault current.
6. The cable is not used as a combined CPC and bonding conductor on a PME installation unless suitably sized.
7. The cables are properly terminated in correctly sized manufactures brass glands selected for the external influences prevailing.
8. Where a removable gland plate is present on the enclosure to which the cable is attached the earth ring (banjo) supplied with the gland is used and is connected to the earth terminal in the enclosure with a separate CPC. This CPC terminated in an eyelet to a bolted connection to the earth ring.
9. Any protective coating on the enclosure surface is removed under the contact surfaces of the gland and associated earth ring to expose bare metal.
10. All the wires of the armouring enter the gland and the gland nut is adequately tightened. The cable is adequately supported up to the gland with cable cleats to prevent mechanical strain on the gland.

References

1. BS 7671:2001 amended to 2004 Requirements for Electrical Installations.
2. IEE Guidance Note 1 Selection and Erection.
3. IEE Guidance Note 7 Special Locations.

John Peckham

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