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Planning of (single-sideband) power line carrier systems

Planning of (single-sideband) power line carrier systems

Conception des systčmes ŕ courants porteurs (ŕ bande latérale unique) sur lignes d'énergie

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CONTENTS

iTeh STANDARD PREVIEW
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SIST IEC 60663:1997
https://standards.iteh.ai/catalog/standards/sist/f82b384d-2f9c-42fb-bc04-52ed634f8b1d/sist-iec-60663-1997

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PLANNING OF (SINGLE-SIDEBAND) POWER LINE CARRIER SYSTEMS

FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.

2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.

3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

PREFACE

This report has been prepared by IEC Technical Committee No. 57: Power Line Carrier Systems and Telecontrol Equipment.

It is intended to be used as a guide to good practice when designing power line carrier systems and also to the use of the following IEC publications:

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Publications Nos. 353: Line Traps.
358: Coupling Capacitors and Capacitor Dividers.
481: Coupling Devices for Power Line Carrier Systems.
495: Recommended Values for Characteristic Input and Output Quantities of Single-sideband Power Line Carrier Terminals.

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This report has been prepared in accordance with the decision taken at the meeting held in Athens in 1972. Drafts were discussed at the meetings held in Ljubljana in 1973, in Moscow in 1975, in Oslo in 1976 and in Stockholm in 1977. As a result of this latter meeting, additional information concerning the precautions to be taken to avoid interference with aeronautical services was added and a new draft, Document 57(Central Office)16, was submitted to the National Committees for approval under the Six Months' Rule in February 1978.

The National Committees of the following countries voted explicitly in favour of publication:

Austria	Italy	Switzerland
Belgium	Japan	Turkey
Canada	Norway	Union of Soviet Socialist Republics
Czechoslovakia	Poland	United Kingdom
Denmark	Romania	United States of America
Egypt	South Africa (Republic of)	Yugoslavia
France	Spain	
Germany	Sweden	

SIST IEC 60663:1997

PLANNING OF (SINGLE-SIDEBAND) POWER LINE CARRIER SYSTEMS

1. Introduction

The transportation of electrical energy from the production plants to the load centres and the interconnection of plants for reasons of economy and security has resulted in the development of complex national and international networks. Such systems require extensive telecommunications facilities for speech and data such as telegraph, telemetering, telecontrol and protection signals extending between control centres and generating stations, switching stations and supply points.

The electricity industries use a variety of transmission media for their communication systems depending on the required information bandwidth, the economic and various technical factors. The electricity industries are unique in that they have available to them very reliable physical paths viz. – the power lines which interconnect the points of generation and supply and between which the signals can be transmitted by means of an HF carrier. Amongst the systems in extensive use in addition to power line carriers are rented circuits, (public telephone company, national telecommunications authority) buried and overhead cables, and privately owned radio links.

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Power line carrier telephone systems are *not normally interconnected* with the public telephone network and are therefore *considered as private* (utility-owned) *systems.*

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2. Scope

This report is intended to provide information regarding the application of power line carrier systems to electricity supply networks and to provide specific information on the properties and the performance of power line carrier (PLC) systems and associated equipment useful to the systems planning engineer, and on the precautions to be taken in order to ensure that PLC radiations do not interfere with other radiocommunication services.

Figure 1, page 60, illustrates the associated IEC standards for PLC-Systems.

As single-sideband (SSB) systems are now almost universal, the report is concerned with amplitude modulated systems of this type, however other types of system such as double-sideband and frequency modulated systems exist as described in Sub-clause 4.5.1.

3. Power line carrier systems (PLC)

This clause gives a brief description of the use of PLC systems together with the basic means of coupling. Variations of the basic methods outlined exist. Consideration of high voltage and

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telecommunication engineering, economic and other factors will dictate which method is employed in a given case.

3.1 *PLC frequencies*

The range of frequencies suitable for conventional power line carrier transmission extends from about 30 kHz to 500 kHz and sometimes up to 1 MHz, the lower limit being fixed by the limitations and cost of coupling equipment, the upper limit by line attenuation.

For insulated earth wire transmission, the range of frequencies extends from about 5 kHz to 500 kHz.

PLC systems must not cause interference to priority radiocommunication services within the frequency bands laid down by the ITU Radio Regulations (International Telecommunication Union).

The actual range of frequencies available for use in a specific country must take account of the needs of various radio services and broadcasting services, including aeronautical and maritime navigation systems, together with any local or national restrictions or regulations affording them the appropriate protection.

3.2 *Applications*

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Power line carrier systems are principally used to carry:

- either analogue information in the form of speech, and/or
- digital or analogue information, termed "signals" representing telegraph, telemetering, telecontrol, teleprotection, data, etc.

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"Signals" are, depending upon requirements, transmitted at modulation rates from 50 to 1200 bauds (Bd), mainly by voice frequency telegraph channels (VFT) located in the speech band or superimposed on a reduced speech band ("speech-plus signals" operation), but direct keying of the carrier may also be employed.

3.2.1 *Telephony*

PLC systems can be used to provide speech facilities ranging from a simplex party line system to integrated private automatic subscriber trunk dialling networks, sometimes equipped with priority facilities for operationally important subscribers.

Four-wire tandem switching is normal practice.

Considering the size and the number of tandem-operated trunk sections in such private networks an effectively transmitted speech frequency band of 300 Hz to 2400 Hz may be regarded as desirable for the required grade of service. However, in order to accommodate even more superimposed signalling channels or wider band channels, some authorities reduce the upper limit further to about 2000 Hz which would of course reduce the speech performance but this may still be considered to be acceptable in practice.

3.2.2 *Telegraphy and facsimile*

Private telegraph (teleprinters) facilities are also operated over PLC circuits. Such applications may also include facsimile transmission.

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Some electricity industries favour the teleprinter in operational management due to the fact that hard copies of the information exchanged are produced both at the command and at the execute levels. Both point-to-point and switched circuits are used.

The modulation rate is usually 50 Bd or 75 Bd, depending on the teleprinters used; facsimile may require higher rates.

In general, VFT channels should conform to the appropriate C.C.I.T.T. Recommendations. (C.C.I.T.T. = International Telephone and Telegraph Consultative Committee).

3.2.3 *Telecontrol and teleindication*

For the purpose of providing telecontrol and teleindication facilities, PLC systems generally use coded signals in order to achieve a high degree of security over the PLC systems and to avoid maloperation or loss of information.

The transmission speed for single systems may be as low as 50 Bd but in complex multi-point time-shared systems bit rates of up to 2400 bits/s or more are in use.

In general, VFT channels should conform to the appropriate C.C.I.T.T. Recommendations.

3.2.4 *Teleprotection*

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In order to prevent danger to life, damage to plant, and also to ensure the best possible continuity of supply, a power system must be protected against faults. In order to do this, high speed signals are transmitted between the ends of a line.

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Three types of protection system are in general use:

a) For direct tripping of a circuit-breaker from a protection device at the other end of the line.

b) For transferring discrete information from the protection relays at one end of the line to those at the other, for example to perform an accelerating or blocking function.

c) For transmitting analogue information between the protective devices at each end of the line to control the operation of the relays.

Protection signalling must be capable of being received during power system fault conditions which may introduce additional noise and attenuation in the circuit at time of transmission.

The permissible maximum overall signalling time of a protection channel is quite small, typically less than 50 ms.

Protection equipment may share a channel in the utility telecommunications system (e.g. a VF channel in a multipurpose PLC system), or may require a complete carrier frequency channel. The choice will depend on the security required, time for operation and on economic and/or bandwidth availability considerations.

Protection signalling equipment is characterized by the limited time available for the transmission and the recognition of the teleprotection signal transmitted very infrequently (a few times per annum) at unpredictable times. It invariably requires an extremely high

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probability of achieving "wanted" operation, and an extremely low probability of "unwanted" action (e.g. false tripping due to noise) and "missing" action (delay or total failure to trip or to block, whichever is appropriate, when required to do so).

In certain PLC systems (used for teleprotection) the carrier signal is normally quiescent and it is only sent for the brief and infrequent time when a protection signal is required to be transmitted. Often a clock test facility is included whereby a brief test signal is sent through the complete system at regular intervals of, say, 30 min to prove that the equipment is healthy.

In questions of frequency assignment where the risks of possible interference from PLC transmitters require to be considered, it is clear that different considerations apply to such quiescent carrier systems as opposed to the conventional PLC systems in which speech and other signals necessitate continuous transmission of carrier.

For PLC systems when protection signals are included, it has become common practice in some parts of the world to disable the speech circuit and all or some predetermined superimposed channels whilst active protection signals are transmitted so that the level of the protection signal may be boosted accordingly.

3.3 *Communication paths and coupling equipment*

To enable the conductors of a high-voltage line to be employed for communication purposes, some form of coupling equipment is required which will permit the injection of the high-frequency carrier signal without undue loss and at the same time de-couple the communication equipment from the power line in so far as the power system power-frequency voltage, switching surges, lightning surges etc. are concerned. The coupling system is also required to minimize the shunt loss caused by the substation equipment, and to render the impedance at carrier frequencies reasonably independent of switching conditions at the substation.

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The value of line impedance to be assumed for designing the coupling system is, in the case of single conductor phase wires, about 400 Ω for phase-to-earth coupling and about 600 Ω for phase-to-phase coupling. If the phase conductors are of the bundle type, values of 300 Ω and 500 Ω respectively are assumed.

It should be noted that the figures quoted are mean values calculated over the entire frequency range and for all possible terminations of the uncoupled phases. Thus the actual values may differ considerably from the mean but this is generally not significant from the system design point of view, as it only increases the overall loss by some tenths of a decibel, unless excessive mismatch causes intermodulation in the final amplifier.

Essentially coupling equipment comprises:

a) A coupling capacitor or capacitor voltage transformer (CVT) of suitable voltage withstand properties which is inserted between the coupling device and the high-voltage conductor. Values are of the order of 1000 pF to 10000 pF.

Consideration must be given to the choice of the coupler design to ensure an optimum selection based on capacitor cost versus bandwidth requirements. Reference should also be made to IEC Publication 358: Coupling Capacitors and Capacitor Dividers.

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b) A device known as a "line trap" (or "wave trap") which is connected in series with the power line between the point of connection of the coupling capacitor and the substation, or at the line trap. Basically the line trap consists of a choke coil, rated to carry the full line current, a tuning and protective device. The value of line trap inductance is of the order of 0.1 mH to 2.0 mH. Typical blocking bandwidths are shown in Figure 4, page 63. Reference should also be made to IEC Publication 353: Line Traps.

The tuning devices, used to improve the blocking efficiency of line traps, may be of different types. Those with narrow-band characteristics ensure a high blocking impedance for one carrier frequency (CF) channel. Those with double-band characteristics present a high blocking impedance for two non-adjacent CF channels, and those with broad-band characteristics present a blocking impedance for several CF channels. The latter is recommended when tuned for a specified minimum resistive component.

c) A "coupling device" which is inserted between the low-voltage terminal of the coupling capacitor and the CF connection to the carrier terminal and comprises a drain coil, surge arresters, and a matching transformer, which in some equipment is also designed as a drain coil to the power-frequency current. Typical coupling bandwidths are shown in Figures 2 and 3, pages 61 and 62. The requirements for coupling devices are covered by IEC Publication 481: Coupling Devices for Power Line Carrier Systems.

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The function of the drain coil is to offer a low impedance at power frequency and high impedance at carrier frequencies. It is designed to provide a path to earth for the power frequency current through the capacitor and so limit the potential of the capacitor terminal at the point of connection to the carrier equipment, in the interests of safety. As the coupling device is inserted between the low-voltage terminal of the coupling capacitor and earth, an earthing switch (blade earthed) is provided to ensure direct earthing of the coupling capacitor during maintenance or commissioning.

Statutory safety rules may require different procedures for the operation of this earthing switch and typical arrangements are as follows:

An earthing switch which earths the capacitor when the coupling device housing is opened.

A manually-operated switch interlock which does not allow the cover to be removed before the switch is operated to the earthed position.

A pole-operated earthing switch with suitable warning notice.

Whichever arrangement is used, it is recommended that an indication of the earthed position of the earthing switch should be clearly visible.

d) A "connecting cable" inserted between the secondary terminals of the coupling device and the carrier terminal.

This connection may be made with either a balanced or unbalanced (coaxial) cable depending on the impedance of the carrier terminal.

Commonly used values for the impedance of the cable are 150 Ω for the balanced cable and 75 Ω for the coaxial type.

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When coaxial cable is employed, different methods of earthing the screen may be used.

For cables lying within the same earth mesh, two methods are used; earthing the screen of the coaxial cable at both ends or at the carrier equipment end only.

The first method ensures the safety of maintenance personnel, as there will never be potential differences between local earth and the cable screen. Obviously, during faults, this connection may allow power-frequency currents to circulate in the screen and in the "hot" conductor. If this causes secondary problems, for example with coils and windings having magnetic cores, earthing at one terminal only may be used. This practice, whilst eliminating power-frequency current circulation, may cause high voltage across the windings of the coupling transformer which will need to be designed for this duty. Consequently, maintenance personnel will need to take precautions against the possibility of potential differences, during faults, between cable screen and local earth.

When the coupling device and carrier terminal are not part of the same earth mesh, earth potential differences may be high in the case of a fault and circulating currents in the screen of the coaxial cable may be dangerous. Therefore it is common practice in this instance to earth only one side of the screen at the carrier equipment end. Similar problems can arise in the case of armoured cables, except that secondary problems are unlikely to occur, and the same considerations apply. By the use of balanced cables some of the above problems can be avoided.

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With regard to the type of coupling used, coupling devices may be of the phase-to-earth, or of the phase-to-phase types.

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In the case of the latter, the coupling may be made with either a single phase-to-phase device or with two phase-to-earth devices properly connected. If the first arrangement is used, the distance between the low-voltage terminals of the capacitors and the coupling device is generally greater than with the second arrangement with a greater possibility of damage and interruption. Consequently, in order to achieve higher security, use of phase-to-phase coupling should be made with two phase-to-earth units, with the connection between them made on the secondary side of the matching transformer.

3.3.1 *Phase-to-earth coupling*

In this type of coupling the carrier equipment is connected between one phase conductor and earth as shown in Figure 1, page 60. Only one coupling capacitor and one line trap is required at each coupling point, so that this system offers economies in coupling equipment but it normally results in higher attenuation than phase-to-phase coupling and less security in the event of an earth fault on the coupled phase. It is to be noted that although the coupling takes place between one phase and earth, the actual transmission involves the two remaining phase conductors in a complex manner.

Because of the economic advantages, phase-to-earth coupling may be employed where high reliability in the presence of line faults is not essential.

3.3.2 *Phase-to-phase coupling*

In this case two coupling capacitors and two line traps are required at each coupling point, so the cost of the coupling equipment will be approximately twice that of phase-to-earth

SIST IEC 60663:1997

coupling. Phase-to-phase coupling however offers a number of important advantages, including lower attenuation, greater security against communication failure due to line faults, and less interference, both radiated and picked up.

As approximately 80% of all line faults are single-phase, this arrangement may be expected to give higher security.

3.3.3 *Inter-circuit coupling*

When two parallel high-voltage circuits are run without discontinuity on the same poles or towers, it is possible to utilize one phase on each of the circuits to provide the equivalent of phase-to-phase coupling on a single circuit line or two phases on each circuit to provide a double differential form of coupling. With this form of coupling, communication is maintained even if one power circuit is taken out of service and earthed.

3.3.4 *Insulated earth wire coupling*

It is customary on high-voltage lines, particularly those above 110 kV, to provide one or two earth wires above the phase conductors. These are primarily intended to protect the lines against lightning strokes, but they also serve to reduce the step voltage which would otherwise exist at the towers and substations under earth fault conditions on the lines. In addition, the earth wires help to minimize induction effects on nearby telecommunication circuits during earth faults on the power lines.

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The earth wires are normally in metallic contact with the line towers, but it is known that their efficiency as lightning protectors is not affected if they are insulated from the towers, the insulators being by-passed by spark gaps rated to flash over at about 15 kV to 30 kV. This fact has led to the utilization of insulated earth wires for communication purposes, the principal advantage being the saving in coupling equipment since although coupling capacitors and choke coils are still required they need not be rated for the full operating voltage and current of the line.

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The method has, however, a number of disadvantages:

a) The attenuation at carrier frequencies is, in general, appreciably greater than that of the power line, where multi-strand steel conductor is employed for the earth wire. However, where composite conductors (for example "Alumoweld") are used for the earth wire(s) the attenuation is more acceptable.

b) The need for insulating the earth wires at each tower and at the terminal points adds to the costs, and for longer distances the additional costs may exceed the savings in coupling equipment.

c) The effectiveness of the earth wires in their protective role under line fault conditions is reduced to some extent by the insulation at each tower.

Because of these drawbacks, the use of insulated earth wires for carrier communications has so far found only limited application.

3.3.5 *Coupling to power cables*

In general, coupling of carrier frequency signals to power cables is carried out in the same way as to overhead lines, both in the case of a three-phase cable or three individual

SIST IEC 60663:1997

single-phase cables. Phase-to-earth or phase-to-phase coupling is possible, the latter generally resulting in lower attenuation figures at the expense of higher costs.

In comparison to overhead lines, the characteristic impedance of power cables is smaller by a factor of 10 to 20. Consequently, the inductance of the line traps decreases, the capacitance of the coupling capacitors increases by the same figure for equal frequency bands compared with overhead lines.

4. Power line carrier system planning

4.1 *Carrier frequencies*

4.1.1 *System bandwidth*

The majority of SSB PLC systems that are available are arranged for a 4 kHz nominal carrier frequency band in the carrier frequency range. In some countries an alternative of 2.5 kHz has been adopted.

Table I lists typical values for the effectively transmitted band for a one-way single channel.

TABLE I

Typical values for the effectively transmitted band for a one-way single channel

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Nominal carrier frequency band	Use	Effectively transmitted speech and signal bands
4 kHz	Speech	300 Hz to 3.4 kHz
	Signals	300 Hz to 3.4 kHz or more
	Speech plus signals	300 Hz to 2.4 kHz plus 2.64 kHz to 3.4 kHz or more
		300 Hz to 2.0 kHz plus 2.16 kHz to 3.4 kHz or more
2.5 kHz	Speech	300 Hz to 2.4 kHz
	Signals	300 Hz to 2.4 kHz
	Speech plus signals	300 Hz to 2.0 kHz plus 2.16 kHz to 2.4 kHz

It should be noted that PLC equipment used for protection signalling only may use a nominal carrier frequency band of less than the figures quoted above, but values that are not compatible with the nominal carrier frequency band used throughout a system may be wasteful of frequency spectrum.

4.1.2 *Frequency allocation*

Most of the multi-purpose PLC systems require a bandwidth of 4 kHz for each direction of transmission; therefore, the available range of carrier frequencies (30 kHz to 500 kHz) is divided into a number of channels each 4 kHz wide. Two of these will be required for each two-way carrier circuit but they need not necessarily be adjacent. Where bandwidths of 2.5 kHz are in use, the channels are 2.5 kHz wide, two of these being required for each two-way carrier circuit. Other channel widths have also been adopted in some countries to suit their special needs.