Energy Efficiency Analysis Using Optical Switch and Splitters for Smart Sensors Charging

Jovan Shikoski[1], Juli Zlatev[2], Tinko Eftimov[3], Georgi Stanchev[4]
[1]Faculty of Telecommunications at Technical University of Sofia
8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria
[2]Faculty of Telecommunications at Technical University of Sofia
8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria
[3]University of Telecommunications and Post1 Stefan Mladenov sreet
Sofia 1700, Bulgaria
[4]Faculty of Mechanical Engineering at Technical University of Sofia
8 Kl. Ohridski Blvd, Sofia 1000

ABSTRACT: *Optical switch and splitters are used form smart sensors charging. There are many methods out of which we have reviewed two system of photon energy charge. While reviewing we have also performed energy efficiency analysis and compared it with similar methods. We have documented that the system with optical splitter is technically easier for construction and maintenance and also lesser than other systems.*

Keywords: Smart sensor, Optical splitter, Optical switch, Optical power, Optical fibre, Power IR laser, Photovoltaic power converter PPC-4E

Received: 15 November 2021, Revised 23 February 2022, Accepted 1 March 2022

DOI: 10.6025/jes/2022/12/2/48-54

1. Introduction

In the case of high level and high-frequency electric interferences under extreme meteorological conditions, explosive environment etc., it is not appropriate for the sensors to get charged with copper conductors or standard photovoltaics [1,2]. Lately there has been a trend for optical fibers to be used for photon energy transmission in the range of 100mW~2W, generated by a laser diode for the charge of remote smart sensors [3,4]. For that purpose specialized photovoltaic power converters are being offered with a convertor for coupling to optical fiber [5,6] (PPC-E – for 12V, 6V and 4V).

The article reviews the possibility of optical power sharing using two photovoltaic convertors PPC-4E with the purpose of autonomous charging of two separated smart sensors, positioned at a distance from each other.

The sharing of the optical power, coming from the IR laser, to the relevant photovoltaic inputs have been made by a passive optical splitter [7]. The main task of the following release is to present alternative schematic for sharing of optical power, which would have better energy characteristics by specific consumption in the grid circle and conditions of exploitation. There are also algorithms for controlling both types of grid charging.

In addition in the following article both circles of optic power sharing have been analyzed. The main purpose is to compare their energy efficiency as well the conditions in which the suitable method could be used.

2. Principle of Operation

2.1. Optical system for distribution of photon power with an optical splitter

A splitter with two outputs has been chosen for the purpose of receiving more energy at the outputs, which has to be delivered to the corresponding photovoltaic by a 62.5 µm core diameter multi-mode optic fiber. The sharing energy at the splitter 1x2 is equal at every output (each 50%) with a loss of 3.83dB.

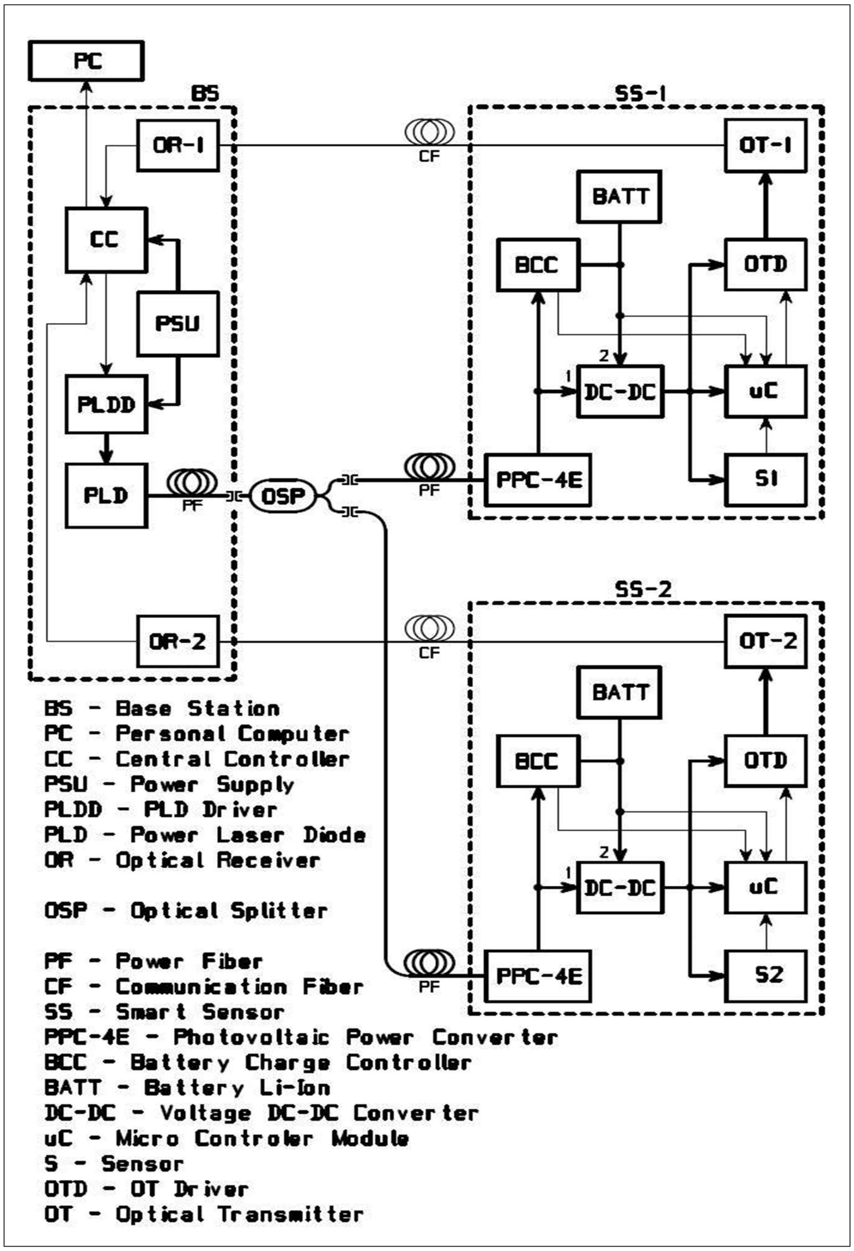

Figure 1. Optical network with a splitter

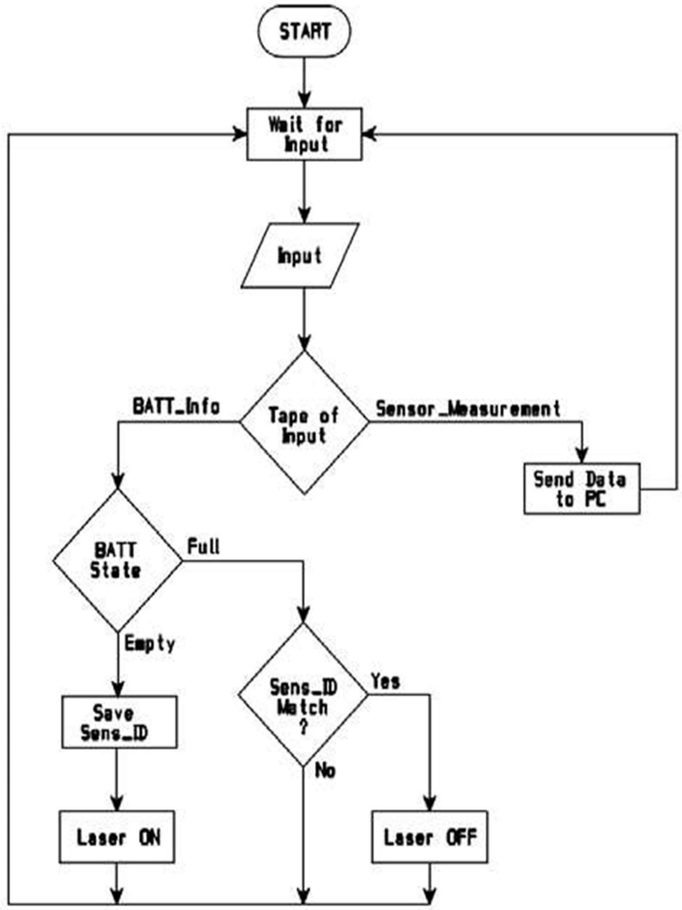

Figure 2. Algorithm for optical network with a splitter

In the Figure 1 was represented a block diagram of an optical system for optical energy sharing with optical splitter. Microcontroller in the smart sensor SS, parallel with his main functions, observes the condition of the Li- ion battery. When the voltage of the battery reduces to a level of 3V, there is a request for recharging to the central controller transmitted through the optical transmitter on the channel for data CF (optical communication fiber). The central controller switches on and drives the powerful IR laser diode PLD through the PLDD driver. The photon energy from the laser, at the input of the optical splitter OSP, splits equal to both exits. The light energy, through optical fibers PF (electric cable), distributes simultaneously to both photovoltaic converter PPC-4E, then transforms in electric energy and both charger devices BBC in the sensors start charging the batteries. Until the charging process lasts, DC-DC converters supply the sensors with electrical energy, that comes from the input 1 (the voltage of photovoltaic). DC-DC converters have been designed to automatically switch and use the voltage of inputs 2 (voltage of the batteries), when the voltage of inputs 1 are zero (voltage of photovoltaic). That happens, when the charging of the batteries is over. As opposed to the sensor, which requests starting of charging process, the battery of the other sensor is not empty, but after the powerful laser switches on, the photon energy, delivered to the optical splitter, enters equally to both photovoltaic cells and both batteries are starting to recharge simultaneously. The battery with the higher voltage at the beginning of the process will charge to 4,2 V earlier and the sensor SS2 indicates to the central, that the battery is fully charged. The central controller CC checks the ID address of the relevant sensor and confirms that this sensor has not given any request for charging and continues with the charging. When the battery is charged to the level of active mode of sensor SS2, it receives energy trough the DC- DC converter of the photovoltaic, but if the sensor is in sleep mode, then the delivered energy of the photovoltaic would be spend inefficiently. In the moment when the central controller receives the output signal from the relevant sensor, that the battery is fully charged, the charging process disconnects.

In Figure 2 has been described the specified algorithm of operating of the grid.

2.2. Optical System for Distribution of Photon Power with an Optical Switch

The difference between optical splitter compared with optical switches is, that the photon energy is sharing simultaneously and equal to all of the exits by the splitters and the full energy is distributed only in one output channel, which is the focus of the mirror, by the switches.

The experiments in the article are made for optical switch with 1 and 2 outputs with 62,5 μm core diameter multimode optical fiber. The losses on the first exit are 0,58 dB and for the second 0,35 dB. The maximal optic power, which is the limit of working conditions for the switch is 500mW at a wavelength of 850nm. The switch time from one position to another is 8 ms. The control system of the switch is digital through l2C or TTL interface.

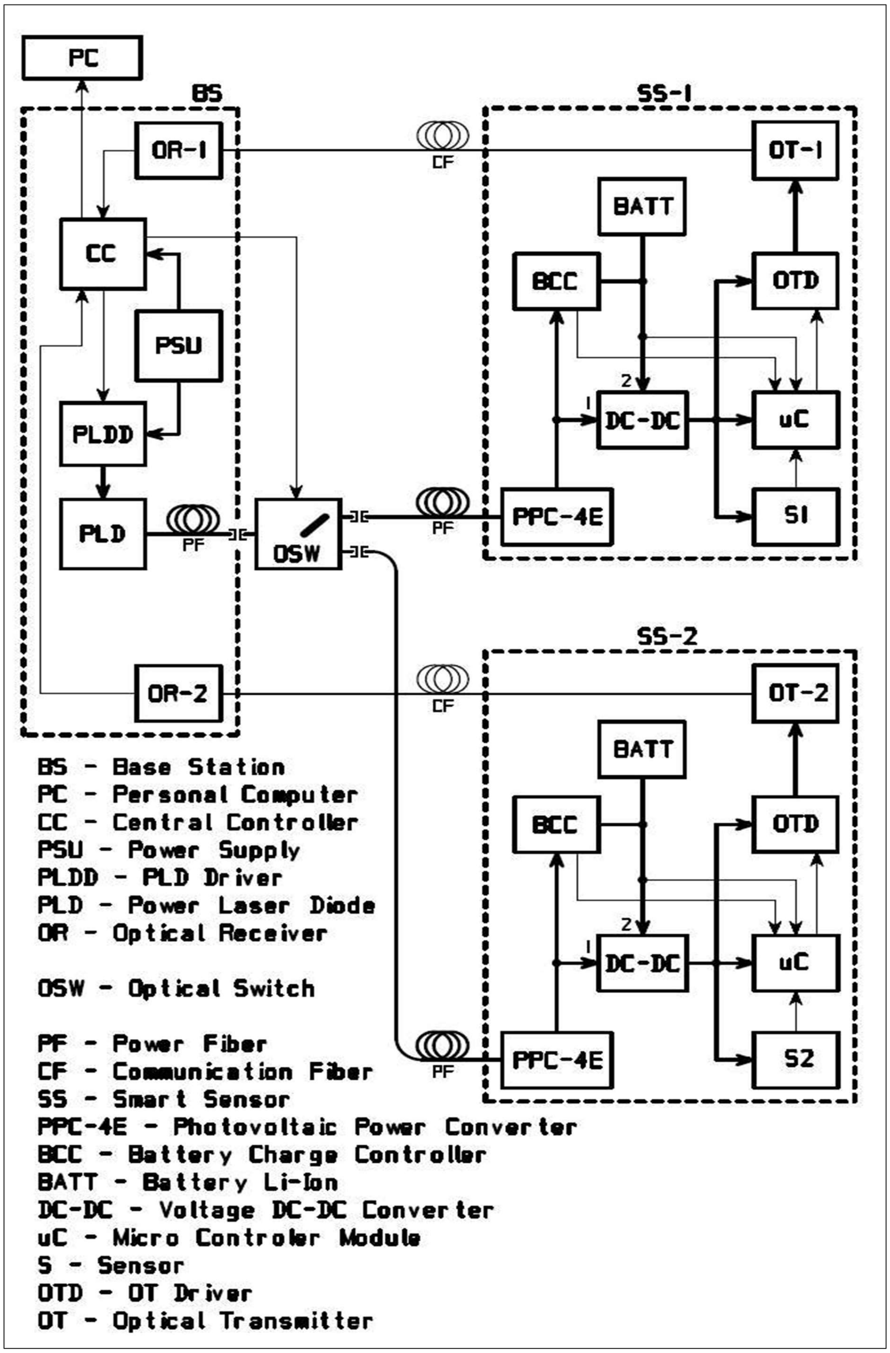

Figure 3.Optical network with a switch

The block diagram of distribution of photon energy with an optic switch is described in Figure 3. When the smart sensor SS1 sends request for charging to the base station, the main controller CC manages the optical switch through I2C interface and aims the mirror to the outputs of the optic fibre to the direction of the relevant sensor. With the help of the PLDD driver the main controller switches on and controls the powerful IR laser diode PLD with a maximum power of 500mW. Compared to the splitter, the optic switch delivers the whole photon energy through the optical fibre to the photovoltaic of the relevant smart sensor. When the battery is charged to 4,2 V, the smart sensor sends a signal to the main station thorough the communication optical fibre CF, the central controller stops the power laser and the process of charging interrupts. The same process replays by the charging of the other sensor. The frequency of charging of the smart sensor in the grid depends on the time of charging of the batteries. Because the charging of the sensors is successive, it is necessary that the sensors be chosen with different consumption from the batteries or with phase displacement by the charge process, in order for the system to charge them just in them with energy. The main target is to avoid the situation of charging both of them simultaneously. For the optimisation of the charging time the battery must start to be charged from the moment of voltage under 3,5 V (0,2 V under the nominal value). The consumption and the time of active regime of the sensors to be distributed without critical situations is of great importance in the design of this type of sensor system, where the both sensors must be charged simultaneously.

The block algorithm which describes the work principles of the optic system for sharing of photon power with optical switch is shown in the Figure 4.

3. Design Instruction

At the beginning of the design of the optic sensor grid must be evaluated the main energy losses as a sum of the losses of every single component from the pick tail of the powerful laser to the photovoltaic device [8]:

$$B = n_{connector} B_{connector} + n_{splice} B_{splice} + z.b_f + B_S \text{ [dB]} \tag{1}$$

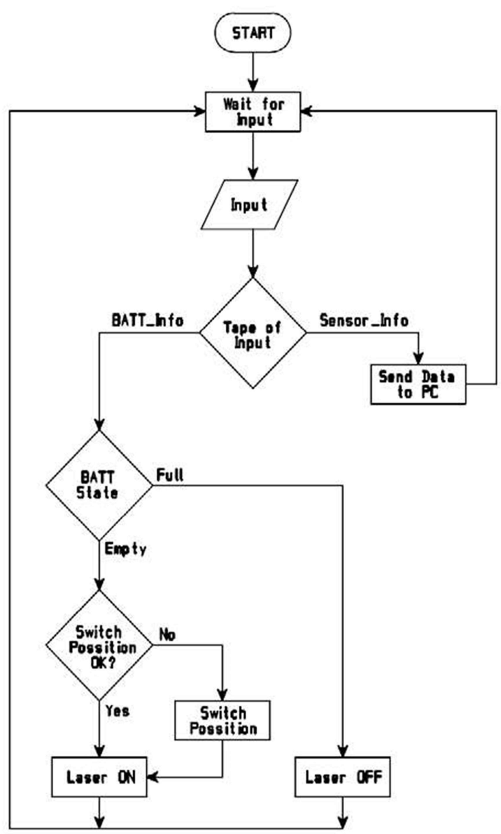

Figure 4. Algorithm for optical network with a switch

as they follow: $n_{connectors}$ = 2 is the number of connectors from the sensor to the base station, $B_{connectors}$ = 0,5dB are the losses in the connectors, n_{splice} = 2- number of the weld seams in the optic fiber B_{splice} = 0,1 dB- those are the losses in the welds of the optic fiber, bf = 2,7 dB/km are the losses for a kilometer through multimode 62,5 μm optic fiber with light with length of the wave of 808nm [9]. The length of the optic fiber in centimeters in "z", measured in kilometers. B_S are the losses in the optic distributor as it follows: optic splitter - B_S = 3,83dB and optic switch B_S = 0,58dB for the first one and B_S = 0,35 dB for the second output. From the equation (1) the main energy loss for the optic system with splitter is B = 6, 38 dB, for optic system with optic switch is B_S = 3,13dB for the first and B_S = 2,9dB for the second output.

The energy design of the optic system is a response of the following equation:

$$P_S = B + P_{PV} \quad \text{[dBm]} \qquad (2)$$

here P_S is the optical power of the source of light, in our experiment IR laser, B- the main energy losses in the optic system and P_{PV} -The optic power on the input of the devices of photovoltaic converter. From equation (2) for the calculation of the provided optic power in the system we obtain the following condition:

$$P_{PV} = P_S - B \quad \text{[dBm]} \qquad (3)$$

The IR laser with an optical power of 1W (30 dBm) has been chosen for the optic system of photon energy sharing of with passive splitter, where every photovoltaic have inputs power of P_{PV} = 23,6 [dBm]. In the optic system with optic switch, the power of the IR laser has been reduced to 500mW (27dBm). When we add the losses in (3), we obtain the optic power in the first output of the photovoltaic P_{PV} = 23,9 [dBm] and on the input of the second P_{PV} = 24,1 [dBm].

We convert the power from dBm to W with the following equation:

$$P_{(mW)} = 1mW.10^{\frac{P(mW)}{10}} \qquad (4)$$

After the convert from (4), by the system with splitter with input optic power of 1W, every photovoltaic of the equipment receives $P_{(mW)}$ = 229 mW. For a system with switch and adjusted power of 500mW input optic power, the hardware of the first photovoltaic receives $P_{(mW)}$ = 251mW and at the input of the second $P_{(mW)}$ = 257 mW optic power.

In Table 1 we can see the dependency of the maximum output electric power with adjusted different levels of experimental power on the input of the photovoltaic [6].

Optical Power (mW)	**100**	**250**	**500**	**750**	**1000**	**1500**	**2000**
P_{max} (mW)	34.8	86	168	240	304	432	512
V_{mp} (V)	4.4	4.3	4.2	4	3.8	3.6	3.2
I_{mp} (mA)	8	20	40	60	80	120	160

Table 1. Electrical power by different levels of optic power for photovoltaic PPC-4E

4. Conclusion

When the times of voltage drop of the batteries are almost the same, the use of an optical splitter sharing of photon energy is the better solution, because it gives the opportunity for simultaneously recharging of all batteries in the optic grid. A larger number of sensors will need a splitter with a larger number of outputs, which comes with higher optic power of the supply laser. The use of a more powerful laser is considered as a disadvantage, because they are more expensive and the increase of the optic power leads to the destruction of the structure of the optic fiber [10]. That's why there is a limit of the optic power through the fibers and it will limit the number of the sensors. A disadvantage of this method of sharing of energy could be the ineffective usage of the energy from the sensors, which need to charge their battery, but they are in sleep mode.

The usage of optic switch as sharing of optic power is the better decision, when the times of discharge are different and it is possible every single battery to be charged separately. Compared to the splitters, the optical switch sharing of optical power is discrete to every fiber, which allows the usage of laser lower power supply. This makes this type of system more energy effective. Because of the limitation of the power to 500mW, the working power of the switch, the usage of microcontroller and sensors is necessary. The biggest effort comes with the management of the time for charging of the separate sensors and the avoidance of the situation, when two or more sensors must be charged simultaneously. With bigger number of sensor this issue definitively grows. The possible solution could be made with the software with the building of command structure between the sensors in the optic system. That means, that the sensors which have more time in active mode must be with higher priority for recharging in compare with others, which are higher time in sleep mode.

From the analysis and the comparison of the both models for sharing of photon energy can be noted, that the system with optical splitter is technically easier for construction and maintenance and also cheaper.

The method of sharing of optic power with optic switch has better energy effectiveness in the following aspect: the whole optic energy is used for charge, the supply laser is two times less powerful, the effective moment power by the separate sensors is a little bit higher, because of the lower losses in the switch.

References

[1] JDSU (2006). Photonic Power Solutions for Sensor Applications.

[2] Werthen, J.G., Cohen, M.J., Wu, T.C. & Widjaja, S. ELECTRICALLY ISOLATED Power Delivery FOR MRI APPLICATIONS, photonic power business unit. Proceedings of the Intl. Soc. Mag. JDSU: Milpitas, CA, USA.

[3] Furey, J. & Anaheim, C.A. (2009)/0016715 (US), Power over optical fiber systems, Ulllted States Patent Application Publication, No: US, A1.

[4] Wilson, C., Kawasaki (JP) & Chee, S.S. (2010) Kokubunji (JP); Nutt L. Houston, TX (US); Yamate T.,Yokohama (JP); Kamata M., Kawasaki (JP); Methods and apparatus for photonic power conversion downhole, Ulllted States Patent, No. US 7,696, B2, 901.

[5] JDSU (2006). Photovoltaic power converter, 12v, (PPC-12E), datasheet.

[6] JDSU (2014). Power over Fiber Kit PPM-500-K.

[7] JDSU (2014). Power over Fiber.

[8] Mitzev, C. & Dimitrov, K. (2013), Optical Communications seminar exercises guide, Technical University, Sofia, ISBN:978–954- 438-77-8, pp. 10–27.

[9] Corning Incorporated (2011). *Corning Clear Curve Multimode Optical Fiber Product Information,* pp.2-4.

[10] Seo, K., Nishimura, N., Shiino, M., Yuguchi, R. & Sasaki, H. (2003). *Evaluation of high-power Endurance in optical fiber links. Furukawa Review*, 24.