Backup power source for Ethernet devices using Power over Ethernet technology

Martin Pospisilik and Tomas Dulik

Abstract— Currently, the technology of Power over Ethernet becomes rather popular, mainly for powering of terminal devices. Provided these devices are used to drive larger wireless network, it is appropriate that they were provided with a backup source in case of power failure. As the voltages used by Power over Ethernet technology are compatible with voltages of standard lead-acid batteries, the construction of the backup source can be simplified by omitting the output voltage inverter. Although the simplest way of creating a backup source is just to connect the appropriate lead-acid battery in parallel to the output of the main power source, there are more convenient solutions based on switches with MOSFET transistors. More sophisticated control of the battery connecting and charging will significantly prolong its life. One of such solutions is provided within the framework of this paper. The basic concept of the backup power source provides the output voltage of 24 V, but it can be optionally equipped with converters increased this voltage up to 48 V or decreasing it down to 12 V. The description of the converters is provided as well.

Keywords—Power over Ethernet, Electronic Diode, Low Power Dissipation, Power Backup.

I. Introduction

ANY electrical appliance's performance is affected by the quality of the electrical power network from which the appliance is fed. This problem is crucial in case of those appliances that are expected to operate permanently, such as network devices. According to [2] the following power supply network malfunctions occur at most:

- total power network failure (blackout),
- short undervoltage (usually without negative consequences),
- long undervoltage showing the decrease of the power supply voltage by more than 15 %,
- overvoltage,
- short voltage spikes,
- waveform distortion,
- noise,
- electromagnetic interferences.

The statistics published in [2] shows that more than 90 % of power supply network failures are the total power network failure and long undervoltage, resulting in the lack of the supplied power and malfunctions of the powered appliances. This problem has been solved by employing the UPS (Uninterruptable Power Supply source) units that are capable of delivering the power from accumulators in case the power supply network failed. The more sophisticated systems are capable of the voltage spikes and noise on the power line elimination.

On the other hand, the power supply backups for Power over Ethernet applications deliver DC supply and therefore there is no need to control and restore the shape of the AC sinusoidal waveform.

A. Power over Ethernet principle

The principle of the Power over Ethernet (PoE) technology is depicted in Fig. 1. It shows that the network device can be powered directly by means of potential difference between transmitting and receiving pairs of the LAN cable.

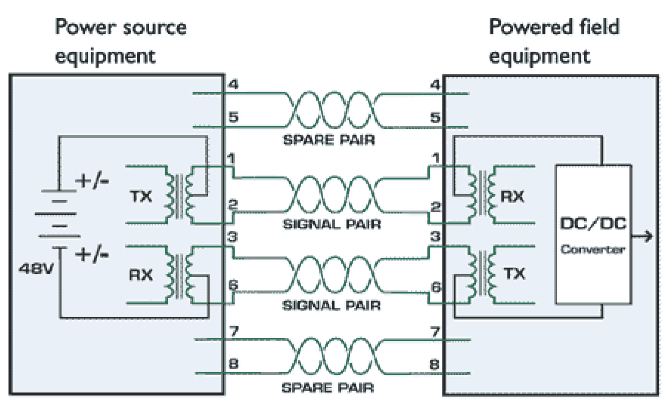

Fig. 1 Power over Ethernet principle [7]

The appropriate standards distinguish between active and passive PoE. While the passive PoE device is simply fed by the Power source equipment of the required output voltage and power, the active PoE device can report to the Power source equipment which voltage it needs for proper function. More information on this topic can be found in [7].

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The application of PoE is very efficient in case of powering outdoor devices, as depicted in Fig. 2. In this case, the outdoor wiring is reduced and the operator and/or serviceman's comfort is increased, because the PoE technology enables monitoring of the power consumption of the connected devices and moreover, the hardware of the uninterruptable power source including batteries can be mounted on an easily accessible place.

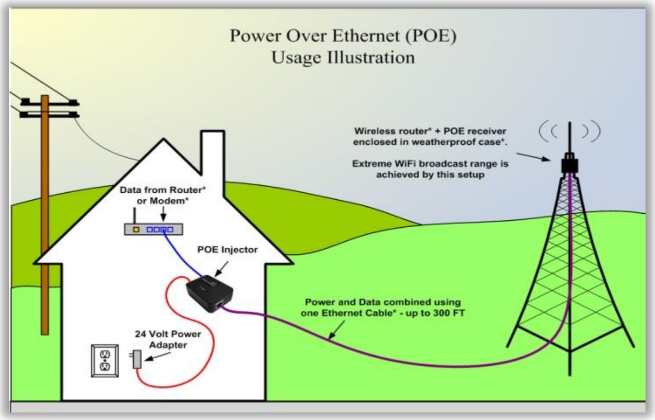

Fig 2. PoE device installed outdoors [8]

B. *Generic concepts of backup sources*

In general, the backup sources can be divided into two main groups:

- On-line UPS
- Off-line UPS

The block diagrams typical for each of the groups are depicted in Fig. 3 and Fig. 4.

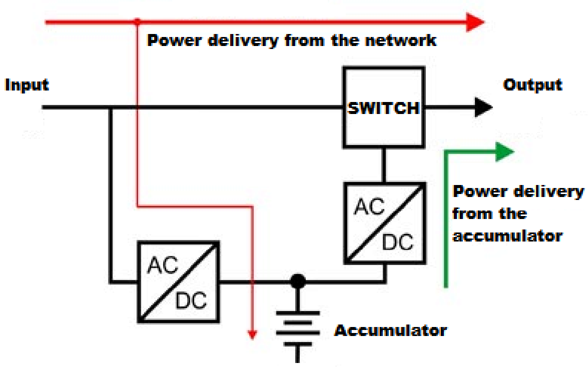

Fig. 3 Off-line UPS block diagram [2]

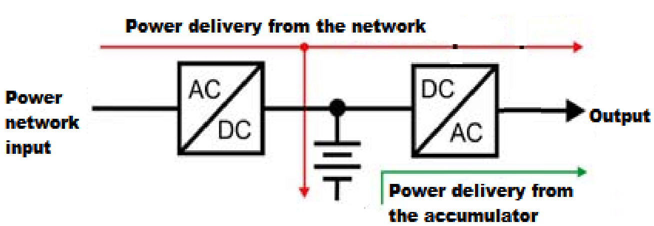

Fig. 4 On-line UPS block diagram [2]

The difference between off-line and on-line UPS is obvious from the above depicted figures. While the off-line UPS employs switch between the accumulator and the power network input, in case of on-line UPSs the accumulator is connected directly to the power branch. This solution brings considerable advantages as follows:

- No need for switching devices,
- No power dissipation at switching devices,
- Increased reliability due to lack of switching devices,
- Great voltage spikes reduction,
- Simple construction as the output voltage converter can usually be omitted.

On the other hand, the on-line solution brings several disadvantages that can considerably affect the battery life, resulting in decreasing of backup time or increased risk of battery malfunction after longer time of usage:

- The charging current of the battery is not controlled, especially at the beginning of the charging process.
- The battery suffers from current spikes that are caused by voltage scattering.
- Damaged battery may short-circuit the output of the power source.

Apart from off-line and on-line concepts, one can also meet a concept of line interactive UPS [2], which is supplemented by the possibility of communication with a controlling unit that is capable of driving the switches, remote testing of the state of the battery et cetera.

II. CONCEPT AND ITS DEVELOPMENT

In [6] the authors introduced a functional sample of an on-line backup source with a simple battery switch. By developing of the basis of the concept, major revisions of the construction were made, resulting in rather different concept based on the off-line structure.

A. *Starting idea*

The previous idea was to combine the advantages of the on-line construction with the advantages of at least partially isolated battery that would be recharged with a defined current. The main target was to find such configuration of the On-line UPS that would be simple to manufacture, effectively operating, reliable and friendly to the accumulator. The nominal output voltage of 24 V DC was considered with the fact that, if necessary, other voltages can be generated by means of an appropriate DC/DC converter.

Because in each of the powered network devices an individual DC/DC converter is implemented, there was no need for stabilizing the output voltage. Therefore the output stabilizer was omitted in order the efficiency of the supply source was as high as possible. According to the condition of the accumulator, the voltage in the power supply network and the load connected to the output of the power source, the output voltage could vary from 19.6 to 26.0 V considering the 5 % voltage drop at the transformer when it was fully loaded and the power supply voltage fluctuations as high as ± 12.5 %.

The charge current of the accumulator was limited to 0.5 A provided the nominal supply network voltage does not exceed the permitted tolerance of ± 10 %. When fully charged, the accumulator is being charged only with the maintaining current the level of which is limited to 5 mA. The current limits were adjustable according to the capacity of the utilized accumulator.

B. *Final concept*

Based on the experience gained with the functional sample of the construction introduced in [6], a complex revision was necessitated mainly due to the following requirements:

- Communication with an independent controlling unit,
- Improved power factor correction (switched mode power supply unit must be involved),
- Monitoring of the mains power delivery,
- Decrease of power dissipation,
- Independent operation in case of controlling unit failure,

Due to the above mentioned requirements, the design was divided into several sub blocks. Their design can be individually fine-tuned, including the components placement on the printed circuit board.

The block diagram of the revised electronic switch is depicted in Fig. 5. Except of the 230 V_{AC} to 24 V_{DC} switched mode voltage converter, all components are placed on a single printed circuit board.

For better description of the design, several standardized signals were defined as well as some of the wires were named. Some of them are connected to the interface with the controlling unit. In that case their voltages are adjusted to 3.3V TTL logic signals. Their description is provided in Table I.

Table I Controller interface signals

Abbreviation	Description
SMO	**Switch Mains Off** If a rectangular waveform with a frequency higher than 20 kHz is applied, the mains power supply is disconnected. This can be used to check the state of the battery by the controller. See text for more details.
MA1	**Mains Active 1** Gives information about the presence of mains voltage. It is in HIGH state when the mains voltage is present.
MA2	**Mains Active 2** Gives information about the operation of the AC/DC converter. It is in HIGH state when there is 24 V_{DC} present at the output of the converter. If MA1 = H and MA2 = L, the malfunction of the converter is indicated.
MA3	**Mains Active 3** Gives feedback on SMO signal. If MA2 is in HIGH state and SMO signal is present, MA3 must be in LOW state. This indicates that although the mains supply is active, the output of the switch is fed from the battery.

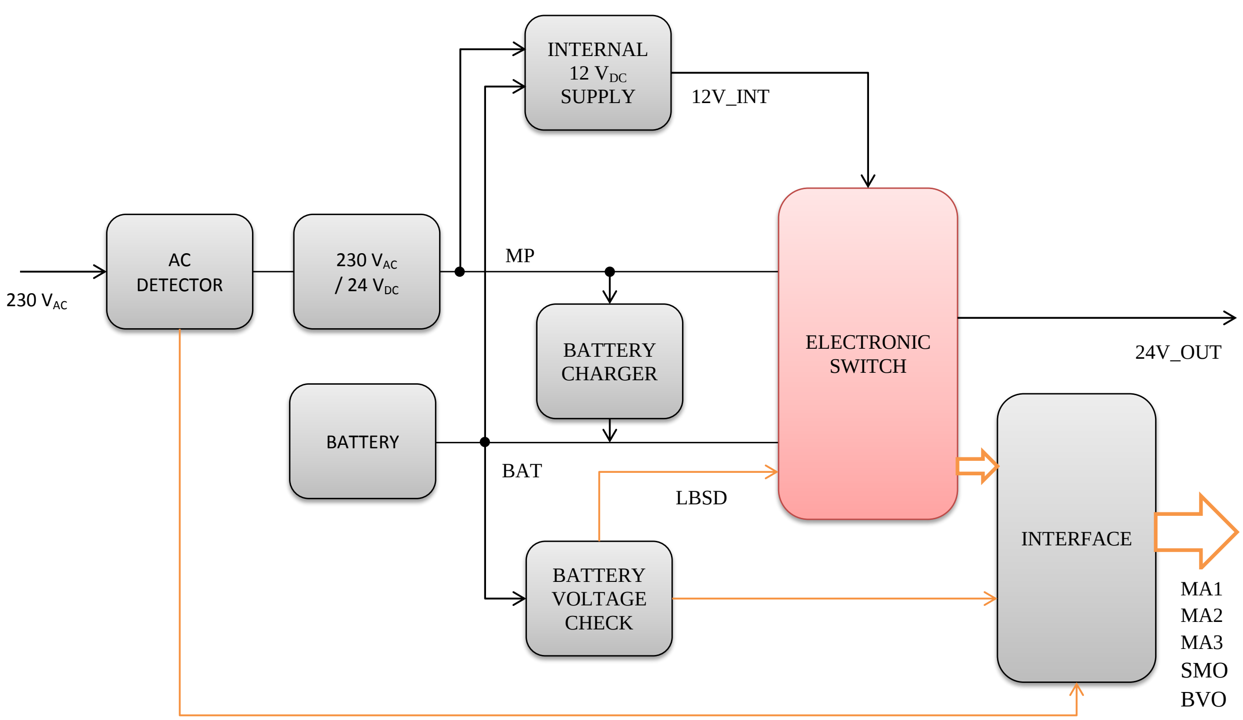

Fig.5 Electronic switch block diagram

BVO	**Battery Voltage** The voltage at this output is proportional to the voltage on the battery with a negative DC offset. The measurement range is from 21.5 V to 29 V, resulting in voltages from 0.54 to 2.8 V at this output.

The internal signals that are given names are described by Table II.

Table II Internal signals

Abbreviation	**Description**
V_REF	Reference voltage derived from the internal power supply, approximately 5 V.
12V_INT	Internal power supply stabilized to 12 V.
BAT	Positive pole of the battery (fuse protected).
MP	**Mains power** First node at the back end of the AC/DC converter
LBSD	**Low Battery Shut Down** If the output is fed from the battery and the battery goes too low, the LBSD signal is generated to switch off the whole system immediately. The operation of the system is restored once the mains power supply is active.
24V_OUT	Power output, max. 6 A

According to Fig. 1, the blocks of the electronic switch module are as follows. The mains power supply is monitored by AC detector. The only duty of the detector is to give the controller information on the presence of the AC power supply. Switching between the mains and the battery supply is operated at the hardware level, not using the AC detector. This solution increases the reliability of the system. The AC power supply is converted by the switched mode AC/DC power converter that incorporates power factor correction. This component has been bought from an external supplier. Once the AC power supply is present, at the output of the AC/DC converter there is a voltage of 24 V in the MP node. This voltage feeds the Internal power supply block that is necessary to power the internal electronics, mainly the operational amplifiers. It also feeds the battery charger that keeps the battery in the charged state. Most of the energy is deliverer to the power output through the electronic switch with low power dissipation. In case of AC power supply malfunction, the Internal power supply block is fed directly from the battery, the battery charger is out of order and the Electronic switch delivers the power from the battery to the output of the circuit. The state of the battery is monitored by the Battery voltage check module that can, in case of the deep discharge of the battery, generate the LBSD hibernating signal. If the AC power delivery is resumed sooner than the battery is discharged, the output is automatically switched to the AC power delivery and the battery is being recharged. In case the AC power deliver is out of order for a prolonged time and the battery is discharged, the whole system is switched off by the LBSD signal in order to protect the battery from its destruction by deep discharge. Once the AC power delivery is restored, the system is switched on, being fed from the AC power, and the battery is recharged again. The possible states of the circuit are indicated by the appropriate signals as described in Table III.

Table III Possible states of the system

Combination			**State**
MA1	MA2	MA3	
H	H	H	The AC power supply delivery is active, no errors detected.
H	H	L	The controller delivers the SMO signal in order to test the state of the battery by short time monitoring of its voltage drop. In this case the output is fed from the battery although the AC power is present. In case the SMO signal is not generated, this indicates malfunction of some of the electronic circuits.
H	L	L	This state indicates that the AC power supply delivery is present, but the output of the circuit is fed from the battery due to malfunction of the AC/DC converter. This is a state of emergency. The AC/DC converter must be replaced sooner than the battery is discharged.
L	L	L	The AC power supply delivery is not present and the output is fed from the battery.
L	H	H	A malfunction of the Electronic switch is indicated. This is a state of emergency. The whole module must be replaced until the battery runs low.
L	L	H	
L	H	L	

During all the possible states the voltage at the battery can be monitored by means of the BVO signal. The conversion table between the BVO voltage and the voltage of the battery is enlisted below.

Table IV Conversion table between BVO and battery voltage

BVO	**Battery voltage**
0.54 V	21.5 V (LBSD threshold)
1.0 V	23 V
1.45 V	24.5 V (nominal voltage)
1.9 V	26 V
2.37 V	27.5 V (fully charged)
2.8 V	29 V (overcharged)

As obvious from Table IV, the LBSD signal is generated when the battery voltage drops below approximately 21.5 V.

III. CONSTRUCTION OF THE BACKUP CIRCUITRY

The complex description on construction of all of the circuits cannot be provided in the framework of this paper. However a brief description on the circuits is provided below.

A. Electronic switch

The most important of the circuits is the Electronic switch. This circuit switches the power delivery from the AC/DC converter and the battery. The switching is done on the hardware basis, using a simple comparator. This increases the robustness and the reliability of the solution and enables the system to operate without any controller, if needed. The electronic switch also supports LBSD and SMO signals and generates the MA2 and MA3 signals. It involves one low-voltage quadruple operating amplifier with non-symmetrical power supply of 12 V. The schema of the Electronic switch circuitry is depicted at Fig. 2. The power terminals are as described in Table V.

Table V Power terminals of the Electronic switch

Terminal	Description
X1	24 V_{DC} input from the AC/DC power converter
X2	Battery (fuse protected)
X3	Power output

At the X1-1 terminal, there is the MP node. The voltage at this node is monitored by a comparator that involves IC1C operating amplifier. The threshold is set to approximately 20 V. The reference voltage of the comparator is defined by the voltage at V_REF node. The output of this comparator delivers MA2 signal, which is adjusted by resistors R21 and R30 to LVTTL levels. The power from the MP node can be switched on and off by means of Q1 low-drop MOSFET transistor. This transistor is controlled by IC1B operational amplifier and Q9 transistor respectively. Normally, the capacitor C2 is charged to the internal power supply voltage and the comparator involving IC1B is in H state (the reference is also taken from the V_REF node). The voltage at the gate of the Q1 transistor is low, keeping it in open state. The power is then delivered to the output via Q2 which is connected as a low-drop diode, involving also the transistors Q5, Q7 and the Zener diode D3. The voltage in the node between the transistors Q1 and Q2 is monitored by another operational amplifier, IC1A. This amplifier is connected in the same way as IC1C and generates the MA3 signal. When the output of IC1A is HIGH, the comparator with IC1D is driven no LOW state causing the transistor Q3 to be closed. If the voltage at the battery is lower than the voltage at the output of the electronic switch, the electronic diode with Q4 does not allow the current to be sung by the battery.

Once the SMO signal pulses occur, the capacitor C2 is discharged by transistor Q11. As the consequence, the comparator IC1B is driven to the LOW state and the transistor Q1 is closed. The power delivery from the node MP is switched off. At the same moment, IC1A is also driven to the LOW state which drives IC1D to the HIGH state. The transistor Q3 is now open and the energy is delivered from the battery by electronic diode with Q4. The electronic diode with the transistor Q2 blocks the voltage from turning the IC1A comparator the HIGH state.

When the power supply delivery from the AC mains is interrupted, the similar situation occurs. IC1C and IC1A go to the LOW state. As a consequence, the transistor Q3 is opened and the power is delivered from the battery. This action is preformed once the voltage at X1 clamps drop below approximately 20 V since it is guaranteed that the battery voltage is higher. Once the battery voltage is too low, LBSD signal is driven HIGH, which turns the comparator IC1D to the LOW state via the Q10 transistor. Now the transistor Q3 is closed. Because it is the only way to deliver energy to the circuit when the AC power is interrupted, the whole circuit is switched off as soon as the internal blocking capacitors are discharged. In this state it is necessary to resume the AC power delivery in order to wake up the switch. This mechanism prevents the battery from the risk of serious damage that can occur when the battery is deeply discharged.

B. Internal power supply

This block is necessary to deliver the power supply to all of the circuits of the system. The internal power supply is fed from both the MP and the BAT node. Because the supply delivery can be interrupted for a short period in which the switching from mains to battery and versa is processed, large blocking capacitor must be present at the front end of the circuit. The circuit is a simple step-down converter that involves conventional MC34063A driver. The output current is approximately 300 mA including two fans that can be optionally connected in case the cooling of the electronics mounted in a rack is not sufficient. The circuit diagram is depicted in Fig. 3.

The operational amplifier IC2A is a low voltage amplifier with non-symmetrical power supply that acts as a lowpass filter. It serves to derive the V_REF reference voltage from the reference voltage of the MC34063A driver. The V_REF voltage is approximately 5 V and its accuracy is not critical.

C. Battery charger

The battery charger is a conventional step-up converter with MC34063A driver. It delivers the stabilized output voltage of 28 V unless the output current is not higher than 0.65 A. If so, the current is limited in order to protect the battery. When the battery is discharged a lot, the charging current is limited. Once the battery is close to the fully charged state, the charging current lowers and when the voltage at the battery reaches 28 V, only the refreshing current is delivered to the battery. The output of the converter is protected by an electronic diode involving the transistor Q13. The circuit diagram is depicted in Fig. 4.

D. AC Detector

This circuit generates MA1 signal, when the power in the AC mains is present. Its connection diagram is depicted in Fig. 5. When the AC voltage is present, the LED in OK1 optocoupler flashes rhythmically, discharging the capacitor C17. This keeps the comparator involving the operating

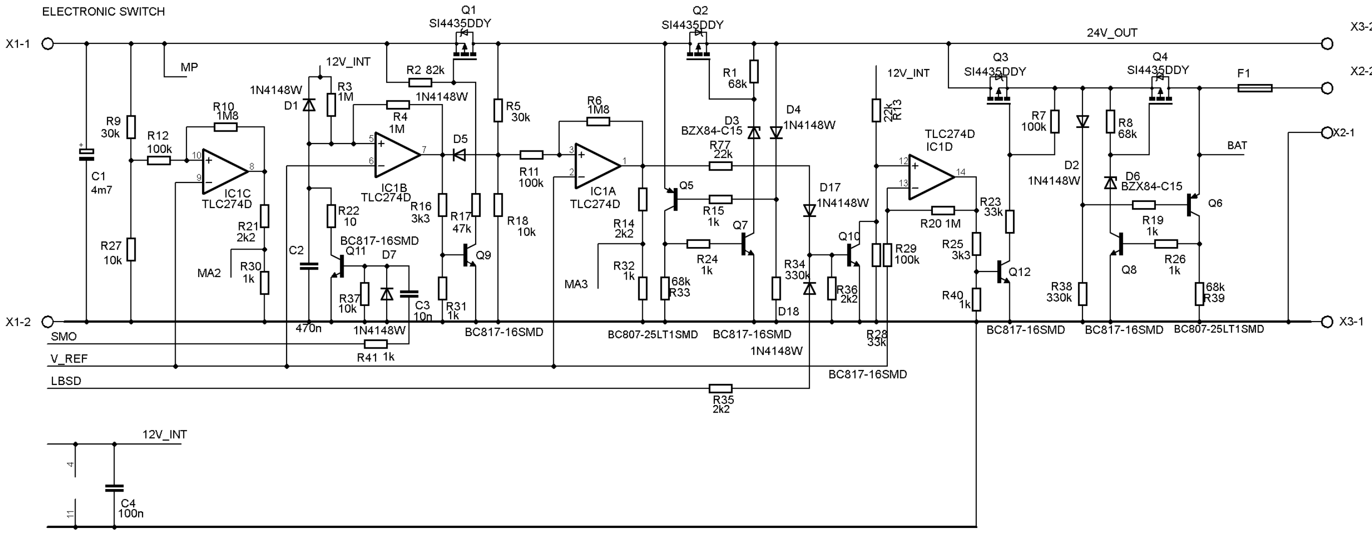

Fig. 6 Connection diagram of the Electronic switch

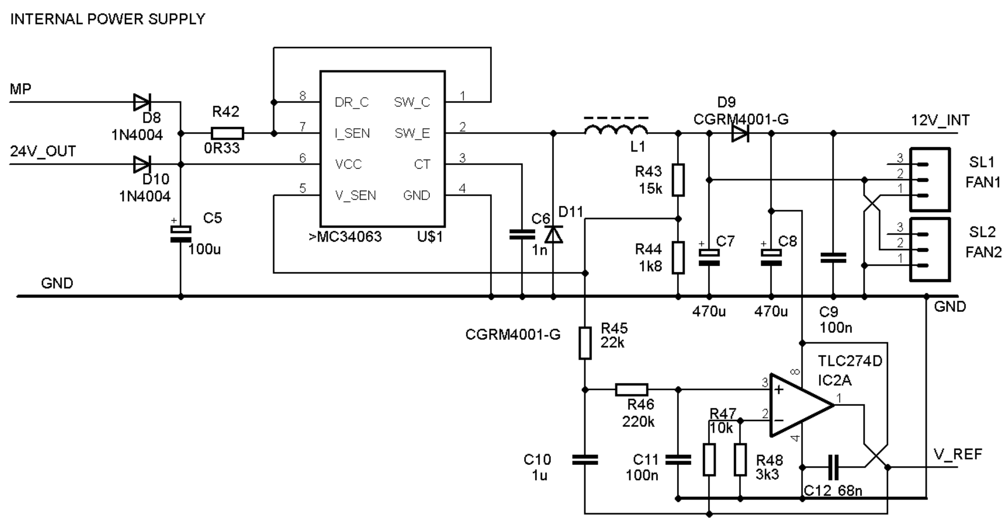

Fig. 7 Connection diagram of Internal power supply block

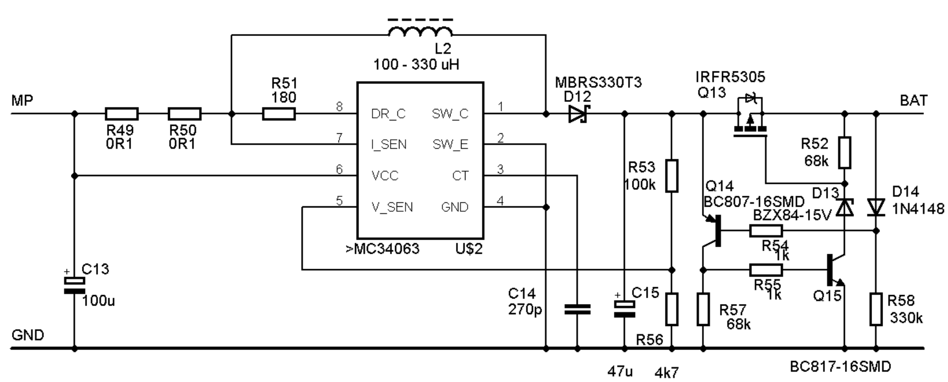

Fig. 8 Connection diagram of Battery charger

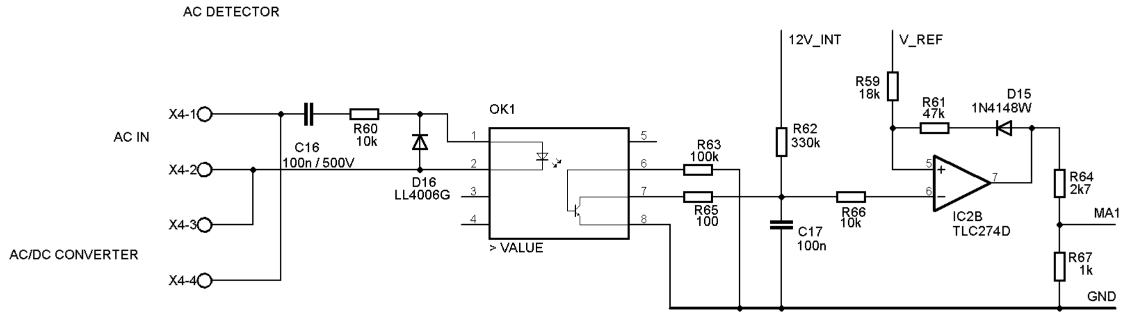

Fig. 9 Connection diagram of the AC detector circuit

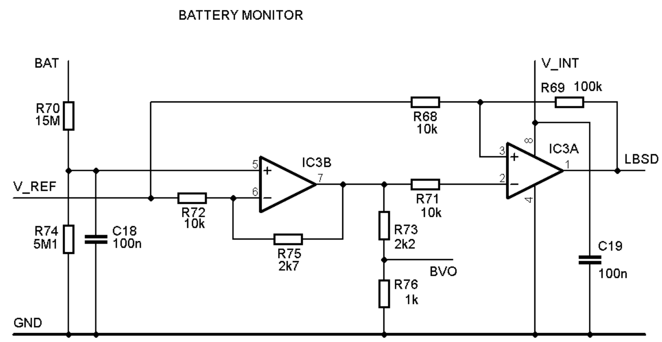

Fig. 10 Connection diagram of the Battery monitor

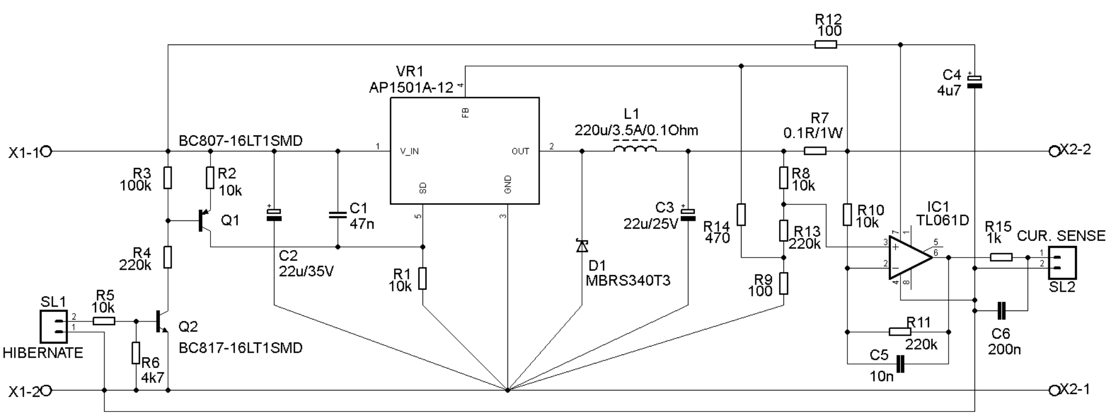

Fig. 11 Connection diagram of Step-down converter with AP1501A-12

amplifier IC2B in HIGH state. When more than 3 periods of the AC voltage are omitted, the capacitor C17 is charged and the IC2B goes to the LOW state.

E. Battery monitor

The battery monitoring circuit permanently measures the voltage of the battery and delivers the BVO signal, described by Table IV. The operating amplifier IC3A is connected as a comparator with a hysteresis of approximately 0.5 V. Once the voltage at the battery drops below the acceptable limit (approximately 21.5 V), the comparator goes to the HIGH state, generating LBSD signal.

IV. Voltage Converters

Although the switching circuitry is designed for operation with the voltage of 24 V, there are also 12V and 48V devices operating in Ethernet networks. Therefore at the back-end of the switching unit a set of voltage converters can be connected. In the framework of searching for the right concept with low production price, two types of step-down converters were constructed, using a simple MC34063 driver in one sample and more complex AP1501A-12 driver in the other sample. The performance of both step-down converters was compared. The most interesting experience is described in the text below, more information can be found in [9]. The step-up converter was constructed only as one sample based on MC34063 driver as the experience with this construction was satisfactory. All drivers are described in the text below.

A. Step-down converter with AP1501A

The step-down converter with AP1501A was considered to be a precise voltage converter from 24 V to 12 V with the output power of at least 25 W.

1) Construction

The circuit diagram of this step-down converter is depicted in Fig. 11. The circuit is supplied from the output of the backup unit by means of X1 clamps. Its operation can be externally hibernated by LVTTL voltage connected to SL1 connector.

The detailed description of AP1501A-12 can be found in [10]. The switching transistor is integrated on the chip. The manufacturer claims that the operating frequency of this integrated circuit is 150 ± 25 kHz and the minimum achievable output current is 2 A. The inductance of L1 inductor is calculated in that way so the circuit operated in a continuous mode with a minimum output current of 0.1 A and maximum input voltage of 28 V. With a series resistance of 0.1 Ω maximum, the expected power dissipation is lower than 0.4 W. The saturation voltage of the switching transistor is approximately 1.7 V, so a power dissipation of approximately 3.5 W can be expected at the output current of 2 A. The expected total efficiency is 80 % at the output current of 2 A.

The circuit is equipped with the output current monitor based on the operating amplifier IC1. The values of the devices are calculated so the conversion ratio was approximately 2.2 V/A and the cutoff frequency was as low as 100 Hz (only DC component is measured).

The output of the converter is at the clamp X2 and the output of the current monitor is connected to the SL2 connector.

2) Experience

The circuit was constructed and loaded at different input voltages. Its performance was evaluated by observing its output voltage and power efficiency, both dependent on the output power. The relevant graphs are depicted below.

It is obvious that the efficiency of the converter is approximately 80 % as was expected at the time of its designing, but the voltage regulation is quite poor. The output voltage depends on the input voltage and drops by up to 0.5 V when the circuit is loaded. This is caused by the presence of R7 resistor that is used to measure the output current of the converter. Its influence cannot be compensated by a negative feedback as the feedback is built directly inside the AP1501A integrated circuit.

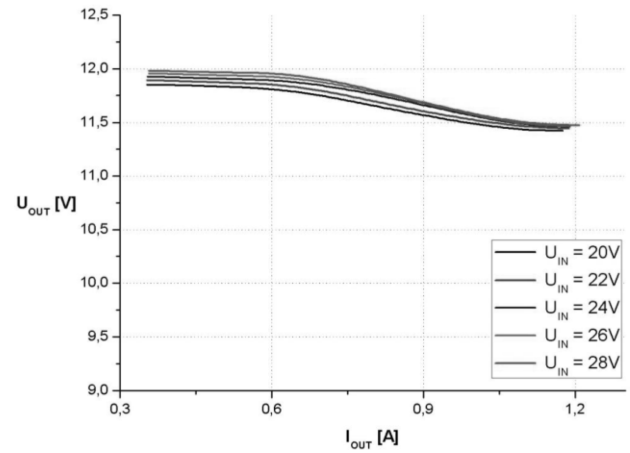

Fig. 12 Output voltage of the converter vs. output current

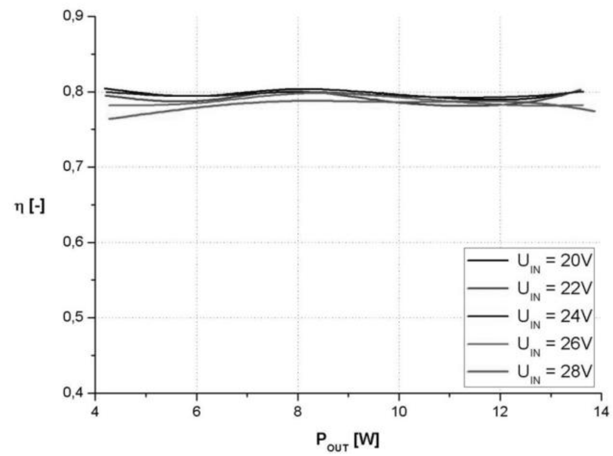

Fig. 13 Power efficiency of the converter vs. output power

B. Step-down converter with MC3406A

This step-down converter was considered to be a low cost alternative to the converter with AP1501. It also reduces the voltage of 24 V from the output of the switching unit to 12 V.

1) Construction

The circuit diagram is depicted in Fig. 14. The input of the circuit is at clamps X1. The input voltage can vary from 20 to 28 V. The input current is measured by resistor R1. Setting of the maximum input current affects the operation of the circuit including its operating frequency. The detailed information on operation of the circuit MC34063 can be found in [10].

The power switching transistor Q2 is mounted separately on a printed circuit board on a poured copper area that ensures its cooling. It is driven by means of Q1 transistor that is switched by the internal switch of the integrated circuit IC1. The inductor L1 is the same as was employed in the circuit with AP1501. The sample of the converter is not equipped with a circuit measuring the output current.

The operating frequency differs according to the input voltage and the current load of the converter. A typical operating frequency lies between 30 and 70 kHz.

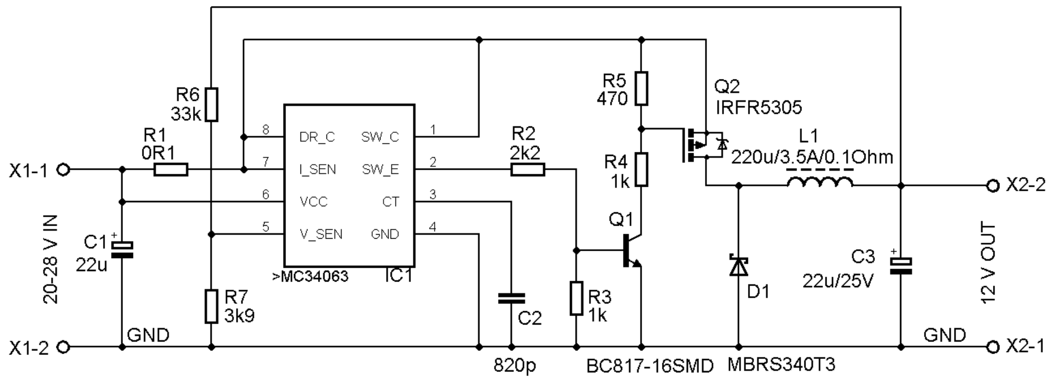

Fig. 14 Connection diagram of Step-down converter with MC34063

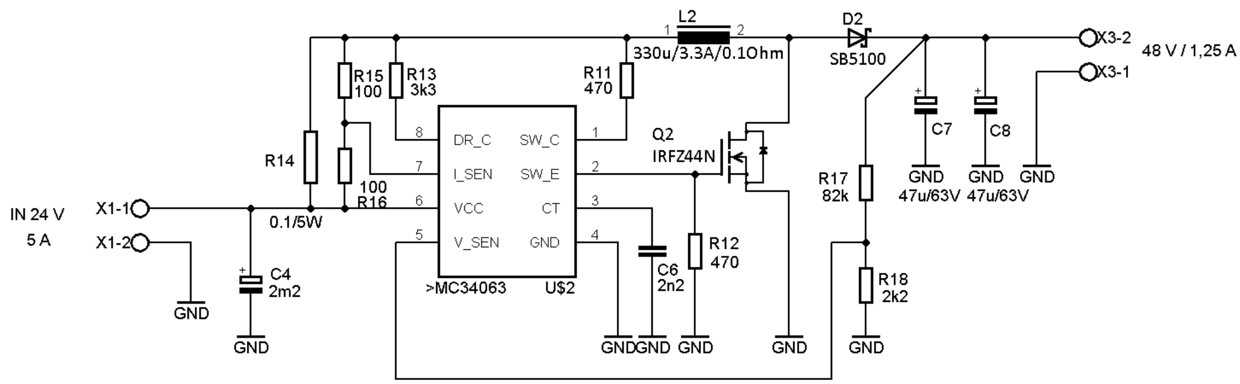

Fig. 15 Connection diagram of Step-up converter with MC34063

The main advantage of this construction is its low price and simple construction. On the other hand, the operating frequency of the circuit depends on its load and in some cases it can produce wide spectrum interference.

2) *Experience*

The circuit was constructed and loaded at different input voltages. Its performance was evaluated by observing its output voltage and power efficiency, both dependent on the output power. The relevant graphs are depicted below.

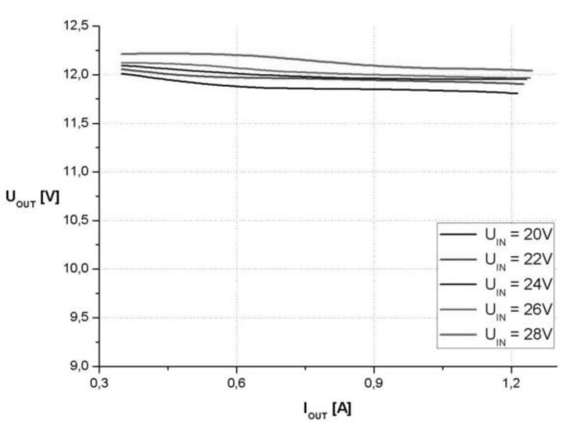

Fig. 16 Output voltage of the converter vs. output current

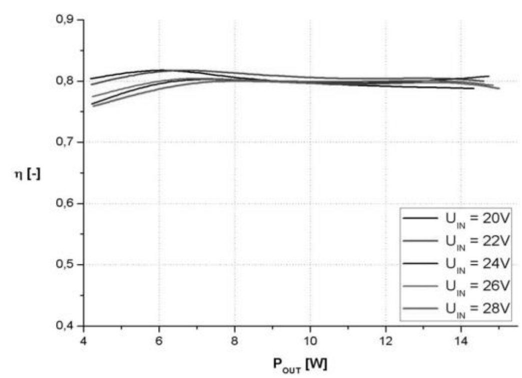

Fig. 17 Power efficiency of the converter vs. output power

The efficiency of this converter was also approximately 80 %. The output voltage depended less on the output current, but more on the input voltage. The voltage stabilization is slightly worse than in case of AP1501.

C. *Step-up converter*

The step-up converter increases the voltage at the output of the backup unit from 24 to 48 V. Its nominal output power is 60 W. It also incorporates the MC34063 driver equipped with an external transistor. Different transistors were tested in this construction in order to reach sufficient efficiency with low production costs.

1) Construction

The circuit diagram of the step-up converter is depicted in Fig. 15. The input terminal is at clamps X1. The input current is measured by means of the resistor R14 and the proper ratio is adjusted by the resistors R15 and R16.

The power transistor Q2 is mounted separately. Different transistors were tested in order to find out which is the most suitable for this application. The best results were obtained with MOSFET transistor IRFZ44N with a discharge resistor 470 Ω.

2) Experience

The circuit was constructed and tested with different types of Q2 transistor. As stated above, the best results were obtained with IRFZ44N. The performance graphs are depicted below.

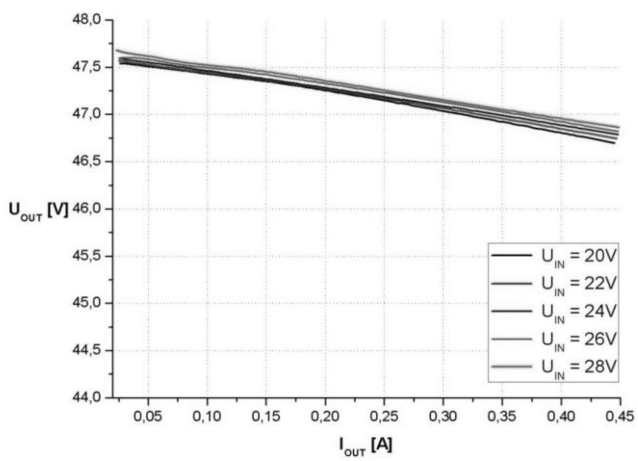

Fig. 18 Output voltage of the converter vs. output current

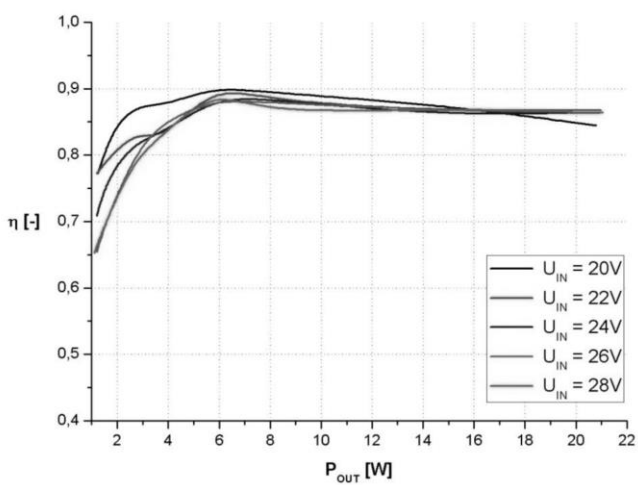

Fig. 19 Power efficiency of the converter vs. output power

As depicted in Fig. 19, the power efficiency of this converter is rather high, around 85 %. On the other hand, the output voltage decreases when the output current is being increased.

V. Current State

Most of the circuits described in this paper were tested as separated functional samples in order to fine-tune their operation. On the basis of the practical experience the final version of the advanced switching circuit has been sent to production.

The voltage converters were constructed separately and tested in the framework of a diploma thesis [11].

In figure 20 an example of a functional sample of the Electronic switch module with TO220 transistors is depicted.

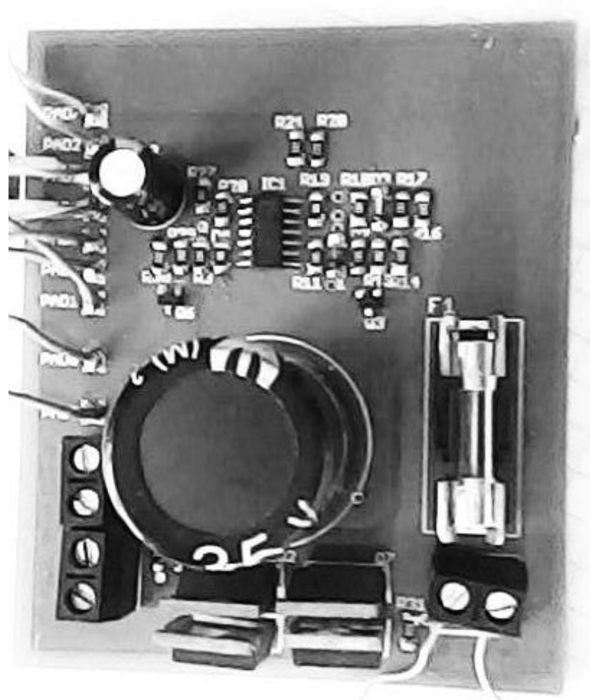

Fig. 20 Electronic switch functional sample

VI. Conclusion

This paper describes the design and construction of electronic switch that is a part of uninterruptable power supply system for devices that utilize the Power over Ethernet technology. With low power dissipation, this module switches between the AC mains and the battery power supply. It is also capable of recharging the battery and of communication with an external controller, when involved in more complex system. The controller can obtain information about the state of the circuits and the battery. As there is a need to check the battery performance at certain intervals, the module supports overriding of the automatic switching, so the output can be fed from the battery although the AC power delivery is present.

The hereby described module is suitable for all Power over Ethernet backup sources that operate with the 24 V_{DC} voltage provided the power consumption of the connected devices is not higher than approximately 150 W. Optionally, it can be equipped with voltage converters that deliver the power supply according to 12V and/or 48V standards as well.

Compared to conventional solutions, based usually on on-line backup sources [4], [2], this solution protects the battery from excessive voltage spikes, overcharging and deep discharging which results in its longer life.

The controlling board and the PoE panel with appropriate connectors are designed separately and built at separate printed circuit boards. This solution increases the modularity of the appliance.

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