

# One CANopen Application Profile for Mobile and Stationary Energy Management Systems

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**The CANopen application profile CiA 454 Energy Management Systems was designed for light electric vehicles (LEVs). In the course of a revision, now the application spectrum was expanded to stationary standalone systems for PV hybrid energy supply.**

## Introduction

There is a big cut-set between the two applications LEV and stationary standalone systems for PV hybrid energy supply. In both the electrical storage and the energy management that comes along with it play a central role. For PV hybrid DC coupled standalone systems the *Universal Energy Supply Protocol (UESP)* was developed at the Fraunhofer Institute for Solar Energy Systems ISE. It was decided to bring the contents of UESP into a CANopen application profile. The mentioned cut-set led to the decision to do this in the form of an extension of the application profile CiA 454 LEV. In many kinds this means a generalisation or abstraction of components. For example, the original specification described a DC/DC converter and a charger separately. In the course of the extension, now all kinds of voltage converters are representable like inverters, chargers, bidirectional DC/DC converters etc. CiA 454 describes the system components as virtual devices in separate specification parts. Two new parts were designed, describing loads on the one hand and generators on the other hand. Loads can be controllable, influenceable or non controllable. In analogy to that, generators can be stochastic, due to their renewable

energy resource or controllable. These characteristics are made transparent to the network in a standardised way which enables different manufacturers' components to be exchanged or seamlessly integrated into a running system by the superior energy management system and its control strategy.

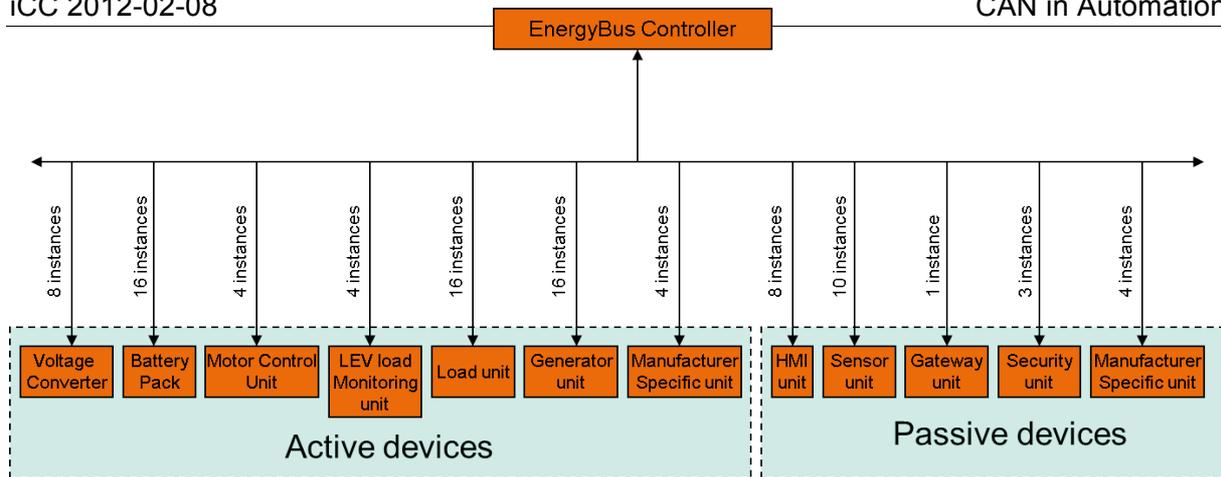
## CANopen Basics

Realising a communication infrastructure with the help of a CANopen application profile usually means that an application is divided into several virtual devices. A virtual device represents a functional unit. Using CANopen's concept of virtual devices enables the device manufacturer to unify the functionalities of different virtual devices in one logical device with one node identification.

## CiA 454 Energy Management Systems

Originally CiA 454 was designed for the EnergyBus that comprises not only the communication but also the plug and wiring loom of LEVs. EnergyBus distinguishes between active and passive devices. Active devices are coupled to the main power lines whereas passive devices

**Figure 1: CiA 454 Virtual device architecture**



are sufficiently supplied by an auxiliary power supply. Systems conforming to CiA 454 fulfil a virtual architecture that is illustrated in Figure 1.

The *EnergyBus Controller (EBC)* is a supervisory unit that is implemented as a virtual device. It is responsible for setting input and output set points (voltage, current, power) in the components that exchange power through the EnergyBus.

The other virtual devices are categorised as active or passive devices. In the first version of the specification that was restricted to the LEV application the active virtual device *Voltage converter* was simply a net connected battery charger. In the course of the revision all kinds of voltage converters are representable as will be shown in more detail in the section *Voltage Converter*. The active virtual device *Battery Pack* plays a key role in standalone systems because it has a significant share in the investment costs. Depending on the cell chemistry different charge and discharge boundaries must be carefully considered. In the course of the network configuration during system start up or when a new component is registered to the network, communication channels between loads and generators on the one side and associated batteries on the other side must be established. All passive devices and the active devices *Motor control unit* and *LEV load monitoring unit* are specific for LEVs and have less relevance in the scope of this paper because they are of less importance regarding the extension of the application profile to stationary PV hybrid standalone systems. The most important devices in the scope of this paper *Voltage converter*,

*Battery Pack*, *Load unit* and *Generator unit* shall be presented in detail in the next sections.

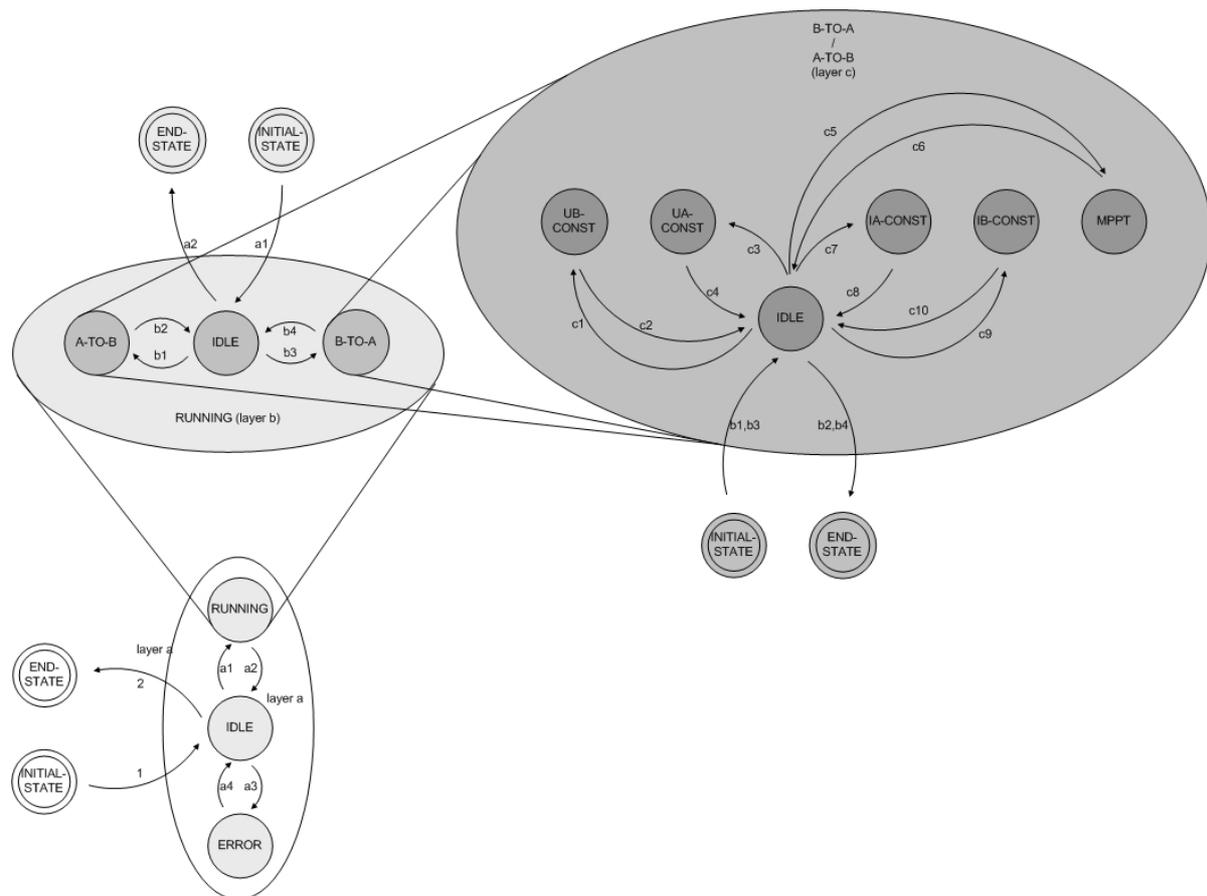
### Voltage converter

Through specification part 5 *Voltage converter* not only a simple net battery charger can be modelled but also bidirectional converters transferring power in both directions. In order to clearly elucidate the state of a voltage converter a finite state automaton as shown in Figure 2 is used. Three layers of operation are distinguished, in the figure represented by the same grey scales. Layer *a* is similar for the active devices *Load unit*, *Generator unit* and *Battery pack*. It indicates whether a device is in error state *ERROR*, idle state *IDLE* or running state *RUNNING*. For the converter example in the figure in layer *b* the two states *A-TO-B* and *B-TO-A* denote a power transmission from side *A* to side *B* and vice versa. This is due to the fact that also bidirectional converters are representable where there is no explicit input or output side. In either state five modes of control are defined (see layer *c*). Modes *UA-CONST* and *UB-CONST* mean a constant voltage regulation for side *A* and side *B* respectively. The same applies for constant current regulation in states *IA-CONST* and *IB-CONST*. The state *MPPT* depicts a control mode in which the input voltage of a PV charger or inverter is set in a way that the PV module is operated in the maximum power point (MPP).

**Load Unit**

Before the extension of the specification all loads besides the motor controller were controlled by a so called *DC-to-DC converter unit*. This device is capable of converting the operating voltage (12 V) to 6 V typically used by LEV loads like lamps, horn, etc. The clue about this device is that it detects a broken wire in case a load is switched on but no current flows. For stationary energy supply standalone

cannot be influenced at all, like for example consumer electronics in a household. An influenceable load cannot be fully controlled but there is a possibility to provoke tendencies. An example is a household where electricity tariffs could be displayed to give an incentive to the user to reduce power consumption manually or to switch on loads in times when excess power is available. Loads and generators



**Figure 2: Voltage converter finite state automaton (FSA)**

systems a new virtual device *load* is specified as a new specification part. Here, loads are described in an abstract way. To enable the EMS to integrate a newly connected device, the load identifies itself as controllable, non-controllable or influenceable. A controllable load can be switched on / off or varied in input power according to the best scheduled energetic exchange calculated by the EMS. An example for a fully controllable load is a water pump that can deliver water into a reservoir as long as the reservoir is not full. A non-controllable load is a load that

may have priorities that allow the EMS to decide which loads are preferably switched on or off.

**Generator Unit**

Similar to loads, generators are categorised in order to enable a seamless integration into the control strategy of the EMS. Generators can be controllable or stochastic in their operation. Generators that use renewable energy resources are typically stochastic generators because the natural environment (sunshine, wind)

determines the disposability of electricity. Backup generators like Diesel engines or fuel cells fall under the category *controllable generator*. Again, to enable the integration of the generator into the EMS best schedule of energetic exchange the generator indicates at the time it is registered to the network whether and if yes to what extent it is adjustable in output power.

### Battery Pack

In conventional PV hybrid standalone systems the battery has a very simple interface: Positive and negative electric poles of lead acid batteries. To base a control strategy on battery voltage is possible since the voltage decreases when the battery is discharged. But, this applies only for the open-circuit voltage. Determining the real state of charge of a battery in a system with irregular step changes in load is a complex issue. Still, algorithms and models exist that are able to accomplish a rather adequate calculation. The state of charge is a very important control variable for an effective energy management and therefore is broadcasted in the network via process data object (PDO). But, since electrochemical storages are not always lead acid batteries, the cell chemistry is another important parameter on which the charging strategy selection is based. It is foreseen that the EBC is responsible for getting the relevant information from the *Battery unit* and take care of the voltage and current set points in the charging device.

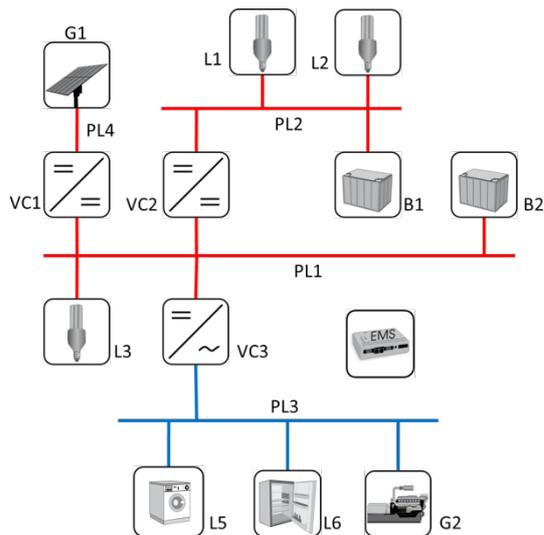
### PDO Usage

While most common CANopen devices conform to the predefined connection set according to DS 301 this does not apply for application profiles. As this application profile describes a fully meshed control system with regard to the process data communication, here, message identifiers for process data objects (PDO) are defined in the separate specification part 3 *PDO Communication*. As shown in Figure 1, a distinct number of instances exist for each virtual device. Ten PDO messages are defined. The first message contains a device status word and the device

dynamic limitation that shall be described later in this paper. The second message provides DC voltage and current of a DC coupled device. The first two PDO messages are common to all virtual devices. The third message is special for the *Battery unit* as it transmits the energy that is currently stored in the battery next to the battery's temperature. Messages four, five and six contain LEV specific information like motor speed, accelerator position, break position etc. Both the UESP and CiA 454 LEV originally were designed for pure DC coupled systems. In the course of the extension, now also AC coupled systems are representable. Therefore, three new PDO messages are defined containing three phase voltages, three phase currents and three phase power factors plus the net frequency. In case a voltage converter is a DC/DC-converter, so far, one side of the converter can be covered by PDO message number two. In order to communicate the other DC side of the converter, a tenth message is defined containing current and voltage of the second side of a DC/DC-converter.

### Application

Usually when CANopen networks are set up, the node identifiers of all devices are preconfigured via dip switches or the like. In order to come closer to true plug and play ability the CANopen layer setting services (LSS) are used. These services can be compared to the dynamic host configuration protocol (DHCP) known from TCP/IP networks. Through the LSS address that is made up of four identification numbers all CANopen devices can be explicitly addressed worldwide. The EBC is the LSS master. If a new device is connected to the system, the EBC will put all components to a safe operating mode and stop the network. Next the EBC will scan the LSS address of the new device. If the device is *known*, a free node identifier will be assigned to the newly connected device.



**Figure 3: Power lines and system components' positions; DC lines in red, AC lines in blue**

“Known” in this context means the following. Due to the simple fact that communication and power transfer lines are separated, a minimum configuration must be undertaken in order to provide the system topology. This means that the EBC must *know* where in the system in regard to the power lines the new component is situated. For this reason the EBC holds a list of power lines and the system components connected to it. A power line is simply a low resistant conductor through which the different components can interchange electrical power. As long as no voltage converters are used, there is only one power line. But, behind every voltage converter like DC/DC converters, inverters or frequency converters a new power line appears. Figure 3 shows an example setup with several power lines. In this example there are three voltage converters: one inverter (VC3), one charge controller (VC1) and a bidirectional DC/DC converter (VC2). This results in four power lines PL1, PL2, PL3 and PL4. Furthermore, six loads, two batteries and two generators are present in the example system. As mentioned earlier, the battery must be treated carefully. Therefore, each generator and each load should have an *associated battery* so that it can behave according to the state of the “right” battery. In the example there are two batteries. In case of a low state of charge (SOC) of battery B1 loads L1 and L2 may lower their power consumption. Loads L3, L5

and L6 on the other hand are responsible for battery B2 rather than for B1 because B1 is only accessible through an additional voltage converter VC2. For conventional systems this means that a breadth first search algorithm should be used in order to find the appropriate battery to be associated. If a low battery SOC is detected by the EBC it can trigger a generator to produce power. If the generator is behind a voltage converter the appropriate set point values for voltage and current must be written to the object dictionary of the voltage converter feeding in to the power line the battery is connected to. This must be done in a way that loads possibly varying in power consumption are supplied while at the same time a constant current flow into the battery may be assured.

### Device Dynamic Limitation

Normally the EBC is responsible for putting the appropriate set point values in order to achieve a sustainable energy management. If this is not sufficient and an over current or an over voltage are detected devices are able to signal this to all components of the network via the dynamic limitation. Three objects are contained in the first PDO message that reflect the percentaged overload in input current, output current and voltage. As a result, receive PDOs must be configured in all devices that shall listen to a dynamic limitation of another device.

### Modes of Operation

Three modes of operation shall be supported by all devices in a PV hybrid standalone system. In the normal operation mode a superordinate energy management system (EMS) that is implemented in the *EnergyBus Controller* (EBC, specification part 4) controls all devices by sending commands to manipulate their finite state automats. The EMS is application specific and not part of the specification.

In case there is no designated EMS and the EBC virtual device is not present in the network the power supply shall still not be interrupted. In this so called *masterless* control mode the system components

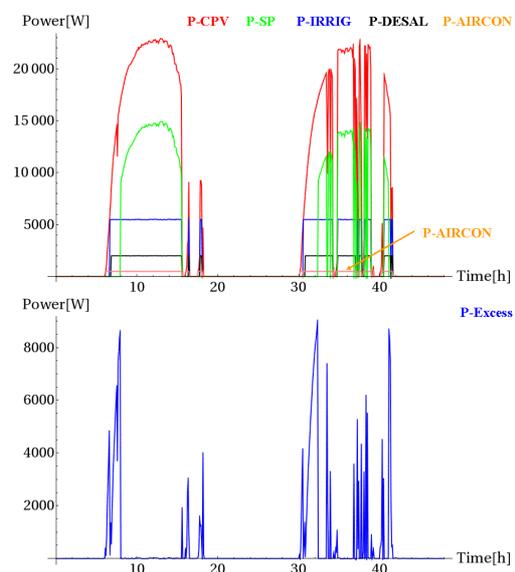
locally decide upon their energy exchange. Therefore, in each load and in each generator, threshold values are deposited which decide on how energy exchange shall be handled at what battery state of charge (SOC). For example a water pump will pump water as long as the SOC is greater than or equal to the switch off threshold of 70 %. If the pump is switched off, it will first be switched back on in case the SOC arrives at the upper threshold value of 100 %.

Many devices must operate even in case there is no CANopen communication available or intended. Therefore exists yet another backup operating mode that forms the de facto standard for components of a PV hybrid standalone system. This operating mode called *communicationless* is not explicitly mentioned in the specification because it takes effect in case of a total communication absence. Nevertheless, in the *communicationless* mode in analogy to *masterless* operation objects exist that function as threshold values. In case of a directly / DC coupled battery, these threshold values define at what battery voltage a component shall switch itself on or off. Alternatively, in case of an AC coupled system, the net frequency that may be varied in correlation to the battery SOC behind a voltage converter may be the basis for the component's local decision whether to switch on or off.

### Use Case Water Treatment in Upper Egypt

A first field implementation is currently undertaken in a system for water pumping, irrigation and desalination in Wadi el Natroon, Upper Egypt. This is the first off-grid concentrating photovoltaic (CPV) system and it uses CANopen according to *CiA 454 Energy Management Systems*. CPV modules are special photovoltaic modules that use Fresnel lenses to concentrate direct sunlight to a small sized high efficiency solar cell. For the focal point always to arrive on the solar cell the modules must be put on a tracker that follows the course of the sun. The aim of the project is to use as little battery storage as possible in order to reduce investment costs. The application is a water pumping, irrigation and desalination

system. The processed water can be stored in reservoirs. This results in a high degree in controllable loads because water pumps can be switched on exactly at that point in time when high irradiation is available. There is a small sized battery that makes sure that enough power is available for a period of three cloudy days to run the trackers. The EMS for this application is based on an algorithm that uses priorities for the loads. The smallest load is switched on as soon as enough power is available. As the sun rises, more power is disposable. In case there is enough power to enable a load with a higher priority, this load will be switched on and the other load is switched off if there is not sufficient power to run both.



**Figure 4:** Available CPV power (red) supplies a submersible pump (green), an irrigation pump (blue), a desalination unit (black) and an air conditioning to cool the battery room (brown). The lower graph shows the excess power that is used to charge the battery.

Figure 4 shows two days of operation. In the upper graph the available power is plotted, supplying the different loads. The lower graph shows the excess power that can be used to charge the battery.

### Conclusions

CiA 454 which was originally restricted to LEVs. The extension to generic PV hybrid standalone energy supply systems is

developing well. While the UESP used proprietary communication services, through CANopen the communication infrastructure is put on a stable foundation and is made available to all CiA members. Hence, a standardized manufacturer comprehensive protocol exists for PV hybrid energy supply systems, clearly defining the interfaces needed for the implementation of a superordinate energy management system. Maintenance of the specification documents is performed by the CiA organization who is expert in protocol specifications. The abstract way in which the components *load*, *generator* and *voltage converter* are described benefits the ability to design arbitrary systems and almost any kind of system setup or topology. Furthermore, while the former solution through the UESP was restricted to DC coupled systems, now, in addition AC or mixed AC/DC coupled systems are representable. The specification is still at an early state so that new members still have the chance to bring their influence to bear. In the course of the first implementations on the one hand the correctness of the specification will be proven to some extent. On the other hand, deficiencies will be revealed that must be lead back to the specification in the form of amendments as a recursive process to approach final integrity.

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