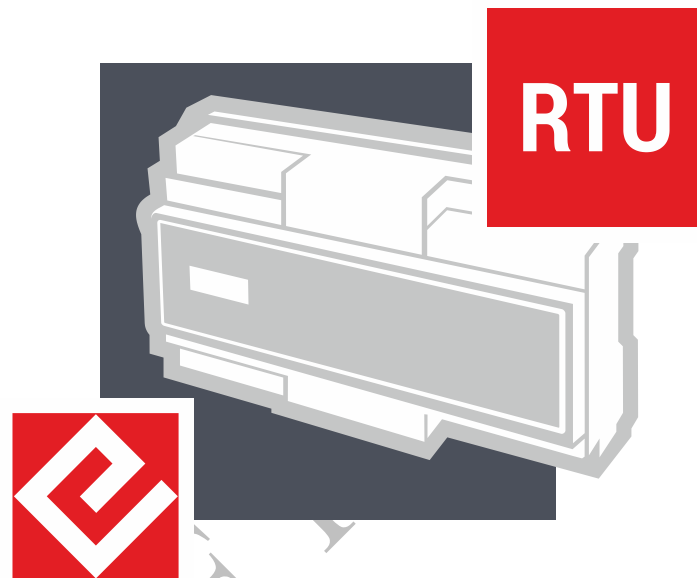




# Vdip2 Distributed Measurement Unit (DMU) User Manual with PMU Functionality



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## CONTENT

1. Introduction .....	3
2. Description of DMU Vdip2 with PMU functionality .....	3
3. Description of requirements for MZSN and MZSP monitors.....	4
3.1. Monitor MZSN .....	4
3.1.1. DMU Vdip2 Requirements.....	5
4. Prototype DMU Vdip2.....	6
4.1. PQM-S card with PMU functionality (code: EQ-3U/230V-3I/5A-S3I).....	7
4.2. GPS signal receiver card for accurate time synchronization (code: COMIO4-GPS) .....	9
4.3. RTU7M chassis with bus (code: CASE-5E P BUS-5N) .....	10
4.4. Power supply (code: PWRIC-230B BAT-24/10).....	10
4.5. Communication card and firmware (code: COMIO-PC3-LTE) .....	11
5. How to configure MZSN.....	11
5.1. Parameterization SW RTU, default parameters .....	11
5.2. Parameterization SW PQM-S, default parameters.....	12
6. Basic application wiring diagram .....	13
7. Prototype Tests.....	14
8. Attachments.....	15



## 1. INTRODUCTION

This manual describes a distributed metering unit (DMU) assembly that is fully compatible with the "Vdip Generation 2" (Vdip2) system for locating faults in high-voltage distribution systems and meets the requirements for the acquisition and processing of fault localization data according to patents EP2940483 and 305209. The device is also equipped with the function of a class S power quality analyzer and measurement of synchronous phasors (PMU) in relation to the reception of time synchronization from GPS.

## 2. DESCRIPTION OF DMU VDIP2 WITH PMU FUNCTIONALITY

For the purpose of applying the Vdip2 method, it is necessary to ensure local measurement of the time courses of the monitored variables (for DMUs with the MZSN function it is 3f voltage), their sorting into a circular memory and reliable transfer of the selected time period of these data from the measured site to the central unit using available communication technologies and standard protocols. The transmission of the selected data set is initiated on the basis of a command from the central unit containing the exact time of occurrence of the fault event in the MV network. For the exact time classification of the measured waveforms and at the same time as a basic prerequisite for the functionality of the PMU, it is necessary to equip the device with a sufficiently accurate time source, including a PPS (Pulse Per Second) signal, most often a GPS receiver. An effective solution is the integration of specific HW and SW modules into ELVAC's proven RTU7M series while using the maximum of components from the existing platform. A distributed measuring unit with parameters and functions complying with the requirements for MZSN monitors (according to Chapter 3) is a measuring device with a follow-up communication and power supply part according to the block diagram given in Fig. 2.1.

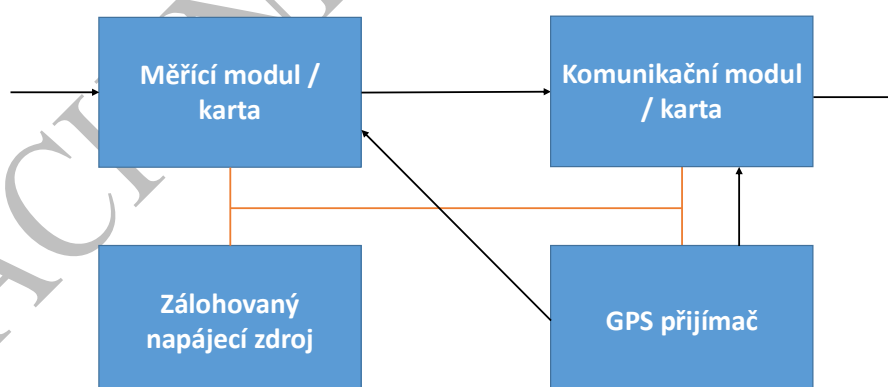


Fig. 2.1: Block diagram of DMU Vdip2 with PMU functionality

The current implementation of DMU Vdip2 with PMU functionality is based on the modular concept of ELVAC's proven RTU7M series of units. The mechanical design of the chassis with the bus, power supplies and communication modules are therefore based on the standard product line, but they have been extended in some technical details and supplemented with new firmware that supports the required processing and data transmission for Vdip2 technology. A key component that, in addition to

the appropriate adaptation of the RTU7M base, allows the configuration corresponding to the DMU Vdip2 to be assembled, is the specially developed and optimized "PQM-S card with PMU functionality-enabled card" (see Chapter 5.1). The chassis with the RTU7M bus and the method of connecting the PQM-S cards with the control system allow for the simultaneous full-fledged operation of two cards in Vdip2 mode (fast transfer of measured samples to the ring memory on the communication card), other cards in one system can work in a mode limited to PQM and PMU functionalities. In one RTU set (on one bus), it is possible to operate up to two MZSN units (for DTS with two transformers powered from another part of the HV line), which saves resources and space (a single power supply, a communication card and a chassis with a bus are sufficient).

A significant advantage of the solution used is the fact that the DMU Vdip2 base is still fully compatible with other components and SW for the RTU7M series, which offers existing and new users of products from this series an easy extension of their (in some cases existing) telemetry units with support for Vdip2 technology – all you need to do is provide a PQM-S card and new firmware.

### 3. DESCRIPTION OF REQUIREMENTS FOR MZSN AND MZSP MONITORS

The Vdip2 system uses two basic components located at distribution transformer stations (DTS) and HV substations. "Voltage return monitors" (MZSN) in the form of DMU Vdip2 are installed at DTS, and "current return monitors" (MZSP) are installed at substations, the function of which is performed by appropriately configured outlet protections providing fault records in COMTRADE format. The requirements for the MZSN (DMU Vdip2) necessary for the function of the Vdip2 system are briefly summarized in Chapter 3.1. The requirements for the MZSP necessary for the function of the Vdip2 system are the subject of application documents containing principles and recommendations for the deployment of the Vdip2 system.

#### 3.1. MONITOR MZSN

The MZSN voltage return change monitor is equipped with three voltage (and optionally three current) inputs that measure the instantaneous values of phase voltages  $u_1, u_2, u_3$  (and possibly also currents  $i_1, i_2, i_3$ ) on the secondary side of the HV/LV distribution transformer. From these instantaneous values of voltages and currents stored in the ring memory, a COMTRADE file is created on request from the Vdip2 system headquarters containing a defined time period before and after the occurrence of a failure on the HV line (detected by the protection of the outlet in the substation). From the obtained records, the phasor of the return component  $\bar{U}^{(2)}$  of the system frequency voltage is then calculated (the selected algorithm must be insensitive to the remaining frequency components commonly occurring in the network, e.g. HDO). An example of the absolute value of the return voltage component of the real earth fault is shown in Fig. 3.1, where the time 0 s corresponds to the time of the fault and in the time of 2 to 4 s the auxiliary resistor  $R_p$  was attached.

Subsequently, its average reference values are calculated  $\bar{U}^{(2)}$  from the voltage feedback phasor in two time windows:  $F_1$  and  $F_2$  ( $U_{Re, F1}^{(2)}, U_{Im, F1}^{(2)}, U_{Re, F2}^{(2)}, U_{Im, F2}^{(2)}$ ), where the windows are shifted relative to each other by the time interval  $\Delta t$ , while the size of the time windows  $F_1$  and  $F_2$  as well as the time interval  $\Delta t$  is user-selectable with regard to the operating conditions of the monitored system (auxiliary resistor attachment times or expected duration of failure/short circuit). In the example presented in Figure 3.1, the auxiliary resistor is clipped for a period of 1 s, the size of the time windows is ten periods of the system frequency, and the time interval  $\Delta t = 0.5$  s.



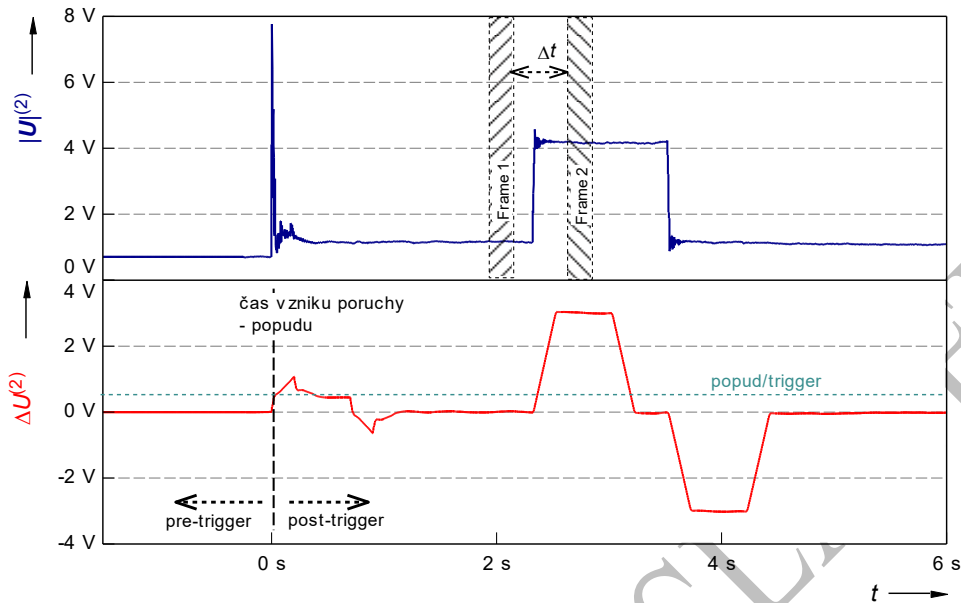


Figure 3.1: Example of the course of the calculated voltage return component and the change of the voltage return component by the MZSN monitor for real ZS

In the next step, the modulus of change of the phasor of the reverse component of the voltage  $\Delta U^{(2)}$  (hereinafter referred to as the change of the return component of voltage or current) is continuously calculated  $\Delta I^{(2)}$ , which is given by the difference of the calculated reference values of the phasors of the reverse component of the voltage of both time windows F1 and F2. An example of the course of this change is also shown in Figure 3.1. It is this change in the return component of the voltage that is evaluated and related to the place of installation of the MZSN in the subsequent localization of the fault site.

### 3.1.1. DMU VDIP2 REQUIREMENTS

The requirements for distributed units of measurement are defined in the points below:

a) Phase Voltage Measurement Accuracy:

- a. **measurement uncertainty  $\pm 0.1\%$  in the nominal phase voltage range of 80% to 120%**, outside this range according to the requirements for a Class S quality meter,
- b. Minimum measuring range from 0 to 150 % of the nominal phase voltage,
- c. minimum resolution of the measured phase voltage of 20mV (resolution of the instantaneous value of the voltage stored in the fault COMTRADE record),
- d. **minimum sampling rate of 1 kHz, fixed and continuous sampling.**

Note: If the requirements for Class S quality analyzers are met, the DMU will also be compatible with VQI functionality

b) Parameters of the COMTRADE fault record:

- a. **recording of instantaneous values of phase voltages on the LV side of DT (3 x for  $L-N$ ),**

- b. recording sampling rate of at least 1 kHz, fixed and continuous sampling (voltage monitors using dynamic sampling frequency can also be used, then an oscillogram of phase voltages with dynamic sampling, which is supplemented by time stamps of individual samples, is stored in the fault records),
  - c. Data samples must be available for reading/sending at least 1 minute after the event occurs,
  - d. the minimum length of the transmitted recording is 6 s,
  - e. The DMU must allow:
    - i. transmission of a record with a defined start time and length based on a control command containing these parameters,
    - ii. transmission of a recording of the required length (e.g. 6s) with a defined section before and after the command time based on the set configuration parameters,
  - f. the maximum time for data transfer to the center is 90 s from receiving a command from the center (requesting a fragment of sampled data), preference for technology minimizing the time of recording transmission (extends the time needed to locate the fault),
  - g. the record saved in COMTRADE format, see IEC 60255-24 ed.2 2013 (ČSN EN 60255-24).
- c) Feed:
- a. The minimum duration of the backup power supply is 2.5 min, i.e. the maximum time needed to send any recording to the center from the occurrence of the failure).
- d) Time synchronization requirements:
- a. maximum time deviation of 200 ms, use of NTP or GPS synchronization, note: the use of GPS synchronization reduces the size of the transmitted recording (synchronization error increases the length/size of the transmitted recording).

#### 4. PROTOTYPE DMU VDIP2

The prototype of the DMU Vdip2, on which the function of the Vdip2 method has been verified, is a specific sample configuration of the RTU7M assembly containing all the necessary HW and SW components to meet the defined requirements. The block diagram of the assembly corresponds to Figure 2.1 (Chapter 2), a view of the front panel of the prototype configuration is shown in the figure below.





Figure 4.1: Prototype assembly of DMU Vdip2

The following subchapters briefly describe the key components along with links to more detailed technical documentation.

#### 4.1. PQM-S card with PMU functionality (code: EQ-3U/230V-3I/5A-S3I)

To ensure the required parameters and functions by the Vdip2 method, a new measurement card for the RTU7M was developed – the aim was to achieve the necessary accuracy class U, I, P, Q and EE, according to the standards set for the Class S quality analyzer (PQM-S), including complete support for the analyzer functions. By combining the requirements, a multifunctional component was created, which allows users to activate multiple functions in one system without the need to purchase several separate devices.

The card is configured for the purpose of DMU Vdip2 to measure 3 voltage and 3 current inputs as standard. For the needs of fast transfer of measured voltages to the communication card, it is supplemented with a CAN communication interface on the internal RTU bus (ICC transmission). The card supports precise time synchronization from the GPS receiver located in the RTU bus, up to the level of assigning the synchronization pulse to the measured samples, which, in conjunction with the newly implemented support on the firmware side, allows obtaining information about synchronous voltage and current phasors from the card (a simple PMU function).

Within the Vdip2 project, the card was first developed in the "model 1" (G3) version, primarily meeting the requirements for the quality meter and measurement for the Vdip2 system, the functionalities of the PMU are finalized only on the card in the "model 2" (G4) version, which is the final version that will be produced and deployed in the future. The PMU function is implemented on the card in such a way that the card evaluates voltage and current phasors every time a second pulse arrives on the bus, which it writes to specified registers in the address range of the card. To transmit these values, an internal communication line to the RTU bus and the Modbus RTU protocol are used – a list of available values and their addresses are given here:

Namapovaná data	Bázová adresa		Velikost, typ	Jednotka
	DEC	HEX		
GMT čas pulzu	19840	0x4D80	64b, KMB time	<i>KMB time</i>
časová značka pulzu	19844	0x4D84	64b	ns
frekvence	19848	0x4D88	32b, float	Hz
U <sub>1</sub>	19850	0x4D8A	32b, float	V
U <sub>2</sub>	19852	0x4D8C	32b, float	V
U <sub>3</sub>	19854	0x4D8E	32b, float	V
U <sub>4</sub>	19856	0x4D90	32b, float	V
f <sub>U1</sub>	19858	0x4D92	32b, float	rad
f <sub>U2</sub>	19860	0x4D94	32b, float	rad
f <sub>U3</sub>	19862	0x4D96	32b, float	rad
f <sub>U4</sub>	19864	0x4D98	32b, float	rad
I <sub>1</sub>	19866	0x4D9A	32b, float	A
I <sub>2</sub>	19868	0x4D9C	32b, float	A
I <sub>3</sub>	19870	0x4D9E	32b, float	A
I <sub>4</sub>	19872	0x4DA0	32b, float	A
f <sub>I1</sub>	19874	0x4DA2	32b, float	rad
f <sub>I2</sub>	19876	0x4DA4	32b, float	rad
f <sub>I3</sub>	19878	0x4DA6	32b, float	rad
f <sub>I4</sub>	19880	0x4DA8	32b, float	rad
RoCoF	19882	0x4DAA	32b, float	Hz/s

In addition to the default version of the card designed for measurements on the LV side of transformers in DTS (level 400V L-L / 230V L-N), the PQM-S card was also developed in a version for measuring values on HV via "sensors" with a secondary range of 3.25V for voltage inputs and 225mV for current inputs. This version is mainly used in practice as a quality meter and PMU for HV networks, but in laboratory conditions it can also be advantageously used for tests of the Vdip2 system using RTDS simulators and low-voltage outputs with a range of up to 10V.



Figure 4.1.1: PQM-S prototype card



Figure 4.1.2: PQM-S card for sensor measurements

Type designation of PQM-S cards (applies to production "model 2"):

Variant with 230V AC / 5A measurement inputs

Production designation (KMB): SMC RTU7M 134 5 230 X/5A N N G4

Catalog designation (ELVAC): RTU7M EQ-4U/230V-4I/5A-S3I

Variant with LPVT / LPCT measurement inputs

Production designation (KMB): SMC RTU7M 133 5 3.25V3 X/255mV N N G4

Catalog designation (ELVAC): RTU7M EQ-3U/3.25V-3U/0.225V-S3I

Basic information about PQM-S cards is provided in the appendix "RTU7M User Guide" in the chapter "2.13 Cards for indirect analogue measurements, with network quality analysis". More detailed information is available in the appendices "PQM-S Card User and Application Manuals", a list of which is provided at the end of this document.

#### 4.2. GPS signal receiver card for accurate time synchronization (code: COMIO4-GPS)

To ensure accurate time synchronization in the RTU unit, a new version of the GPS signal receiver card has been developed, which is equipped with a fast binding to the synchronization line of the internal RTU bus of the unit, ensuring the distribution of the PPS pulse from the GPS receiver module with minimal delay. At the same time, a precise mechanism for the distribution of the time data in relation to this second pulse is ensured. Further information on the chassis is available in the appendix "RTU7M User Manual" in the chapter "2.4.1.1 COMIO4 Communication Card".





*Fig. 4.2.1: GPS receiver card*

#### **4.3. RTU7M chassis with bus (code: CASE-5E P BUS-5N)**

For the purposes of the DMU Vdip2 prototype, a five-slot chassis variant with a bus designed only for "indirect" cards (with its own processor) was chosen. This bus supports multiple parallel high-speed communication channels, accurate time synchronization, and identification of the position in which the card is inserted. In connection with the development of the new PQM-S card, these functions were verified and mutual compatibility was ensured. More information about the chassis is available in the appendix "RTU7M User Manual" in chapter "2.2 Bus Trays".

#### **4.4. Power supply (code: PWRIC-230B BAT-24/10)**

The power supply card is used to power the RTU7M unit and all cards in the bus, or it provides backup power from the battery and its recharging. Several fundamentally different types of power cards are supplied, for the purposes of the prototype V-dip set, "AC/DC, galvanically isolated power card with charger and backup" with the type designation "PWRIC-230 BAT24/10" was chosen. The RTU unit can be powered directly with a mains voltage of 230V / 50Hz with this power supply card, an external battery with a nominal voltage of 24V is used for backup purposes. Further information about this card is available in the appendix "RTU7M User Manual" in chapter "2.3 Power Cards". For the purposes of the DMU Vdip2 ready prototype, the compatibility of the power card (in all standard versions) with the PQM-S card was verified.



## 4.5. Communication card and firmware (code: COMIO-PC3-LTE)

The communication card is used to ensure communication of the RTU7M unit with the superior system (a number of standard communication protocols such as IEC 60870-5-104, IEC 61850, DNP3...), to communicate with cards in the bus and to communicate with other devices on other communication interfaces (e.g. IEC 60870-5-104, IEC 61850, DNP3, MODBUS...). In accordance with current cybersecurity requirements, great emphasis is often placed on the security of data channels (encryption) when communicating with a superior system. For the purposes of DMU V-dip, a communication card of the "COMIO-PC3-LTE" type was chosen, which meets all the requirements for a modern "industrial communication router" with an integrated GSM/LTE modem. In addition to basic communication functions, the built-in PC on the card offers space for processing specific tasks, such as processing Vdip2 data from the PQM-S card and then transferring them to the central unit – for this purpose, the standard firmware has been expanded, which in the new version supports fast transfer of measured samples, their local storage, creation of data files based on the timestamp obtained from the fault indicator and subsequent automatic transfer of records to FTP server. At the same time, a standard communication protocol for the transmission of data, states and fault symptoms to the SCADA system is active.

Further information about the communication card is available in the appendix "RTU7M User Manual" in the chapter "2.4 Communication cards".

## 5. HOW TO CONFIGURE MZSN

The DMU Vdip2 configuration for the MZSN functionality is done by default via a remote connection via a built-in LTE modem. The configuration is divided into two parts – on the one hand, on the setting of operating parameters and the system configuration of the RTU unit, and on the other hand, on the detailed parameterization of the PQM-S measuring card.

### 5.1. Parameterization SW RTU, default parameters

The parameterization SW called RTU User Center works with a tree structure of the configuration data of the DMU report, where each component or channel is assigned the required parameters and mappings (addresses). These parameters are transferred to the remote DMU on command, which works with the new settings after the transfer is completed and the new parameters are introduced. It is possible to remotely perform all monitoring and management of the device, including firmware updates.



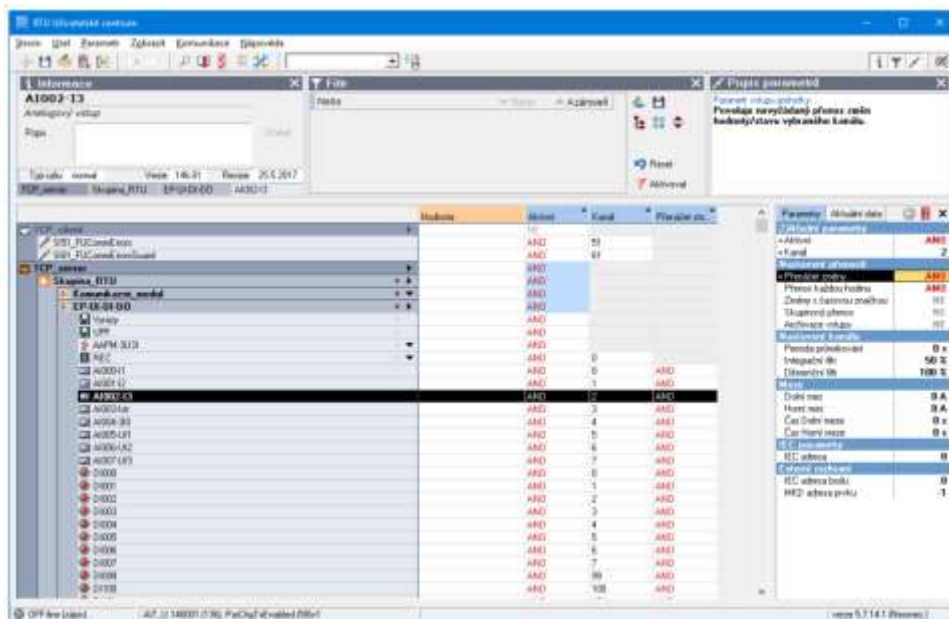


Figure 5.1.1: RTU User Center

More detailed information about the parameterization SW is available in the appendix "User Manual of the RTU Parameterization SW".

In addition to the basic system components such as the power supply and the communication card, the PQM-S measurement card is also included in the DMU configuration tree. On the RTU side, selected measurement and signaling channels from the card's internal registers are mapped here, which can be further transmitted to the superior system using standard communication protocols.

## 5.2. Parameterization SW PQM-S, default parameters

ENVIS is supplied with supported power quality meters and analyzers. It provides the user with a simple tool for configuring and managing measuring instruments, transferring data to a PC and then processing them. Data retrieved from instruments is archived into a SQL database or binary. They can then be exported to common formats such as XML, CSV, PDF, HTML and others.

The program also offers the possibility of on-line monitoring of the current state of the device and provides basic tools for visualization and analytical processing of stored historical data.

The ENVIS installation includes the following components:

**ENVIS** ... software for analysis of archived measurement data. It allows you to display records in graphs and tables, create reports, evaluate quality, energy management and export data. For full functionality, the program requires that a database server is installed on the computer and at least one database is accessible.

**ENVIS. Daq** (Data Acquisition) ... for configuration of instruments, reading of measured data and export of data to various formats. Data reading can be invoked from the ENVIS program by selecting it in the menu or from the list of devices or directly by launching the ENVIS program. Daq in standalone mode.



- ENVIS.Online** ... Optionally licensed system service for automatic data archiving. For testing purposes, it is basically possible to use two measuring instruments without a license.
- UpgradeTool** ... is used to update the firmware of supported devices via USB or Ethernet.



*Figure 5.2.1: SW ENVIS*

For remote management of the PQM-S card via SW ENVIS, a transparent virtual communication channel provided by the RTU unit is used for this purpose. Support for PQM-S cards is available from ENVIS 2.2.x versions, ENVIS must be used to download data. Daq v2.2 and higher, the new console tools for working with devices from KMB also support PQM-S cards.

More detailed information about the parameterization SW is available in the appendix "PQM-S parameterization SW user manual".

## 6. BASIC APPLICATION WIRING DIAGRAM

To integrate the DMU Vdip2 into DTS, it is necessary to ensure the power supply, connect the backup battery, antenna, and, of course, connect the measured voltages and currents to the PQM-S card. A simple basic application scheme is shown in the following figure.

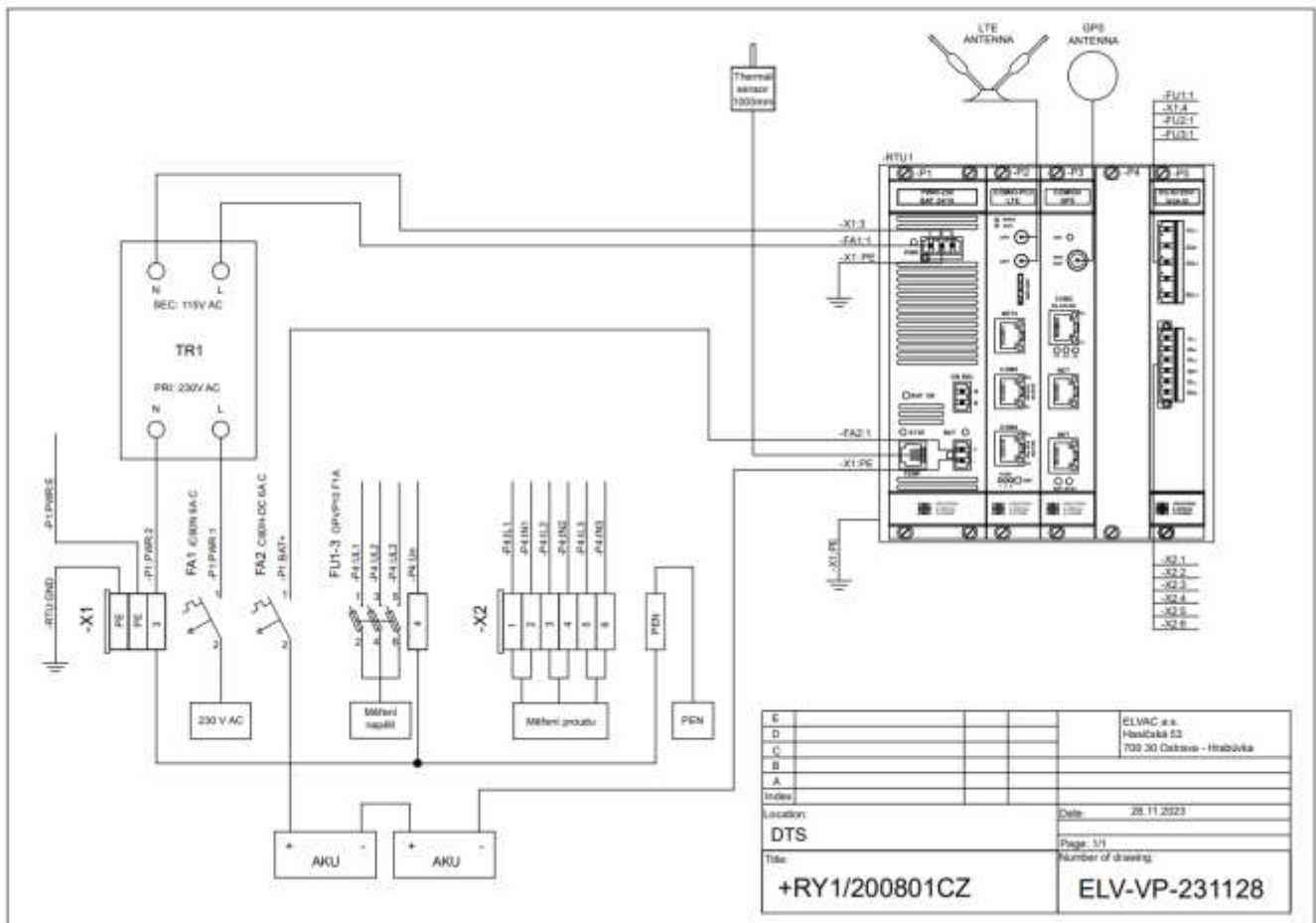


Figure 7.1: Basic application connection of DMU Vdip2

## 7. PROTOTYPE TESTS

The prototype DMU Vdip2 assemblies were first tested "statically" at the level of components (properties of the measuring card) and assembly (interaction and mutual influence within the RTU). Then the properties of the entire chain were verified dynamically with the help of simulated fault signals generated into the analogue inputs of the card with the subsequent comparison of the obtained data sets with the original. Subsequently, the entire group of DMU Vdip2 units was subjected to laboratory tests in conjunction with the central unit Vdip2 (server). In the simulated conditions, the HW parameters and the correct implementation of the required functions, including the reliability of communication and time synchronization, were verified. This testing confirmed the compliance of the achieved results with the requirements of the Vdip2 method.

## 8. ATTACHMENTS

### RTU7M User Manual

File: [Uživatelská příručka\\_RTU7M\\_Rev32.pdf](#) (Standard Documentation)

### PQM-S Card User and Application Guides

File: [SMC-RTU7M-134\\_MANUAL\\_v5.0\\_CZ\\_rev1.0.pdf](#) (from the Vdip2 project)

File: [Modbus\\_MANUAL\\_v4.0\\_CZ\\_rev1.12.pdf](#) (Standard Documentation)

File: [AN0034\\_TimeAdjust\\_CZ\\_rev1.0.pdf](#) (Standard Documentation)

File: [AN0038\\_Sampler\\_CZ\\_rev1.1.pdf](#) (Standard Documentation)

File: [AN0043\\_PMU-RTU7M\\_CZ\\_rev1.0.pdf](#) (from the Vdip2 project)

### User Manual Parameterization SW RTU

File: [RTUUC\\_Manual\\_CSX.pdf](#) (Standard Documentation)

### PQM-S Parameterization SW User Manual

File: [ENVIS-Uzivatelska\\_prirucka-cze.pdf](#) (Standard Documentation, Legacy)

Reference: <https://kmb.cz/cs/produkty/software/envis-app> (application installation package with built-in help)

