

Connection of an energy recovery DC Electronic Load

Abstract

This application note describes the necessary procedure and safety concerns to connect a regenerative DC Electronic load to the mains. As this electronic load has the unique option of back-feeding converted energy into the grid, there are various concerns about its appropriate connection to the local or public grid, so clarification is needed on how correctly connect the load in order to enable it achieving such task.



Figure 1: EA-ELR 9080-510 Electronic DC Load

Introduction

The electronic loads of the Elektro-Automatik (EA) ELR-9000 Series are especially suitable for test systems and industrial controls due to their compact construction. Apart from having basic functions of electronic loads, the electronic loads have an integrated function generator which can produce other several types of curves. In addition, these units are capable of achieving really high power ratings [1].

Though as power to be tested increases, it comes with the concern of wasted energy as heat dissipation [2]. EA offers electronic DC loads with an added eco-friendly solution which consist of converting supplied DC energy into AC and feeding it back into the local or public grid [3].

That solution eliminates the usual heat dissipation to a minimum and saves energy costs at the same time [3]. However, connecting this to the mains might not be an easy task at first; hence the purpose of the next paragraphs is to give clear instructions on how to connect the device, as well as taking appropriate safety measures.

Regenerative Electronic DC Load

The new series of electronic DC loads with energy recovery offers new voltage, current and power ratings for a variety of applications. These devices include four common operating modes: constant current, power, voltage and resistance. In addition, the FPGA based control circuit provides additional features such as a function generator, which is simply a table based regulation circuit for the simulation of non-linear internal resistances. Even response times for the control via analogue or digital interfaces have been improved thanks to the DSP controlled hardware [3]. There is one characteristic that despite making the loads applicable to higher power scenarios, it comes with a disadvantage.

Multiple devices in the ELR-9000 Series are capable of operating in parallel in a master-slave configuration, which mainly allows the user to couple the loads with UUTs that might require higher power capabilities. This capability can be extended up to 105kW in cabinets for a significantly higher total current, with the option to realise a higher power capability upon request [3]. However, as power levels to be tested increase, dissipating this energy may not be an attractive option for some customers, as this certainly implies a not so eco-friendly or 'green' approach [2].

The solution implemented in these devices makes the loads to be known as regenerative or energy recovery loads. The most important feature of these electronic loads is that the AC mains connection, i.e. grid connection, is also used as output for the back-feed of the supplied DC energy, which will be converted with an approximate efficiency of up to 95%. Energy recovering allows to lower energy costs and avoid expensive cooling systems, like the ones required for conventional electronic loads, which convert the DC input energy into heat [3].

Principle of Energy Recovery Operation

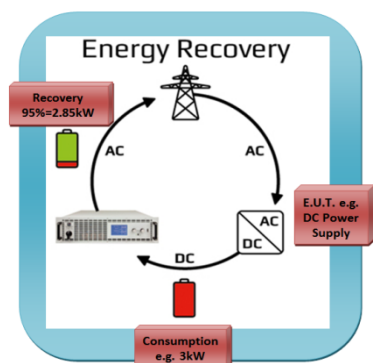


Figure 3: Principle of Energy recovery operation.

The way a regenerative electronic load operates can be easily explained using figure 2 as a reference [Wolfgang doc].

Assume the device under test is a battery cell

which consumes roughly 3KW of power. As seen on figure 3 [Wolfgang doc], the DC energy becomes an input to a DC-DC converter, which conditions the power so that this one can be processed to the next stage of the conversion. The last stage of conversion consists of an inverter which transforms the DC energy into appropriate AC energy. By appropriate, it is meant that the AC energy must be conditioned to meet the respective voltage and frequency levels of the local mains.

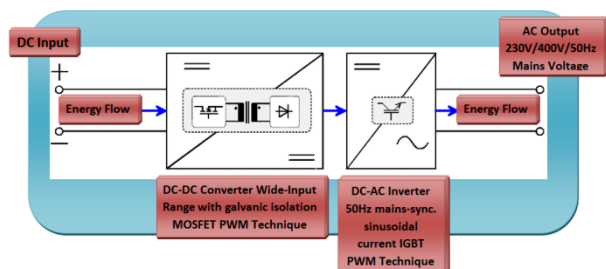


Figure 4: Power conversion process.

At this point, the recovered energy is fed-back into the factory grid and it ends up being utilized by the users inside the correspondent industrial or factory premises (in-house grid recovery). In the case the recovered power is higher than the consumed by the users inside the in-house grid, that one ends up consumed by users in the vicinities through the public grid, outside of the premises where the equipment is currently being tested. It could also occur the factory is not connected to the public grid and, for instance, the

load is being used as a device-under-test with a fuel cell. In such case, the ELR 9000 Series load limit the recovered power to the one that is consumed solely by the users inside in the in-house grid.

Furthermore, depending on the usage given to the load the equipment could end up paying itself in a few years.

Connecting the Electronic DC Load to the mains

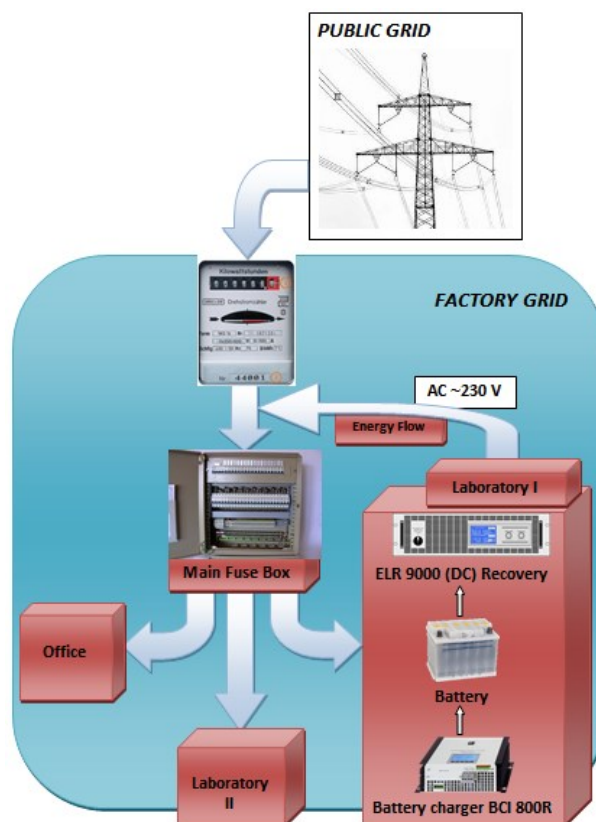


Figure 2: Recovering energy from Laboratory I

Figure 4 shows the process of energy recovery in which three consumers exist. In Laboratory I, it can be seen an energy recovery load being tested as part of a battery charging system. The arrow coming out of Laboratory I signify the load is connected after the meter and before the main fuse box and the energy recovered is being fed back into the factory grid (in-house grid). Connecting the unit in such way is imperative if the unit is going to be used as part of continuous test operations. The recovered energy will then be used by an office or any of the laboratories.

Safety procedures before installation and use

There are several safety procedures before installation and use of the unit and they are as follows [1]:

- The device may, depending on the model, have a considerable weight. Therefore the proposed location of the equipment (table, cabinet, shelf, 19" rack) must be able to support the weight without restriction.
- When using a 19" rack, rails suitable for the width of the housing and the weight of the device are to be used.
- Before connecting to the mains, ensure that the connection is as shown on the product label. Overvoltage on the AC supply can cause equipment damage.
- For electronic loads: Before connecting a voltage source to the DC input make sure, that the source cannot generate a voltage higher than specified for a particular model or install measures which can prevent damaging the device by overvoltage input
- For energy recovering electronic loads: Before connecting the AC mains/output to a public grid, it is essential to find out if the operation of this device is allowed at the target location and if it is required to install supervision hardware, i.e. automatic isolation unit (AIU).

Preparation and mains connection (AC)

Mains connection of an energy back-feeding electronic load is done via the included 5 pole plug on the back of the device. In addition, the wiring of the plug must be at least 3 strand or for some models, 5 strand of suitable cross section and length.

In order to connect the unit to the mains, there are several key points that need to be taken into account:

- Connection to an AC mains supply may only be carried out by qualified personnel.

- Cable cross section must be suitable for the maximum input/output current of the device (see table below).
- Before plugging in the input plug ensure that the device is switched off by its mains switch.
- Ensure that all regulations for the operation of and connection to the public grid of energy back-feeding equipment have been applied and all necessary conditions have been met.

The equipment comes with a 5 pole plug. Depending on the power rating of the load model, this will be connected to a 1Φ or 3Φ mains supply, which has to be connected according to the labelling on the plug and the table below [1]. Required for the mains connection, with or without AIU (Automatic isolation unit), are the following phases (Φ):

Nominal power	Without AIU		With AIU	
	Supply connector	Supply type	Supply connector	Supply type
3500 W	L2, N, PE	1Φ (wall etc.)	L1, L2, L3, N, PE	3Φ
7000 W	L1, L3, N, PE	3Φ	L1, L2, L3, N, PE	3Φ
10500 W	L1, L2, L3, N, PE	3Φ	L1, L2, L3, N, PE	3Φ
>10500 W	L1, L2, L3, N, PE	3Φ	L1, L2, L3, N, PE	3Φ

Table 1: Required phases for mains connection

For the dimensioning of the wiring cross section, the power of the device and the cable length are decisive. The maximum output current of the energy recovery feature per phase is calculated with the formula [1],

$$I_{AC} = (P_n / \phi_n * \eta) / 230$$

Where P_n is the nominal power, ϕ_n refers to the number of phases and η is the efficiency of the ELR unit (refer to models datasheet). The table below [1], based on the connection of a standalone unit, shows the maximum output current of every phase, as well as the recommended minimum cross section (Ø) (for up to 5m cable length):

Nominal power	L1		L2		L3		N	
	Ø	I _{max}	Ø	I _{max}	Ø	I _{max}	Ø	I _{max}
3500 W	-	-	1.5 mm ²	16 A	-	-	1.5 mm ²	16 A
7000 W	1.5 mm ²	16 A	-	-	1.5 mm ²	16 A	1.5 mm ²	16 A
10500 W	1.5 mm ²	16 A	1.5 mm ²	16 A	1.5 mm ²	16 A	1.5 mm ²	16 A

Table 2: Maximum current rating and minimum cross section

The included connection plug can receive cable ends up to 4 mm². It is known that the longer the connection cable, the higher the voltage loss due to the cable resistance. If the voltage loss results to be too high, then the feedback will not function reliably or not at all. Hence the mains cables should be kept as short as possible. Figure 5 shows an example of a supply connection cable [1].

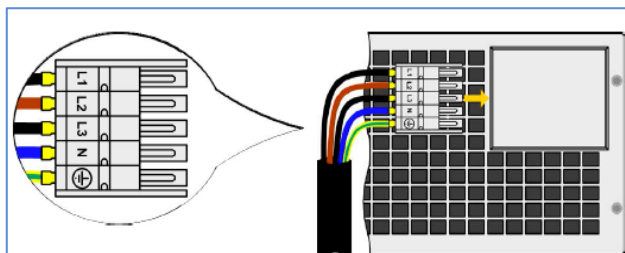


Figure 5: Supply connection cable

About Automatic Insulation Units (AIU)

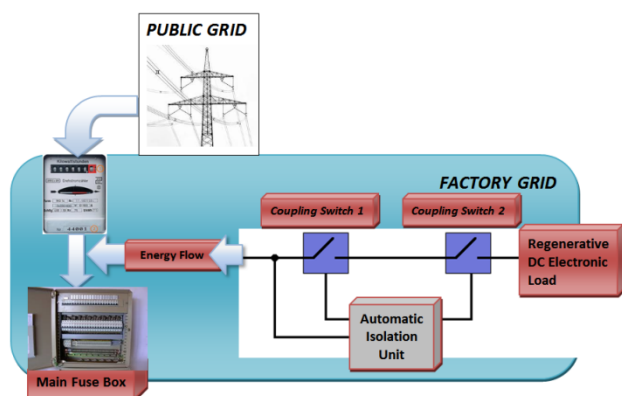


Figure 6: Integration of an AIU in an energy recovery system

An AIU, also known as Network Supervision unit or monitoring relay, supervises the energy recovery regarding the AC grid voltage, frequency and phase angle and automatically cuts the back-feeding device from the grid, by means of coupling switches, in case the supervised parameters are not met [4] [5].

With energy recovery electronic loads, before connecting anything to the grid, it is advisable to consult with local energy supplying companies, i.e. DNOs, whether the operation of this unit is allowed at the target location and whether it is required to install supervision hardware, i.e. AIU [1].

Having recommended that, when operating one of the loads in the ELR 9000 Series an AIU might not necessarily be required, unless the ELR is running in a so-called “isolated operation” or in the case the e-load is being used as the load part of a stand-alone power system (solar panels, battery cells, etc.)

In “isolated operation”, it could happen that the ELR or e-load is supplying energy back to the grid, but there are no consumers, or consumers with too little power to sink energy again. An AIU is also necessary when the load is being tested as part of a performance study of an autonomous generation system. It could happen that the stand-alone system keeps generating energy even after a mains power cut and an operator is nearby, ignoring the fact the system could be generating fatal amounts of current.

Even if the amount of recovered energy inputted into the local grid, though operating an energy recovery load on its own can be safe enough, according to European standards or to the local DNO, the installation of an AIU might still be required. [4].

The fact is each country has certain regulations for generation systems which wish to connect to the Electrical Network. For example, in the UK, the current regulations are the G83/2 and G59/2. An electronic load from the ELR 9000 series however, is intended for general industrial and laboratory operation and therefore does not fall under the regulations of Electric Power Generation and Distribution, as stated in e.g. German Power Utility Standard VDE-AR-N 4105 [Wolfgang Doc]. Although, if an AIU is then required, following the recommendation previously made, then this one has to strictly operate according to the local Network Connection Regulations.

Though the ENS supervision meets the European Community, the German VDE-AR-N 4105 and the Italian CEI-021 regulations, not meeting the British standards, might still be seen as a cause of concern for UK customers. These ones might think respecting the British standards G83/2 and G59/2 is a must. In fact, respecting these regulations is very important, because it helps protecting mainly human lives, as well as any electronic equipment under test, when voltage and frequency fluctuations outside limits occur in the network.

There are other alternatives out there in the Network and System protection equipment market, such as the supervision relay VMD460 from Bender, which in practice carries out similar monitoring tasks to the ones carried out by the AIU from EA. Obtaining a VMD460 could be a good alternative for UK customers, since this unit can be adjusted to meet the British standards for Network connection. In essence, the ENS2 is a chassis which encloses a monitoring relay, similar to the VMD460, which is manufactured by the company UfE.

For continental Europe customers, obtaining an ENS2 comes with added value that if the end user wished to mount the equipment on a rack shelf, he/she can easily do so. The reason to say that is, that this one comes manufactured as a chassis with 19" of width and 3U of height, which makes it adaptable for industrial rack shelves. Another added value is that, the EA 10.5KW rated units, come suitably wired to appropriate contactors (coupling switches), ready for being plugged to the mains and interfaced with a regenerative electronic load; for higher ratings, the choice of contactors and correspondent wiring is left up to the end customer. On the other hand, if the choice is different to the ENS2, though appropriate contactors should be obtained, it should be of no concern for the user, since these monitoring devices and appropriate coupling switches have a similar way in which they can be wired together.

Hence, the purpose of the next sections is to give a general idea and considerations when installing an AIU, taking into account the two examples of monitoring devices (VMD460 and ENS2) previously discussed.

Wiring an AIU

Before commencing the installation is always worth making sure the equipment to be installed has not suffered any damage during transport. Equipment with any damage must not be used under any circumstances [6]. On similar safety note, the user must take into account that the fuses, named AIU fuses in figures 7, 8 and 9, are usually not part of the unit itself and therefore the user has to ensure placing appropriately rated

fuses in the input power lines. As an example, Bender recommends placing 6A fuses to the input power lines of the VMD460 [5].

Having said that, there are two types of installations: Type 1 is made without and Type 2 is made with feedback contacts, as it can be observed from figures 7 and 8, both of which refer to the connection ports as named in the ENS. It basically refers to the fact the contactors have an additional feedback switch, whose objective is to provide the user an indication of whether the contactors have acted (make or break) or not. Furthermore, a contactor with a feedback switch is usually suitable for bigger installations where the installer is capable of determining to use contactors with or without feedback contact [6].

Wiring of unit

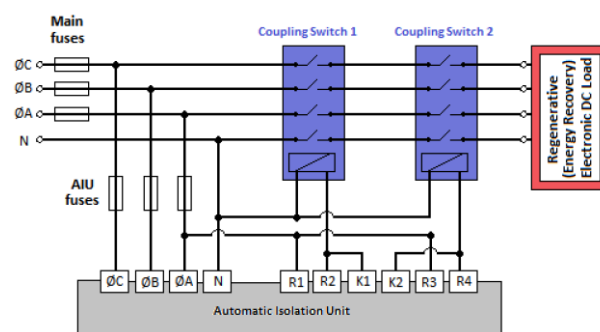


Figure 7: Type 1 installation without feedback contact

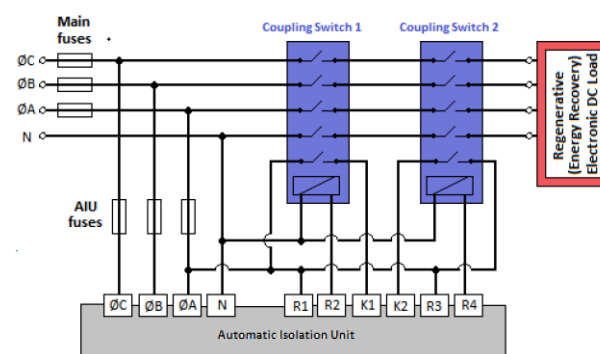


Figure 8: Type 2 installation with feedback contacts

Whether the unit comes with or without preinstalled contactors, it should not matter, as the wiring procedure is relatively simple and very similar with different AIU units. As an example, take figure 8 as a reference, in which case, the contactors have a feedback contact/switch. The

end user has to make sure he/she selects the appropriate contactors, as well as the cabling. The contactors and the cabling need to be selected depending on the maximum ratings of voltage and current. Table 2 could be used as a guide, though if rated power is above 10.5kW, it is the end user's responsibility to select appropriate rated cabling.

The procedure is as follows:

1. Prepare the cables (cut to required length)
2. Strip cables ends (~8mm) and, if flexible cables are used, crimp sleeves
3. Loosen the screws in the screw terminals
4. Connect the regenerative load to coupling switch 2 and PE
5. Connect the contactors to each other
6. Connect the coil of coupling switch 1 to terminal R2 and N wire
7. Connect coil of coupling switch 2 to R4 and N wire
8. Bridge connections between $\emptyset A$ and R1, as well as $\emptyset A$ and R3
9. In this case Type 2 is the type of wiring selected, therefore feedback contact of contactor 1 goes to terminal K1, as well as feedback contact of contactor 2 to K2. On the other hand, if Type 1 is the choice, then simply bridge connections between RA and K1, as well as R4 and K2
10. Connect the coupling switch 1 via main circuit breakers (or fuses) to the in-house grid (public or local?)
11. Connect the AIU to the mains

The procedure for connecting a Bender unit is very similar, as shown in figure 9, though there are obviously some differences:

- a) The VMD460 gives the user the option to select the state of the feedback signal contacts as NC (in non-operating state closed), NO (in non-operating mode open), or simply off (no feedback contacts)
- b) If using feedback contacts, the VMD has dedicated digital terminals called DG1/2, D1 and D2.

- c) In the ENS the terminals R1 and R2 are equivalent to the Bender's 11 and 14
- d) Terminals R3 and R4 of the ENS are equivalent to terminals 21 and 24 of the VMD.

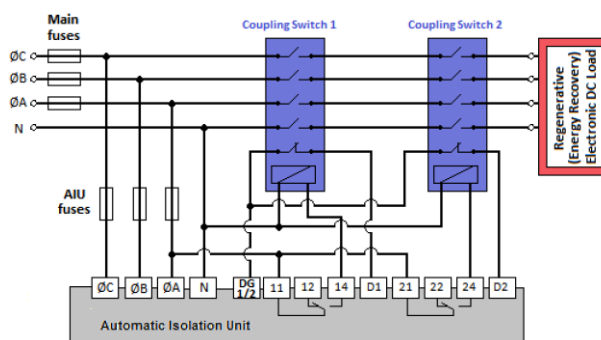


Figure 9: Type of installation used for VMD460

References

- [1] E. A. (EA), *Operating Manual ELR 9000 Electronic DC Load with Energy Recovery*, 2014.
- [2] P. P. S. (PPS), *Application Note: Using a model 3060-MS Series as a Regenerative AC Source for PV Inverter Test Applications*, Irvine, 2012.
- [3] E. A. (EA), *Datasheet EA-ELR 9000 3.5-10.5kW: Electronic Load with Energy Recovery*, 2012.
- [4] E. A. (EA), *Datasheet: EA-ENS2 Automatic Isolation Unit for E-Loads*, 2014.
- [5] B. G. & C. KG, *VMD460-NA Manual*, 2014.
- [6] E. A. (EA), *Operating Manual ENS*, 2014.