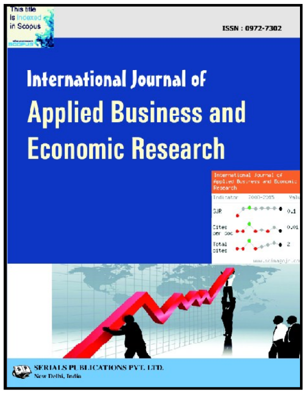


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# Relation of Signals for Time to Time Energy Transfer Monitoring of Solar Cells Toward Efficiency

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***Abstract:*** The need of energy, especially electric energy grows very rapidly. Currently, fossil fuels are still among the most important energy sources. Unfortunately, fossil fuels are not sustainable energy nor environmentally friendly. It is desired, and there is already a trend, to produce electric energy from the sources that are environmentally friendly, such as solar energy which is sustainable. However, the efficiency is still one of basic issues on the transfer of solar energy into electric energy. This paper deals with analysis of transfer from solar energy into electric energy in solar panels. The main interest is on time to time efficiency, where it can be achieved by time to time relation of transfer from solar energy into electric energy. This information is in the need for energy management for minimizing energy use and environmental purposes. To do so, secondary data of real time monitoring of solar energy, and electric energy produced by solar panels were investigated. The data were in time series, the time intervals were an hour and the length of obeservations was five days. Solar energy was represented by the light illumination (in flux) and electric energy represented by the energy in a unit time (in watt). The relation of these time series was sought by applying a least square method and a linear relation of two signals. For the analysis by applying a linear relation of signals, the solar energy was considered as input signal and electric energy was as output signal. Both analyses gave the same slopes meaning that the efficiency of the transfer. The relation of signals, however, yielded more details which time to time relation which of the solar energy and the electric energy.

***Keywords:*** electric energy, energy efficiency, real time monitoring, solar energy, sustainable energy.

## I. INTRODUCTION

The need of energy, including electric energy, grows faster over time. In the last decades, the sources of energy mostly were from fossil fuels, and nuclear energy. Fossil fuels accounted for about 88% of the commercial energy sources used (Judkins, 1993). In Japan energy used in 2010 increased about 70% compared to 1970, and 85% to 90% of the supply was from fossil fuels (gas, oil and coal) (Ishida, 2013). Recently, China, India, Brazil and South East Asia nations lead the increases of the energy demand in-line with their economic growth and population domination. The energy demand in ASEAN was dominated by Indonesia and Malaysia, Singapore and Brunei (Utama *et al.*, 2014). Population density seemed to affect fuel demand in a non negligible way, (Johansson and Schipper, 1997). Again, most of the supply was from fossil fuels. Although substantial increases in energy derived from other sources, fossil fuels would remain a major energy source for much of the 21st century Patel (2014). It is desired, and there is already a trend, to produce energy from the sources that are environmentally friendly.

Modern society avoids or at least minimizes the use of fossil fuels. It is not only the fact that fossil fuels contribute to the air pollution, but fossil fuels are also believed to be responsible for global warming and climate change. Global warming might occur as a result of the release of the so-called greenhouse gases, such as carbon dioxide ($CO_2$), methane ($CH_4$), chlorofluorocarbons (CFCs) (e&, refrigerant gases such as the Freons), nitrous oxide ($N_2O$), and $O_3$, (Smith 1988). Some of them are products of fossil fuels. It needs long time research to relate fossil fuel with global warming and climate change. However, some recent reports about this can be found in World Energy Resources Survey (2013), Energy and Climate Change (2015). Climate change has been a big discussion also in public media as reported in Rogala (2011).

Despite of some researchers did not agree with the idea that fossil fuels directly affected the climate change and global warming, it was still advised to reduce the use of fossil fuels. Brkic (2009) said that human activity including fossil fuel consumption was not the only thing responsible for global warming. Moreover, in (Brkic, 2009) it was also concluded that the human race had to decrease pollution, but this pollution was not always the main reason for the disturbances in the fragile nature balance. On the other hand, fossil fuels are depletable. As the use increase rapidly, the deposit decreasing rapidly. Muda and Tey (2012) reported the prediction of depreciation time of fossil fuel in Malaysia.

It is desired, and there is already a trend, to produce electric energy from the sources that are environmentally friendly and sustainable energy such as solar energy. Some issues on solar energy are the location and the efficiency of the apparatus to transfer solar energy to the desired energy. For the case of transferring solar energy into electric energy the apparatus is solar cell. Research to improve the efficiency mostly has been focused on the material development of the cells. Some recent research on this can be found in Ibraheam (2016), Muzillo (2016), Sun and Cheng (2016). The efficiency of the cells in the 'market' (industrial products) was about 14%. Higher efficient cells are often still under-research or laboratory products. Efficiency of the cells in the end users may still be done by installing the apparatus properly such that they can capture as much solar light illumination as possible, for instance by absorptive/reflective solar concentrator Meng (2016). All of this effort means minimizing energy loss.

Energy loss always occurs in transferring energy from one form to another form. Based on the conservation of energy, it was basically not the energy that was loss. It was just not the energy form in the need. Take an example, power losses occur in the vehicle and the building systems supplying the vehicle when charging or discharging electric vehicles, and understanding loss factors was important to efficient design and use. Apostolaki-Iosifidou *et al.* (2017) conducted research this issue, and obtained that the losses vary from 12% to 36%. The energy loss is an important part of to improve efficiency of the transfer energy apparatus and the use. During the process, the efficiency may be monitored in real time. Baldi *et al.*

(2017) conducted real-time monitoring energy efficiency for energy transfer apparatus boiler. Real time monitoring might provide data for time to time analysis of the transfer, where the results could be important for the efficiency. This paper reports time to time analysis of energy transfer in solar cells.

## II. DATA AND METHOD

### Data

Secondary data in time series were considered from (Asy'ari *et al.*, 2012). The data consisted of solar or light illumination (in lux) and electric energy (per unit time) produced by the solar cells (in watt). For short, terminology light illumination and electric energy will be used. The data was obtained from five days observation, measured every hour. The missing data in the interval of time during the night, i.e. from 18:00 to 06:00 were set to be zero, meaning that there was no light illumination received and no electrical energy produced by the solar cells. In mathematical notation of sets, the two groups of data is in sets of ordered pairs

$$A = \{(t_i, x_i) : 1 \le i \le 109\} \tag{1}$$

and

$$B = \{(t_i, y_i) : 1 \le i \le 109\} \tag{2}$$

where $x_i$ and $y_i$ are light illumination and electric energy observed at time $t_i$. The time $t_1$ was at 6:00 day 1, $t_2$ was at 7:00 day 1, etc. and $t_{18}$ was at 24:00 day 1. At 1:00 day 2 was set as $t_{19}$, 2:00 day 2 was $t_{20}$, and so on. Finally, $t_{109}$ was at 18:00 day 5. The extended data for full five days were graphically presented in figure 1.

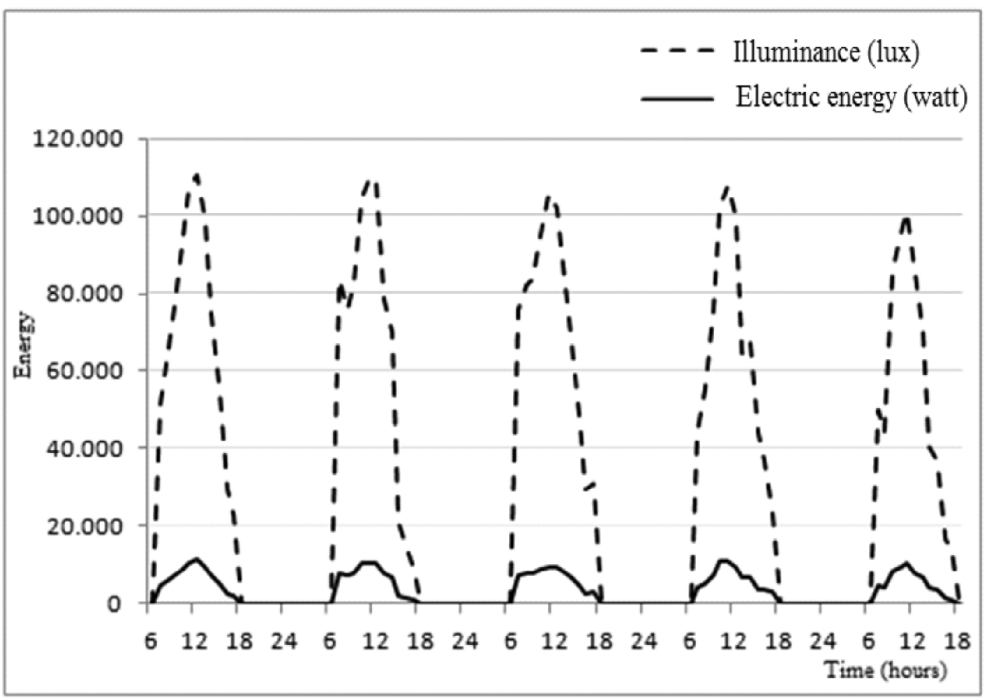


**Figure 1: Data of light illumination and electric energy**

### Method

In conventional way, the relation of the time series of the light illumination and of the electric energy may be obtained by applying a least square method. There are many available source of references for least square methods, (Neter *et al.*, 1990) is one among others. However, least square methods merely provide general relation of two groups of data. Least square methods seek a trend of the relation of a group of data where mathematically is in the form of a set of ordered pairs. For the case of data in equation (1) and (2), least square methods merely considered ordered pairs of $x_i$ and $y_i$ in the set $C$

$$C = \{(x_i, y_i) : 1 \le i \le 109\}. \tag{3}$$

These methods do not provide time to time relation where which is a necessary information for time to time efficiency of energy transfer. On the other hand, linear relation of signals gives time to time relation which provides time to time information for efficiency.

Linear relation of signals was introduced in (Cahyono, 2014). Time series may be considered as a discrete or continuous signal. Let $f(t)$ and $g(t)$ be any signals, where $f$ and $g$ are (mathematical) functions with respect to time $t$. Sets $A$ and $B$ in equation (1) and (2) are discrete functions with respect to time $t$. Linear relation of $f$ and $g$ is given in the form of

$$g(t) = af(t - T) + b + \varepsilon(t) \tag{4}$$

Equation (4) also represents time to time transfer from signal $f$ to signal $g$. In this representation, parameter $a$ is time to time transfer efficiency from $f$ to $g$, parameter $T$ is time lag of the transfer, parameter $b$ is the correction coefficient and $\varepsilon(t)$ is the error. Mathematically, these parameters are sought by minimizing the 'norm' of the error $\varepsilon(t)$. For the application of this paper, signal $f$ and $g$ represent light illumination and electric energy, respectively.

## III. RESULT AND ANALYSIS

Applying a least square method, it was obtained a linear trend of the relation of two data groups below:

$$y = 0.099x - 7.990. \tag{5}$$

The presence of the trend among the two groups of data graphically is presented in Figure 2. This is a good approximation, all points are close to the trend line which is equation (5). Equation (5) can be interpreted as follows. The slope of (5), which is ten percent (0.099), represents the light illumination that was transformed into electric energy. When there was no light illumination, however, the electric energy was negative (-7.990), the intercept of (5). The intercept is expected to be non negative. Theoretically, it is because the electric energy should be non negative, meaning that there is no backward electric current.

The time to time of energy transfer cannot be captured from Figure 2. It only represents general trend the amount of electric energy produced by solar cells from certain value of light illumination. Linear relation of signals was applied to investigate time to time energy transfer. Let $f(t)$ and $g(t)$ represented signals of light illumination and electric energy at time $t$, respectively. Signals of light illumination and electric energy have been presented in Fig. 1. The relation of those signals is (following Cahyono, 2014) given in the form

$$g(t) = af(t - T) + b,$$

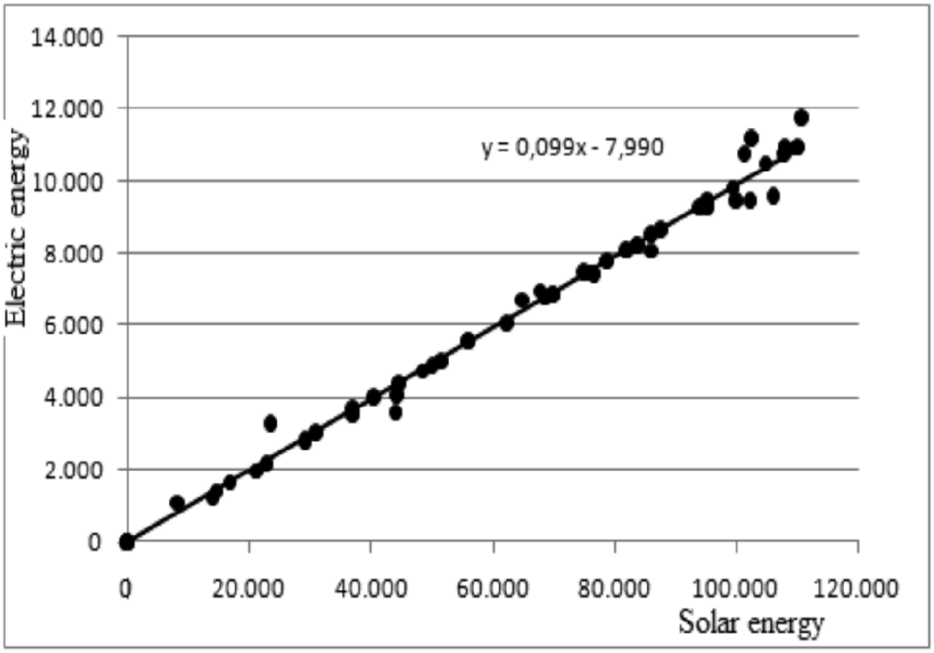


**Figure 2: Graphical representation of light illumination data, electric energy data and the trend of the relation of the two goups of data**

where $a$ is time to time transfer efficiency of light illumination to electric energy, $T$ is time lag of the transfer, and $b$ is the correction coefficient. Minimizing the error, it yields

$$a = 0.09888,\ b = 0,\ \text{and}\ T = 0.$$

Hence,

$$g(t) = 0.09888\, f(t). \qquad (6)$$

Equation (6) can be considered as a prediction of time to time energy transfer. Note that the efficiency of cells often used is about 10%. The time lag which was very small could not be captured by the data recorded in an hour. Figure 3 shows electric energy and prediction given by equation (6). Observe that the data of electric energy and the prediction coincide. There are small mismatch at 12:00 on day 3. This is related to the high temperature during mid day which affected to the efficiency of the cell in producing electricity.

There are several differences and similarities of results from least square methods and from analysis of linear relation of signals. Graphically, it is straightforward by observing the differences of Figure 2 and Figure 3. Figure 2 merely shows a linear trend of the relation of electric energy and light illumination without information about time. On the other hand, Figure 3 shows time to time comparison between electric energy and the prediction from relations of signals. Both show the same slope that is 10% which is in good agreement with comparing data of electric energy and light illumination. Comparison of electric energy and light illumination data is presented in Figure 4. For data which were zero, the comparison was taken as linear interpolation from two adjacent non zero data. Observe that the comparison was in the interval of 8% to 14%.

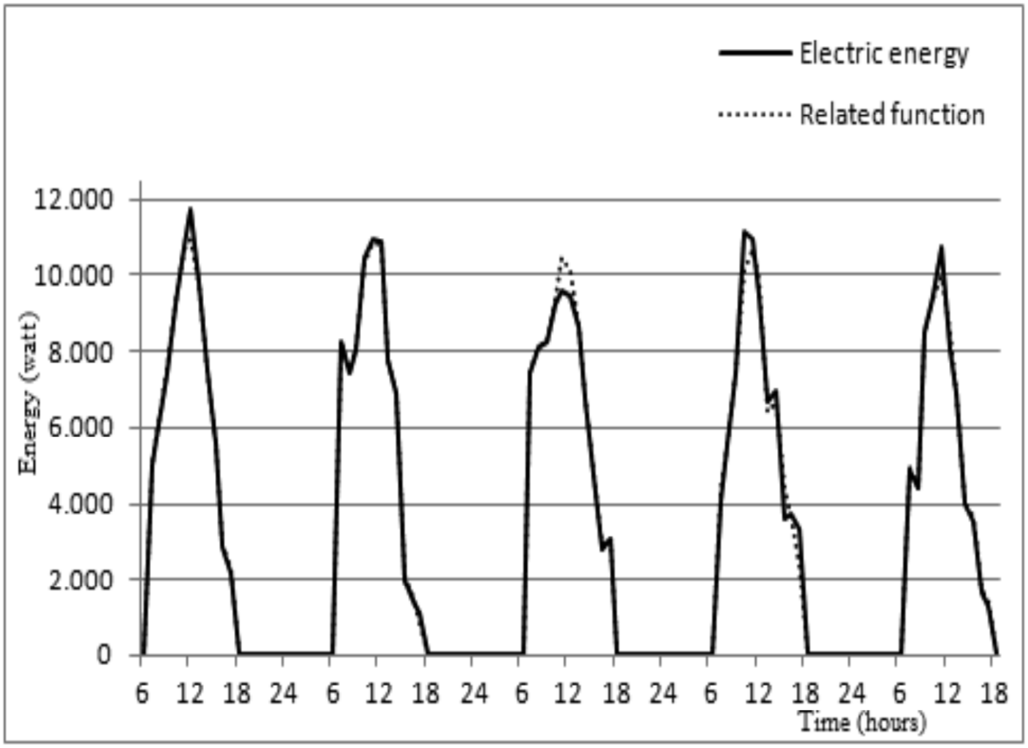


**Figure 3: Linear relation of time series data of light illumination and of electric energy**

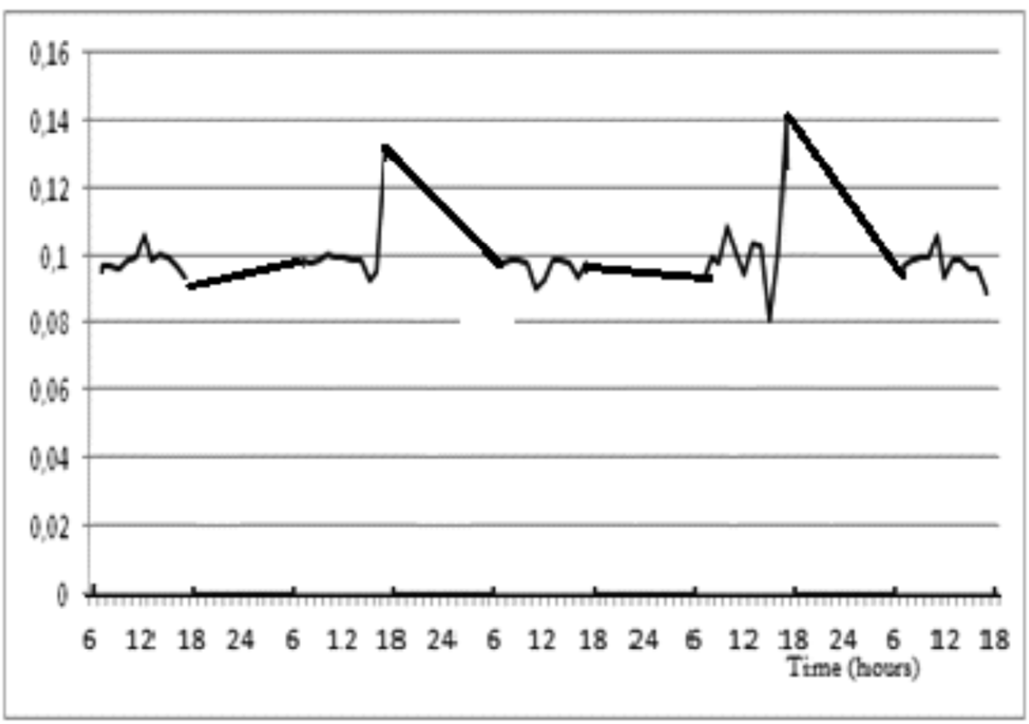


**Figure 4: Comparison of electric energy and light illumination data**

## IV. CONCLUSION AND FURTHER RESEARCH

Energy transfer for solar light into electricity has been considered. Secondary data from five days observation recorded every hour were analyzed by applying a least square method and linear relation of signals. Both analyses yield the information that the efficiency of the transfer is ten percent, which is in good agreement with the data comparison. Analysis by applying linear relation of signals gives more details where there is mismatch between data and analytical results during mid day observation. The electric energy during the mid day is maximum, but the efficiency is also the largest. It may be caused by high temperature that reduces the efficiency of the solar cells. The difference of time to time efficiency may also be caused by the time to time proportional difference of solar electromagnetic wave length received by the panels. Focus of further research will be to understand the energy transfer better. This will be necessary to improve the efficiency, especially during the day.

## ACKNOWLEDGMENT

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