1. INTRODUCTION

Eliminating hard wiring in an energy management installation by using Power-Line Carrier (PLC) continues to be one of the best ways to cut energy costs and realize savings immediately. On larger installations the expense of running the wires can amount to 1/3 to 2/3 of the total job cost.

State-of-the-art technology makes it possible to independently control and interrogate digital-in (DI), digital-out (DO), analog-in (AI) and analog-out (AO) points located throughout a large industrial site or a large building without having to run wires to the various pieces of equipment and sensors. It is also possible to communicate with intelligent remote devices containing closed-loop controllers, which we will refer to as Intelligent Responders, located throughout a facility without having to run wires to those devices. All of this is accomplished by taking commands from the controller that would otherwise be hard-wired to a piece of equipment — converting the command to a digitized carrier signal and applying the signal to existing power lines in one location within the building. This signal is then picked up at the equipment to be controlled (HVAC, for example) by a receiver (known as a Responder or Intelligent Responder) that decodes the command and acts upon it. This process is referred to as Power-Line Carrier and is abbreviated as PLC. The medium of transmission can be 120 Vac up to 600 Vac single-phase or three-phase ac power lines or 0 to 24 Vac dedicated lines. The commands can be shunted around voltage step-down transformers to a limited extent.

The choice of which equipment is to be controlled, which sensors are to be interrogated and the requirements of communication to and from the Responders are made by the installer and entered into the program of the energy management equipment (referred to here as Controller). In the conventional PLC system the Controller is point-per-point wired to the Command Synthesizer, which is the line carrier controlling instrument. The Command Synthesizer creates a precise, highly complex signal, which is superimposed (via Signal Couplers) on the ac wiring of the building or onto a dedicated wire run. The point-per-point wiring to the Command Synthesizer can be eliminated in certain proprietary Controllers.

The outgoing PLC commands result in control of a relay or output of an analog voltage at a Responder, which is a PLC remote interface device. Outgoing PLC commands also issue control instructions to the Intelligent Responders. All of this outgoing information originates as DO and AO from the Controller.

Return PLC signals from the Responders report on switch closures, sensed analog values or pulse counts at the Responder and result in control of a relay and/or output of an analog voltage at the Command Synthesizer. Return PLC signals from the Intelligent Responders provide information to the Controller as to the status of the loads being controlled by the Intelligent Responders and the space temperature. All of this incoming information ends up as DI and AI inputs to the Controller.

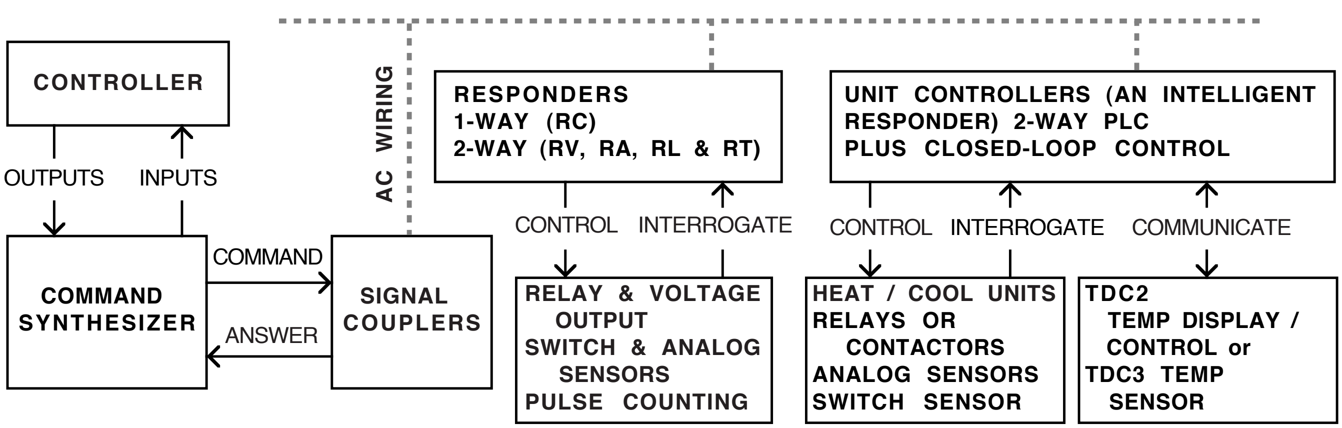
Responders are available in five varieties, which can be selected and mixed for maximum cost savings according to whether or not the application requires transmittal of analog data, switch closure status, command receipt verification, relay output or a combination of these functions.

Intelligent Responders can be intermixed with Responders in a PLC energy management system. Since the Intelligent Responders combine local control of load systems with PLC communication, they provide distributed intelligence without the requirement of running wires throughout the facility.

2. GENERAL OPERATION OF POWER-LINE CARRIER SYSTEMS

This PLC equipment is designed to function properly when it is the only PLC equipment on the electrical service. If it is installed in the same electrical service as other PLC equipment, interference may result. However, many successful systems have been installed in facilities having Simplex Time Clock systems (consult factory).

An energy management system (EMS) utilizing Functional Devices' PLC equipment is composed of as many as eight main components in addition to the building wiring. Referring to the example shown in Dwg. 1, there is a Controller, a Command Synthesizer, one or more Signal Couplers, the ac wiring, many Responders, many loads and sensors, many Unit Controllers (an Intelligent Responder), many Temperature Displays/Controls and many heat pumps or heater/air conditioners (referred to here as Heat / Cool Units).



(Drawing 1) Block Diagram of Possible 2-Way PLC Energy Management System

2.1 THE CONTROLLER

The Controller is an installer-provided component. It can be something as simple as a mechanical time clock, or as complex as a microprocessor-based electronic controller. The Controller decides when the EMS loads are to be on or off by issuing commands to and gathering information from Responders and Intelligent Responders (IRs).

2.2 THE COMMAND SYNTHESIZER

The Command Synthesizer generates the PLC signal. Model CS Command Synthesizers are available for one-way PLC systems (DO only) and model CD Command Synthesizers are available for two-way PLC systems (DO, DI, AI, AO, and pulse count*). The one-way Command Synthesizer is wired point-per-point to the outputs of the Controller. It transforms a particular hard-wired output (open or closed contact, NPN optoisolator or voltage) into an OFF or ON command addressed to a particular Responder. Each Controller output is assigned a unique digital code or identity (ID) at the Command Synthesizer. These same IDs are assigned to Responders (PLC receivers), which are located at the load, by setting positions of switches on the Responders. The PLC signal put out by the Command Synthesizer contains ON/OFF commands as well as the ID. The timing of ON vs OFF commands is determined by the Controller.

Two-way Command Synthesizers control loads in the same manner as do one-way Command Synthesizers. In addition, they interpret the returning PLC answers from RV, RA, RL*, RTC* or RTQ Responders and output the information by means of reed relays and analog voltage outputs. The reed relays and analog voltage outputs are wired point per point to the Controller, which will use the information as DI and AI in its control algorithms. Two-way Command Synthesizers also accept a voltage output from the Controller and send the information to Responders, which, in turn, output that same voltage as an AO. When the one-way and two-way Command Synthesizers described above are used in a PLC system, it is called **free-standing** PLC.

Command Synthesizers are also available to interface with the Controller via a serial I/O port of the Controller, thus eliminating much hardware and the point-per-point interface wiring. Some Controllers include the functions of the Command Synthesizer in the Controller itself or in an associated piece of equipment. Both of the above are called **integrated** PLC.

Under normal operation, an open contact to a Command Synthesizer input will generate an "OFF" command, while a closed contact to a Command Synthesizer input will generate an "ON" command to the Responder. In this context the words "ON" and "OFF" are in reference to the load being controlled by a relay in the Responder.

2.3 SIGNAL COUPLERS

The next component in the communication path is the Signal Coupler, which couples the PLC signal to the ac wiring of the facility. The Signal Coupler for one-way PLC Systems is the CTME Command Transmitter. It is an amplifier and its purpose is to amplify the signal being generated by the Command Synthesizer and inject it onto the ac power lines of the building or onto dedicated lines, where it becomes the PLC signal. The CTME output can be connected to any ac voltage source up to 600 Vac, single or three phase, including any voltage system shown in Drawing 2 of this manual. The CTME must be hard wired to the Command Synthesizer by the installer.

The Signal Coupler for two-way PLC systems is the CTR Command Transmitter / Receiver, which performs the function of the CTME and has the added capability of detecting the PLC answers returning from the Responder or Intelligent Responders and passing this data back to the Command Synthesizer for processing and eventual conveyance to the Controller.

When voltage step-down transformers exist between the CTME or CTR and the Responders or the IRs, then within certain restrictions a TB4 Transformer Bypass can be used to shunt the signal around the transformer.

2.4 BUILDING WIRING

The PLC signal is superimposed onto the ac wiring of the building, which can include any of the voltage configurations shown in Drawing 2 of this manual.

2.5 RESPONDERS & INTELLIGENT RESPONDERS

Responders are located at the loads to be controlled or sensors to be interrogated. The Responder gets its power to operate and also the PLC signals from the ac wiring or a dedicated line. Although the Responder is usually powered from the same ac source as the load, it can be powered from a different ac source.

Model RC Responders are available for one-way PLC communication (DO only) and model RV, RA, RL*, RTC* & RTQ Responders are available for two-way PLC communication (DO, DI, AI, AO, and pulse count*). All Responders, including type RC, can be mixed in a two-way PLC system to satisfy the requirements and minimize equipment cost.

Each Responder has a DIP switch (row of switches) with which its own digital code (ID) is set. When the code being generated by the Command Synthesizer matches the ID of the Responder then that Responder will follow the ON/OFF command of the Command Synthesizer as determined by the Controller and will answer with analog or digital data.

Care should be exercised that the rating of the relay in the Responder is not exceeded, that the Responder voltage input rating is appropriate for the application, and that the Responder is protected from the environment.

If several Responders must be installed at the same location, there can be some degree of undesirable attenuation of the PLC signal at that location. Distributing the Responders among all of the ac phases present at that location will reduce this attenuation. Responders RCQ/A, RC412C/A, RV412C/A and RTQ/A, which take the place of multiple Responders, will minimize this attenuation and result in an equipment cost savings.

***** The use of RL Responders (latching DI) & one of the RTC Responders (RTC9 for pulse count) is limited to certain custom Command Synthesizers.

The Unit Controller (an example of an Intelligent Responder) is located at or in the Heat / Cool Unit. It is hard wired to a wall-mounted Temperature Display/Control which measures the room temperature and allows control input from the user. Combined they completely control the the Heat / Cool Unit. The Unit Controller is assigned its own ID in the same manner as a Responder and its major operating parameters, including occupied / unoccupied status and set point, can be modified using PLC. During unoccupied status the deadband is opened to allow energy savings. The space temperature and the Unit Controller status can be reported via PLC to the Controller. From the perspective of the Controller it looks like a Responder with DO, DI, AI and AO.

The Unit Controller represents a major step toward distributed intelligence by combining local control of loads with PLC communication. This assures continued control of the Heat / Cool Units even if the Controller or the PLC equipment goes down. Typical uses are for controlling heat pumps and small packaged heater / air conditioner units. Other examples of Intelligent Responders are covered in A456.

2.6 LOADS, SENSORS & HEAT / COOL UNITS

The choice of which loads are to be controlled and which sensors are to be interrogated should be dictated by the manufacturer of the Controller or by the installer in order to achieve the proper control algorithm.

☆ 2.7 LAYING OUT THE PLC JOB ☆

In the use of power-line carrier equipment it is paramount to realize that the PLC signal amplitude is attenuated, or reduced, as it is propagated throughout a building's electrical system, as is normal with any form of communications. Just as the 60 Hz power-line voltage is attenuated over long runs of conductor, so is the PLC signal. To minimize the detrimental effects of signal reduction, proper layout is essential. To insure proper operation of PLC, the following rules must be followed:

☞ 1. The CTME or CTR absolutely must be installed within a maximum of 10 feet (wire run distance) of each of the building main electrical disconnects. The shortest possible distance is recommended. Connection must be through a 5- to 20-ampere fused disconnect (not time-lag or slow-blow and not a breaker) to all phases of the load side of each of the main electrical disconnects.

2. A good equipment ground must be connected to the CTME or CTR. A separate wire may have to be run to a known good ground.
3. The CTME or CTR absolutely must be installed downline from current transformers.
4. Installation of a CTR or CTME on the load side of a secondary (branch) disconnect close to a main disconnect may not be used to communicate with Responders or IRs that are fed from other secondary (branch) disconnects.
5. If there are voltage step-down transformers between the building main electrical disconnect and any Responder or IR then a Transformer Bypass (TB4) can be used to shunt the PLC around that step-down transformer but only under definite, limited conditions, which are the following:
   a. The rating of the step-down transformer is no more than 100KVA.
   b. Equipment Ground must be continuous throughout the facility including the ac service supplied by the step-down transformer.
   c. No more than 20 Responders or IRs are being fed from the secondary of the step-down transformer.
   d. The length of the ac wire run from the building main electrical disconnect to the step-down transformer is no more than 250 feet.
   e. The primary voltage of the step-down transformer is no more than 600 Vac.

If all of the above conditions are not fully met then an additional CTME or CTR must be installed at the load side of the step-down transformer and hard wired to the Command Synthesizer.

The layout of the ac lines in a building is typically in the shape of branches of a tree, which makes for short wire runs and little voltage drop from the starting point to the end points. By comparison, one long wire run, which would go from the starting point and attach to each electrical load in succession before ending at the last electrical load, would result in a substantial voltage loss at the last electrical load. That type of wire run would also result in poor PLC communication not only because of long wire runs but also because the PLC signal will be attenuated by all preceding Responders. Therefore, when a dedicated line (case L) is installed, the installer must make certain the line is installed as branches of a tree instead of one long run. There are legitimate reasons for using case L in PLC communication, such as when there are many electrical services in a shopping mall and the need for many signal couplers can be eliminated by the use of case L. Wiring of these installations **must** avoid one long wire run to eliminate possible communications problems.

In wiring the PLC signal from the Command Synthesizer to the CTME or CTR, use two-conductor jacketed cable. Use 22-gauge for up to 1,500 feet of cable, 20-gauge for up to 2,500 feet of cable, and 18-gauge for up to 4,000 feet of cable. Cable with shield is recommended but not absolutely necessary. Where other existing wire is available, the round-trip resistance of the wire should be limited to 50 ohms. The outgoing signal has an RF carrier and may cause interference with telephone lines sharing the same shield. The one cable handles signals going to and from the CTR.

2.8 FREE-STANDING vs INTEGRATED PLC

If a Command Synthesizer is not integrated into the Controller it is referred to as free-standing PLC. The Command Synthesizer is point-per-point wired to the Controller. It appears to the Controller as if it is directly wired to the various DO, DI, AO and AI points. Free-standing PLC can be used to add the cost saving advantages of PLC to energy management systems using almost any Controller. This type of system is also useful in expanding existing hard-wired energy management systems, particularly when the added points are remote from the Controller. Drawing 3 illustrates the head-end portion of a one-way free-standing PLC system and Drawing 4 illustrates the head-end portion of a two-way free-standing PLC system. Drawing 5 illustrates the head-end portion of a generic integrated two-way PLC system in which the Command Synthesizer is part of or integrated with the Controller.

3. COMPONENTS OF A PLC SYSTEM

The Data Sheets in the latter part of this manual describe and specify the components making up a PLC system.