Loss of Load Probability in Wireless Sensor Networks using Solar Cells

Mare Srbinovska, Zivko Kokolanski, Cvetan Gavrovski and Vladimir Dimcev

Abstract – **In design and development of Wireless Sensor Networks (WSNs), one of the main challenges is to achieve long lasting battery lifetime. In this paper it is proposed model to estimate the reliability of the photovoltaic system in WSN. Modeling of the Loss of Load Probability (LOLP) parameter defines the system performance per month.**

Keywords – **Reliability, Photovoltaic system, Loss of Load Probability**

I. Introduction

Wireless sensor networks (WSNs) consist of hundreds or thousands of sensor nodes spread in an environment in order to monitor the specific physical phenomena. These networks have several advantages including easy installation, small size and low power consumption. In recent years, agriculture faces many challenges, so precision agriculture monitoring and remote controlling is rapidly growing [1].

Sensor nodes are small devices that include three basic components: a sensing system for data acquisition from the physical environment, a processing unit for data processing and storage and wireless communication component for measurement data transmission. In recent research, the focus is especially based on low power feature of the sensor nodes because the power consumption is always a challenge for wireless nodes, supplied with batteries [2-4].

So, the main problem in wireless sensor technologies are the constrained energy resources (e. g. Battery, processing capacity), and they should work as long as possible in the environment while collecting and sending data to the central station.

The development of crop production procedures would increase energy efficiency in agriculture and enable sustainable development [2],[3]. Furthermore, the use of renewable technologies on farms is considered as essential, but not single factor to influence modern and energy efficient agriculture [4]. In fact, cleaner production procedures and renewable energy technologies along with reliable real time monitoring systems based on WSNs would contribute in creating the adequate conditions for development of sustainable agriculture [5], [6].

We developed a system for monitoring of crop production which would be tailored to the needs of farmers and therefore, should be easy to build, use, maintain and upgrade, built of low-cost, low powered components and resilient to loss of data.

One of the main advantages of WSNs is their independence of pre-established infrastructure. In most common scenarios, recharging or replacing nodes batteries is not practical due to inaccessibility or huge number of sensor nodes. In order for sensor networks to become a ubiquitous part of the greenhouse environment alternative power sources should be employed. So, if nodes are equipped with energy transducers like, solar cells, the generated energy may increase the autonomy of the sensor nodes significantly.

Techniques to harvest energy via photovoltaic (PV) cells have attracted the interest of the sensor network community [7-9]. Solar energy is certainly one of the most promising energy sources and typical environmental monitoring applications have access to solar energy. Due to the progress in low power design, the energy generated by small solar panels suffices to execute most common data gathering applications. Equipped with photovoltaic cells, perpetual operation becomes possible without frequent recharging and replacement of the batteries.

The demand for the corresponding software control can be seen as one disadvantage compared to the battery operated systems. Also, concerning the hardware the solar panel has to be integrated into the system.

One more additional problem with the solar cells is using them during the night or when the solar radiation is very low (foggy or cloudy days). Thus, a means of storing energy is necessary. The stored energy is used to bridge the gap during the time when the ambient energy supply fades away. There are various means of storing electrical energy: capacitors, primary (non-rechargeable) and secondary (rechargeable) batteries, supercapacitors, etc.

II. Methods for Modeling the PV System

To estimate the solar radiation it can be used statistical method or astronomical method. With a statistical method it is estimating the solar radiation for a given period using the history of solar radiation. With the astronomical model it is estimating the solar radiation using the parameters that affect the angle between the sunlight and the solar panel.

In order to get the statistics, we can use meteorological database, which estimate the solar radiation as the monthly solar radiation Using E_m, we can calculate the peak solar hours (PSH), which is the equivalent solar radiation hours per day assuming that the same amount of solar energy is given at an intensity of $1kW/m^2$. Then, the available energy from a specific solar panel for one day, E_{sol}, can be estimated as the product of PSH and the solar panel output power P_{sol} at $1kW/m^2$ (usually provided by its manufacturer):

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$$E_{sol} = PSH \cdot P_{sol} = \frac{E_m \cdot P_{sol}}{1kW / m^2 \cdot \# days} \quad (1)$$

According to the metrology weather data base for the incident solar radiation in Skopje, Macedonia (latitude φ = 42,005°N, ψ = 21,41°E), one of the lowest values for the solar radiation is taken for December. This data is an average taken over almost 20 years and represent the best data we were able to find. For the experiment we chose minimum value for the month of December (2.10 kWh/m^2/day). This value represent the amount of energy (measured in kWh) accumulated over 1 square meter in a twenty four hour period.

III. Model of the PV System

To estimate the reliability of the photovoltaic system it is used NSol model. It is a computer assisted design tool that is used in the design and analysis of battery based photovoltaic (PV) power systems. There are three major tasks when designing a PV system using NSol:

- Entering the data;
- Optimizing the array tilt;
- Sizing the system and estimating performance

NSol [10,11] uses a proprietary Loss of Load Probability (LOLP) algorithm. Based on the concept of "Markov Transition Matrices" this algorithm calculates the statistical performance of the solar insolation resource, then applies this to the battery based PV system. The result is Loss of Load Probability, which gives a concise estimate of a system reliability.

To design the photovoltaic system, three solar cells of amorphous silicon with dimensions 3 cm x 3 cm are used with the following characteristics:

$$A' = 0,0009\, m^2 \quad (2)$$

Where A' is the effective area of the photovoltaic cell

$$\eta_{pv} = 7,2\,\% \quad (3)$$

η_{pv} is the photovoltaic efficiency refers to the PV cell's ability to convert light energy to current. For the purpose of this analysis, we will assume 7,2 % efficiency of the PV cells.

$$P'_{pv} = A' \cdot G_{sc} \cdot \eta_{pv} = 0,065\, W \quad (4)$$

P'_{pv} is the power generation for one PV module.

$$P_{pv} = 3 \cdot P'_{pv} \quad (5)$$

Multiplied by three, we calculate the power generation for the three modules (equation 5).

$$W = 0,26\, Wh / day \quad (6)$$

To design the PV system we need to multiply the calculated values for the power generation in order to size the PV system using the NSol tool. For the equivalent power generation per day.

$$\overline{P}^e = 7,2\, W \quad (7)$$

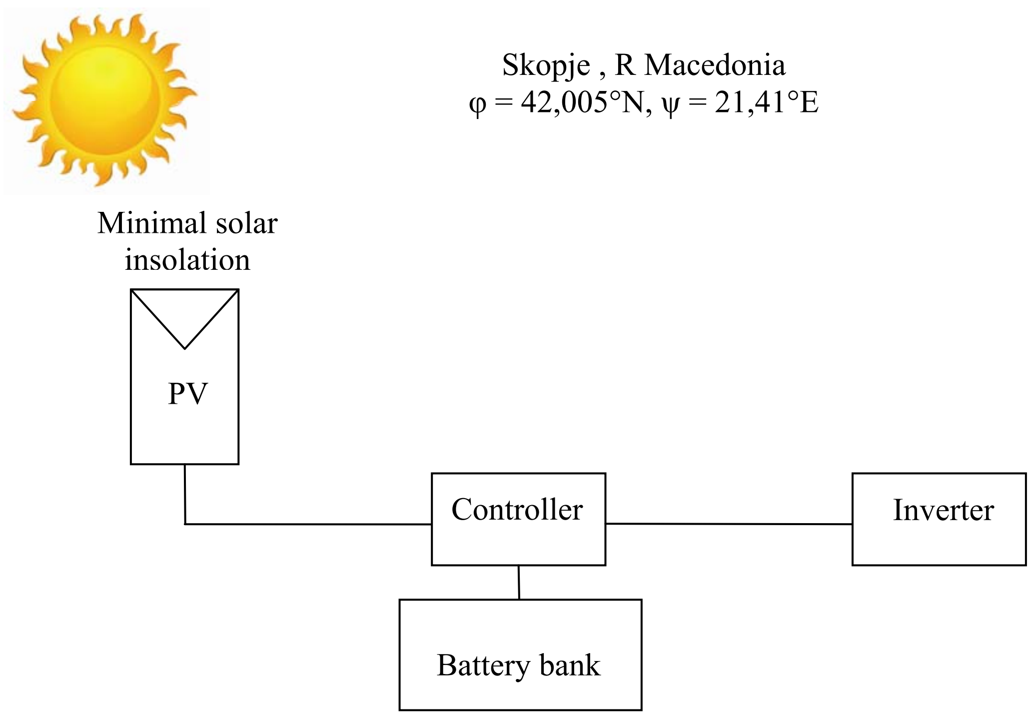

Fig. 1. Model of the PV system

In figure 1 is given the model of the PV system. The model consists of three components: PV, Controller, Inverter and Battery bank. Every component should be properly dimensioned in order to design the system. For example in inverter tab should be defined the VAC operating voltage of the inverter, VDC to DC voltage of battery based inverter, the efficiency and cost of the inverter etc. Battery bank tab defines the model and type of the manufacturer. The controller tab defines the operating voltage of the controller, maximum battery charge amps of controller, while PV tab defines how many PV cells are used in series.

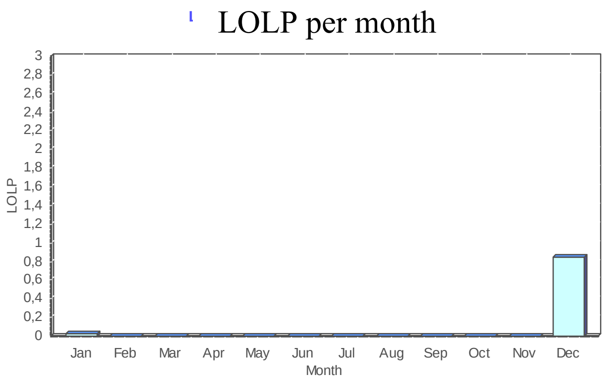

Fig. 2. LOLP per month

On the figure 2 it is presented the Loss of Load Probability factor per months for the designed PV system. According to the calculations the system is very reliable for almost every month. The lowest value for LOLP is calculated for December. LOLP=0,8%, while for January is 0,03%.

TABLE 1. PERFORMANCE PV SYSTEM VALUES FOR SKOPJE

Months	Solar insolation (kWh/m^2/ day)	Battery size (days)	ALR
January	2,32	10,6	1,19
February	3,05	10,7	1,56
March	3,86	10,9	1,97
April	4,43	11,2	2,27
May	4,59	11,4	2,34
June	4,86	11,6	2,49
July	5,08	11,6	2,60
August	5,16	11,6	2,64
September	4,90	11,5	2,50
October	3,91	11,2	2,00
November	2,68	11,0	1,37
December	2,10	10,7	1,07

The Loss of Load Probability (LOLP) is a statistical calculation on whether the array and battery combined can support the load.

A low LOLP (0.3 or lower) indicates that the system is very reliable. An LOLP of 0.3 indicated that the system will lose the load on an average of 0.3 days per month. If the month has 30 days, this is a load disconnect event once every three years.

In the table I are given the parameters that define the performance of the PV system. In the first column it is presented the solar insolation values per month. The lowest value is for December as the worst case. The other parameter is the battery size per days, which defines how long can the system work reliably without loss of load.

The other primary output beside the Loss of Load probability is the Array to Load ratio (ALR). The ALR is simply the energy balance between the average insolation and the average load for the design month. A good system will operate best with an ALR of at least 1,1. The critical value for this parameter is again for December.

Fig. 3. System performance - ALR per months

In figure 3 it is given the graphical representation of the system performance for the Array to Load ratio (ALR) per months. The highest values are for the summer months, while the lowest values are for January and December.

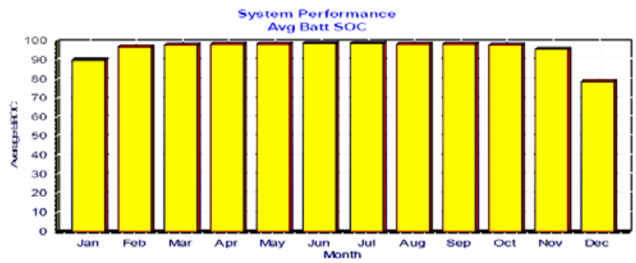

Fig. 4. System performance - BSOC per month

The state of charging of the accumulated battery (Battery State of Charge – BSOC) has typical starting value of 40% SOC, and stop value of 85-95% SOC. Each cycle replaces 45-55% from the capacity of the accumulated battery.

The graphical representation of the BSOC per months is shown on figure 4. This parameter actually defines the efficiency of the system.

The best value is obtained for August, while the worst value is obtained for December.

IV. Measurement of Solar Cells Voltage Drop

The solar cells can work during the day and use the accumulated energy during the night. In this experiment the sensor nodes transmit the measurement data twice in one hour and goes to sleep mode to save energy. During of one month measurement, the solar cells voltage drop is shown in fig.5.

As it can be seen from the figure the maximum value of the solar energy voltage is 4.1 V, which is reached during the day when the sun is mostly intensive, while the lowest value is dropping to 2.5 V.

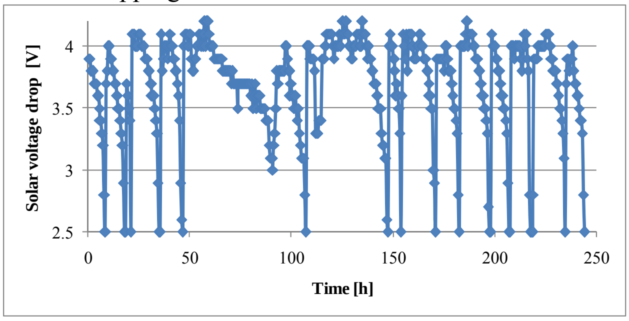

Fig. 5. Solar cells voltage drop taken in August in Skopje, R. Macedonia

This is still operating value for the sensor nodes. The measurements were made in August, 2014 (the best case) and on the figure are presented the measurement results for one week of measurement. It can be seen that the curve is continual without any interruptions during the data transmission. This is because the solar energy is enough to power the nodes the whole time.

V. Conclusion

Energy consumption is one of the most constraining requirements for design and implementation of wireless sensor nodes. Analysis of power consumption and reliability of the measurement system are the crucial factors for the design and development process of the sensor networks.

In this paper, a model for estimation of the reliability of the photovoltaic system is presented. Loss of load probability is a statistical calculation parameter that represents the reliability of the system. The low LOLP (0.3 or lower) parameter indicates that the system is very reliable. The best cases are obtained for the sunny months (July and August), while the worst case is obtained for December and January.

The solar cells voltage drop for one month measurement is presented. The system works continually without any interruption during the transmission of data.

Different design, deployment and functional aspects of a reliable WSN are analyzed in this paper. A wireless sensor node reliability model considering the battery voltage level is evaluated.

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