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DEVELOPMENT OF POWER SUPPLY MANAGEMENT MODULE FOR RADIO SIGNAL REPEATERS OF AUTOMATIC METERING READING SYSTEM IN VARIABLE SOLAR DENSITY CONDITIONS

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In recent years, there has been significant research focus that revolves around harvesting and minimising energy consumption by wireless sensor network nodes. When a sensor node is depleted of energy, it becomes unresponsive and disconnected from the network that can significantly influence the performance of the whole network. The purpose of the present research is to create a power supply management module in order to provide stable operating voltage for autonomous operations of radio signal repeaters, sensors or gateways of WSN. The developed management module is composed of a solar panel, lithium battery and power supply management module. The novelty of the research is the management module, which ensures stable and uninterrupted operations of electronic equipment in various power supply modes in different situations, simultaneously ensuring energy protection and sustainability of the module components. The management module is able to provide power supply of 5 V for electronics scheme independently, without power interruption switching between power sources and power flows in different directions.

Keywords: *power supply, power supply management, smart meters, wireless sensor networks.*

1. INTRODUCTION

Energy usage is a very important concern in wireless sensor networks (WSNs) taking into account that sensor nodes and other WSN elements often operate on limited battery power. In recent years, there has been significant research focus that revolves around harvesting and minimising energy. When a sensor node is depleted of energy, it will die and disconnect from the network, which can significantly influence the performance of the application. Sensor network lifetime depends on the number of active nodes and connectivity of the network, so energy must be used efficiently in order to maximise the network lifetime. Therefore, research on energy management and sustainability is conducted in different directions.

Hence, power conservation and power management take on additional importance. It is for these reasons that researchers are currently focusing on the design of power-aware protocols and algorithms for sensor networks [1].

An example could be a solution applied to the project WSN for water distribution networks in Talsi, Latvia [2]. The sensors of the system have only two regimes: registration of impulses from water meters and transmission of telegrams several times per hour; therefore, synchronization is not used for network sensors. The power consumption of the sensors / transmitters is estimated for at least 10 years of operation time without battery replacement in case of operating regime, when messages are transmitted each 30 minutes. Such operation lifetime is achieved owing to 7500–8000 mAh battery and economical regime of transmitter [2].

According to research [3], energy harvesting involves nodes replenishing their energy from an energy source. Potential energy sources include solar cells [4], vibration, fuel cells, acoustic noise, and mobile supplier. In terms of harvesting energy from the environment [5], a solar cell is the current mature technique that harvests energy from light. There is also a study on the use of a mobile energy supplier such as a robot to replenish energy. The robots would be responsible for charging themselves with energy and then delivering energy to the nodes [3].

Harvesting energy from the environment is feasible in many applications to ameliorate the energy limitations in sensor networks. For example, in paper [4], an adaptive duty-cycling algorithm is presented that allows energy harvesting sensor nodes to autonomously adjust their duty cycle according to the energy availability in the environment. The algorithm has three objectives, namely, achieving energy neutral operation, i.e., energy consumption should not be more than the energy provided by the environment; maximising the system performance based on an application utility model subject to the above energy-neutrality constraint; and adapting to the dynamics of the energy source at run-time.

Another important thing is the ability to run from low power levels. Only smart electricity meters have the luxury to have a grid power source and, even in this case, consumption must be minimised as the power to run the devices comes from the utility and not from the customer. Gas and water meters, on the other hand, need to be able to run from a battery, and guarantee a lifetime of ten years or more. This puts severe constraints on the efficiency of the power converter as well as the remaining meter electronics [6].

Furthermore, new types of meters need to be able to support 32-bit microprocessors and larger memory sizes so that they can provide cryptographic features, as well as more fine-grained usage measurements and data updates via wireless communications [6]. If external electrical power fails, the meter needs to be able to send notifications to the utility, demanding the use of backup energy strategies.

Gas and water meters place stringent demands on efficiency and use ultra-low-energy sleep modes to improve battery lifetime. For such applications, for example, TPS65290 device [7] for power-management of integrated circuits that can operate over a wide range of system load conditions ranging from fractions of microamperes to a few hundred milliamps can be used. This is a typical device used as Low Power, Energy Harvesting Systems. The device operates over a wide 2.2 V to 5 V input-voltage range and incorporates a very-low quiescent current, always-on power supply, a 500 mA buck/boost converter, a 150 mA low dropout regulator, and eight power-distribution switches to provide a high degree of power control to meter electronics. One power switch can maintain the MCU in its sleep state, but cut power to analogue sensors while they are not being used.

The buck-boost converters can work in either PWM or pulse frequency modulation (PFM) modes, the latter being used for very light loads. The device can be configured to work in only PWM mode if output ripple is an issue.

There is also the risk that the battery in a gas or water meter may fail early. Therefore, a backup energy source is needed. Although one option is to use a rechargeable battery, this necessitates the use of a charging circuit to maintain the battery at peak charge for use only in comparatively rare situations. Furthermore, the key requirement is for an instantaneously available backup source that will work at the low temperatures needed for outdoor units. The meter can then immediately transmit status information to the remote hub that collects usage data and alerts.

An effective alternative to a battery is to use a double-layer capacitor or "supercapacitor". This is relatively straightforward to integrate into a circuit because it has the ability to store enough energy to maintain the basic functions of a smart meter temporarily without demanding complex switching logic [8]. However, the application of double-layer capacitors in WSN networks now is rather theoretical than practical.

The purpose of the research is to create a power supply management module in order to provide 5 V operating voltage for autonomous operations of radio signal repeaters, sensors or gateways of WSN. The power supply management module is composed of electronic circuits – signal repeater energy source – solar panel storage solution – battery and power management module.

At present, the world's existing solutions operate by the principle of the foundation, i.e. the scheme when the power is supplied from two sources: "core" and "reserves", and energy to the load is supplied through the unifying schema either from a basic source or from a reserve one. However, fully stable and autonomous power development is a complex process due to the proper selection of components, calibration, and so on.

Therefore, the novelty of the research is to design and test the management module, which ensures stable and uninterrupted operations of electronic equipment in various power supply modes in different situations, simultaneously ensuring energy protection and sustainability of the module components.

It is noted that the single power source unit is solar panels; electric storage type is a lithium battery or equivalent. It is a minimised solution of self-discharge under normal operating conditions, and it allows minimising degradation of all elements over time. It is possible to provide uninterrupted power supply of 5 V for electronics scheme independently, without power interruption switching between power sources and power flows in different directions.

2. POWER SUPPLY MANAGEMENT MODULE DEVELOPMENT

The research was conducted within the framework of the project "Photovoltaic Module Energy Storage and Management Studies Autonomous Electronics – Repeater Development" in 2014–15.

The task of the developed photovoltaic power system is to ensure a sufficient working cycle for collecting metering data from a distributed sensor nodes by receiving or repeating sensor-metering telegrams. These telegrams contain temperature, pressure, moisture, electricity and water usage information. The examples of the wireless network sensors tested for the photovoltaic power system within the framework of the project can be seen in Fig. 1.

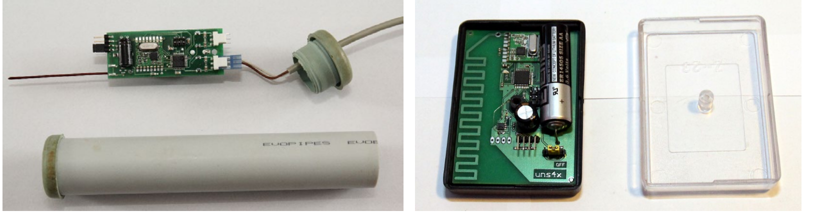

Fig. 1. Water flow (on the left) and moisture (on the right) wireless sensor devices.

To increase the efficiency of a solar panel, Maximum Power Point Tracking (MPPT) is applied. The purpose is to maximise the power output of a selected photovoltaic module by varying the current to the load and battery charging.

The proposed solution consists of two types of solar battery charging circuits suitable for solar power applications in smart metering applications that is able to provide uninterrupted power supply of 5 V for electronics scheme independently, without power interruption switching between power sources and power flows in different directions.

The research was conducted in two stages: the first prototype was developed and tested, then after improvement and additional function adding the second prototyped was created.

A. The First Prototype Development

The purpose of the first prototype is to charge the battery attached to a power sensor, repeater or gateway devices. During dark hours, the stored energy of the battery is used to extend the uptime of the connected equipment. Up to four independent solar cell modules can be connected to the module.

The choice of the solar panel is critical and has to be calculated for the work-operating mode of the connected equipment. The work-operating mode of the connected equipment has to adapt to the charge level of the selected battery and work cycles controlled in combination with microcontroller sleep times.

The module consists of:

- Several uniting diodes for multiple concurrent solar panel connections;
- Step down impulse converter;
- Lithium battery charging controller;
- Battery wrong connection protection (polyfuse);
- Circuit for uninterrupted switchover from the solar panel power to the battery and vice versa.

Uniting diodes

- Make it possible to increase power by connecting additional panels;
- Make it possible to simultaneously use multiple panels toward the sun oriented in different directions.

Step-down impulse converter

LM22675 controller [9] with operating frequency of 500 kHz allows the inductor to reduce the cumulative nominal and dimensions. It operates in pulse mode with the internal circuit-breakers transistor up to 1.8 A per pulse. Resistors R1 and R2 form a divider to compare the output voltage with the reference voltage of 1.28 V. When a voltage is higher than the reference voltage, the regulator reduces the internal power MOSFET transistor open interval, but when a voltage is smaller, it increases the interval. In an open state, the current is accumulated in inductor L1, but in a closed state, the inductor energy is transferred through the diode to capacitor C5. The filter capacitors C6 and C7 are for operational stability. The selected output voltage of 5 V is adapted for the electronic equipment in the particular application.

Lithium battery charging controller

Universal lithium battery charger controller with a fully charged battery nominal voltage of 4.23V. The controller provides the programmed charging current until the nominal voltage current is reached – after that the charging is switched off with a corresponding reduction in current. Charging current is assigned with resistor R3 in correspondence with the measurement of selected solar panel.

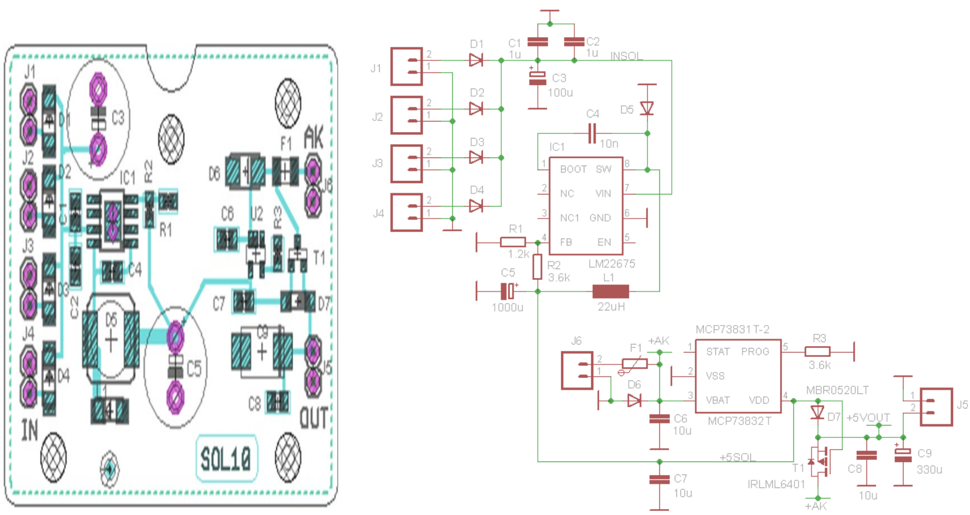

Fig. 2. Electrical and montage schemes of photovoltaic power system module, the 1st prototype.

Battery wrong connection protection

Polyfuse F1 and diode D6 protect the board and the battery in case of incorrect polarity mismatch. The board returns to a normal work mode after the battery is connected correctly.

Circuit for uninterrupted switchover from solar panel power to a battery and vice versa

The scheme consists of diode D7 and transistor T1. Scheme could be built with two diodes, but to reduce the voltage loss during switching on the battery-feeding mode, a MOSFET transistor with a very low resistance in the open state is used. Transistor resistance constitutes just small portion of Ohm – up to 0.05 Ω at high currents. The drop on the diode should be around 0.5 V.

B. The Second Prototype Development and Improvements

The second prototype ensures the charging of a battery and provision of power to the connected equipment by optimising the solar panel maximum possible power rate at variable lightning conditions (see Fig. 3).

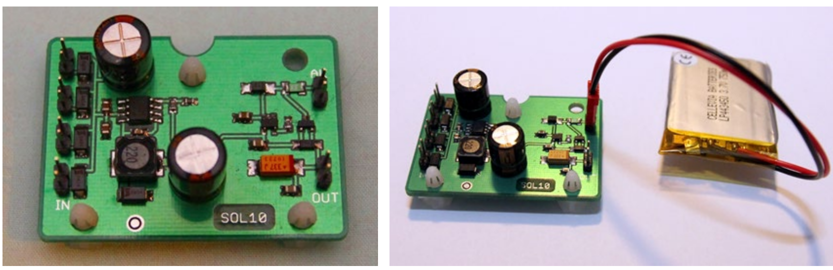

Fig. 3. The appearance of photovoltaic power system module, the 2nd prototype.

The varying maximum solar panel voltages and supplied maximum power are used to ensure maximized usage time of the connected application.

The board consists of such components (see Figs. 4 and 5):

- Uniting diodes to connect multiple solar panels at the same time;
- Step-down impulse converter;
- Lithium battery charging circuit (exchangeable with alternate if the battery type varies);
- Battery wrong connection protection (polyfuse);
- Circuit for uninterrupted switchover from solar panel power to the battery and vice versa;
- Digital potentiometer and ADC;
- Load disconnection circuit;
- Microcontroller;
- Microcontroller software – control algorithm.

Improved photovoltaic power system enables the battery charging current control and adjusts optimal working point of solar cells (MPPT); therefore, the used power is the maximum provided by the solar panels.

In order to save place the authors do not describe such components of the power supply management module as *uniting diodes, step-down impulse converter, lithium battery charging controller, battery wrong connection protection, circuit for uninterrupted switchover from solar panel power to battery and vice versa*. These components have been described in Section A "The First Prototype Development".

Therefore, only the description of additional components is provided further.

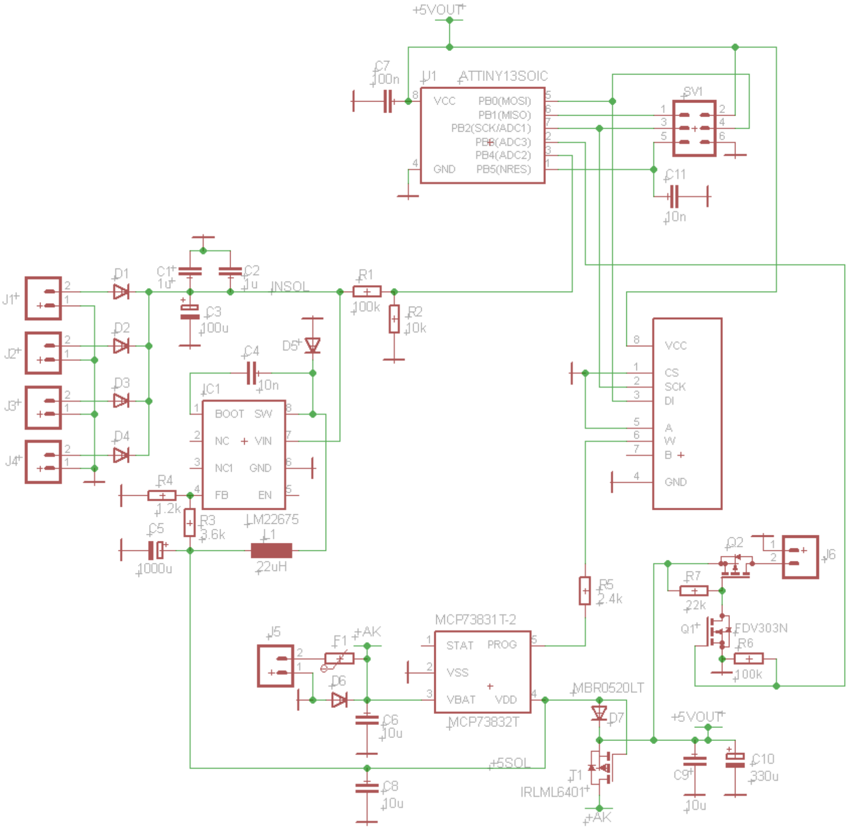

Fig. 4. Electrical schemes of photovoltaic power system module, the 2nd prototype.

Digital potentiometer

The digital potentiometer together with resistor R5 enables the controllers to change the battery charging current and adjusts their optimal working point of solar cells (MPPT) – the used power is the maximum provided by the solar panels. If the digital potentiometer mode is zero, then only the resistor R5 limits the maximum charging current. When the potentiometer is switched on, the charging current decreases. The microcontroller ATTINY13A controls the potentiometer. An essential element of the module is the ADC that is implemented on ATTINY13A pin ADC2. Resistor divider aligns the input voltage from the solar panels to the ADC reference voltage and enables the management software to read the maximum power point and adjust the charging current.

Load disconnection circuit

When it is necessary to shut off the load from the battery, in case of deep discharge or other reasons, the transistors Q1 and Q2 operate and disconnect the load using the signal line from the microcontroller. In other cases, the transistor Q2 is permanently open and connects the load to the power source.

Microcontroller

The task of microcontroller implemented on ATTINY13A is to combine the solar panel voltage measurements with ADC, to drive the digital potentiometer by ensuring the optimal charging current selection and to control the load disconnection and connection. The interface of the digital potentiometer is SPI where the pin number 8 of the microcontroller is used.

Microcontroller software – control algorithm

The control software is modular: ADC, digital potentiometer driver, disconnection module and logical machine algorithm. ADC measured input voltage of the solar panel for the selected panel is in the range up to 20 V. The divisor reduces the voltage to a reference voltage and the software finds the current voltage value. This voltage is the starting point for the determination of the optimal power point for the selected solar panel. This point must be observed by monitoring the nominal voltage drops and adapting the charging current. If the voltage does not decrease, the charging current can be the maximum provided by the solar panel. Connected equipment should be designed to be able to cope with power supply disconnection in cases when a battery approaching to discharge or the light intensity becomes too weak.

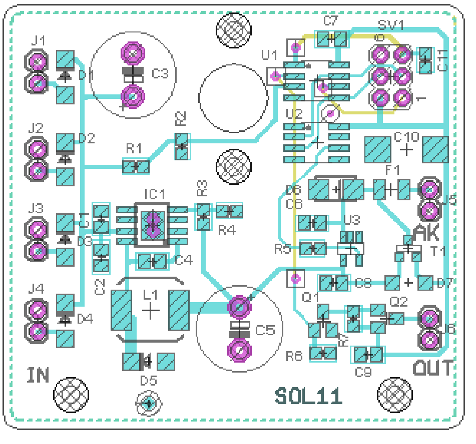

Fig. 5. Montage schemes of photovoltaic power system module, the 2nd prototype.

3. CONCLUSIONS

The aim of the present research has been to create the power supply management module in order to provide stable operating voltage for autonomous operations of radio signal repeaters, sensors or gateways of WSN. The research has been conducted in two stages: the first prototype has been developed and tested, then after improvement and additional function adding, the second prototype has been developed. The second prototype ensures the charging of a battery and provides power to the connected equipment by optimising the solar panel maximum possible power rate under variable lightning conditions.

The developed management module is composed of solar panel storage solution, lithium battery or equivalent and power management module. The novelty of the research is the management module, which ensures stable and uninterrupted operations of electronic equipment in various power supply modes in different situations, simultaneously ensuring energy protection and sustainability of the module components. The management model can provide uninterrupted power supply of 5 V for electronics scheme independently, without power interruption switching between power sources and power flows in different directions.

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ELEKTROAPGĀDES VADĪBAS MODUĻA IZSTRĀDE RADIO SIGNĀLU RETRANSLATORIEM, KAS DARBOJAS AUTOMATIZĒTĀ MĒRĪŠANAS NOLASĪŠANAS SISTĒMĀ MAINĪGOS SAULES RADIĀCIJAS APSTĀKĻOS

K. Kondratjevs, A.Zabašta, V. Šelmanovs-Plešs.

Kopsavilkums

Pēdējos gados vairāki pētījumi ir veltīti problēmām, kas ir saistītas ar enerģijas patēriņa mazināšanu un efektīvu izmantošanu bezvadu sensoru tīklu mezglos. Kad sensors mezgls ir izsmēlis enerģijas krājumu, tas vairs nefunkcionē un atslēdzas no kopēja tīkla, kas var būtiski ietekmēt visa tīkla veiktspēju.

Šī pētījuma mērķis ir izveidot barošanas vadības moduli, lai nodrošinātu stabilu elektroapgādes spriegumu autonomi strādājošiem radio signāla atkārtotājiem, sensoriem vai vārtejām, kas darbojas bezvadu sensoru tīklos. Izstrādātais vadības modulis sastāv no saules paneļu fotoelementu moduļa, uzglabāšanas risinājuma (litija vai līdzvērtīgas baterijas) un elektroapgādes pārvaldības moduļa.

Pētījuma novitāte ir elektroapgādes pārvaldības modulis, kas nodrošina stabilu un nepārtrauktu elektroniskas iekārtas darbību dažādos barošanas režīmos, dažādās situācijās, vienlaikus nodrošinot enerģijas aizsardzību un moduļa sastāvdaļu ilgtspēju. Izstrādātais risinājums nodrošina nepārtrauktu 5V barošanu elektronikas shēmām bez strāvas pārtraukuma, kad notiek komutācijas starp barošanas avotiem un enerģijas plūsmām dažādos virzienos. Elektroapgādes pārvaldības modulis nodrošina stabilu spriegumu mainīgos saules radiācijas apstākļos.

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