Arranging solar panels to maximise power output
Problem 12

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Abstract

This report aims to deliver an efficient method of arranging solar panels in order to maximise the amount of power produced. The power produced by solar panels often depends not only on it's efficiency but also the panel's size, location and orientation. For example, a panel facing the ground or a panel which is constantly shaded will not produce very much power at all. Therefore, it is key to arrange panels in such a way that they are facing the sun (perpendicular to the direction of projected sunlight) for as much time as possible during the day. Various optimisation techniques will be explored to arrive at a conclusive method of maximising power production. However, provisional solutions will also be considered in suboptimal conditions, such as when given solar panels are not of the same specifications (different voltage/current ratings) or in seasonal cases where panels must be adjusted to maximise their power output. The report will hopefully then provide a general method for maximising panel power production that adheres to a suboptimal situation as well as an optimal situation.

1 Introduction

Maximising the power production of solar panels has been of utmost importance to both the public and private sectors since solar panels were first produced in 1954 by Daryl Chapin, Calvin Fuller, and Gerald Pearson of Bell Labs. These first photovoltaic (PV) cells had an efficiency of 6 percent. By 2016, the record of PV cell efficiency had reached 34.5 percent courtesy of the University of New South Wales, Australia. While 34.5 percent may seem like a low number, in terms of efficiency it is very high. Outside of these technological advances, we can improve the power production of panels through taking simple measures pertaining to the arrangement, orientation and size of the solar panels. In fact, through these simple measures we can see huge increases in power, which will be demonstrated.

There are many factors which must be considered when it comes to maximising the power produced by a given set of solar panels. These span from the latitude of the location of the solar panels (for example, the the latitude of London is 51.50 degrees and of Bristol 51.45 degrees). Since the sun moves across the sky throughout the day, it is helpful if the solar panels can be tilted across different angles to keep the solar panels perpendicular to the sun throughout the year. This is because the voltage generated in the solar panels is at a maximum when the panel is perpendicular to the direction of projected sunlight.

2 Solar panel circuits

In order to determine the power output, we need to first know the solar panel specification. To start with, the power relation for electricity is given by:

$$P = VI = V^2/R \tag{1}$$

The power output is equal to the voltage multiplied by the current which is equal to the voltage squared over the resistance. Solar panels are usually connected in an electrical circuit. Ideally, all solar panels in a circuit should be of the same type and rating. That is, of the same voltage and current rating. If all solar panels in the circuit are the same then they can be connected in series or in parallel, the power output is the same either way.

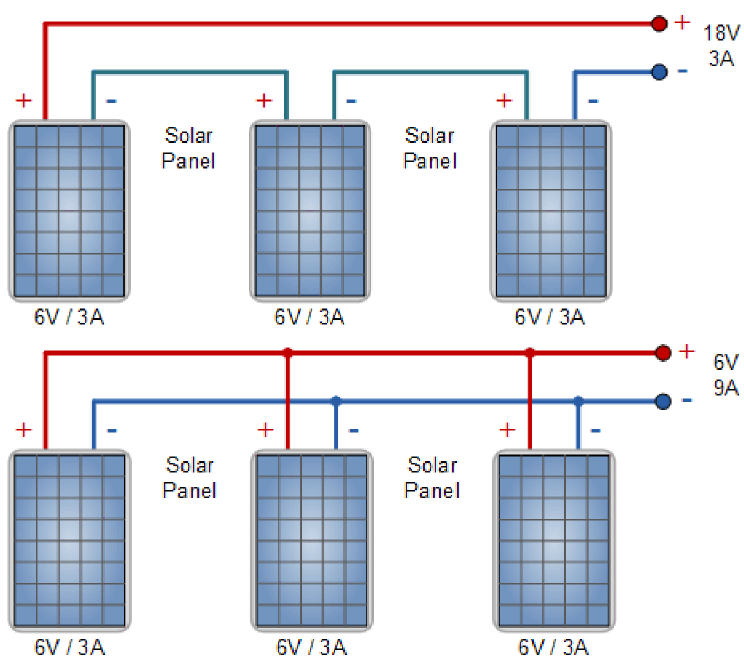

Figure 1: Solar panels connected in series and in parallel with rating 6V/3A [1]

In Figure 1, we see that with four panels connected in series. When in series, the voltages are summed up but the amperage remains constant. We get an output of 18 volts (V) and 3 amps (I). As in Equation (1), we can see that the power output would then be 18 x 3 = 54 Watts.

In Figure 2, we have the same panels except they are connected in parallel. When in parallel, the panel voltages are constant and the amperage is summed up. The output is now 6 volts and 9 amps, which gives the same power output when plugged into Equation (1) of 6 x 9 = 54 watts.

2.1 Problems with non-identical panels

As we see below in Figure 2, when non-identical panels are connected in series they are restricted. This is because for a circuit in series containing elements of different ratings, the lowest current of the elements is the output current. The voltage is summed, but due the first element being only 1 amp the total output power is 19 Watts. Therefore, the largest element on the left with rating 9V / 5A is only operating at 20 percent of it's potential (contributing 9 Watts instead of it's potential 45 watts), resulting a large loss of efficiency and money.

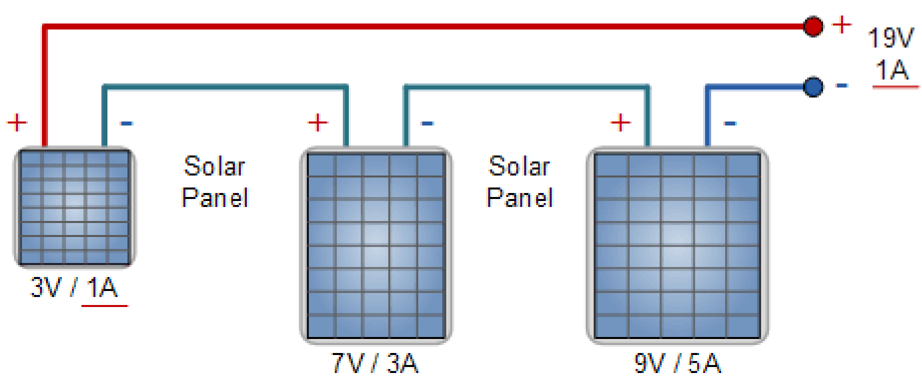

Figure 2: Solar panels connected in series with various ratings [1]

Similarly in Figure 3, where the circuit is in parallel, it is instead the voltage that is output at the rating of the lowest element. So the output voltage is only 3 Volts due to the first element, while the current is summed. This means that the total output power is only 27 Watts. Therefore, the largest element on the right is producing only 15 Watts, 33 percent of it's potential 45 Watts. While this is still non-ideal, it shows us that a parallel circuit is a better choice than a series circuit for these elements.

2.2 An algorithm for non-identical panel optimisation

In order to decide whether you should use a series or parallel circuit for your non-identical panels, use this simple algorithm, Algorithm I.

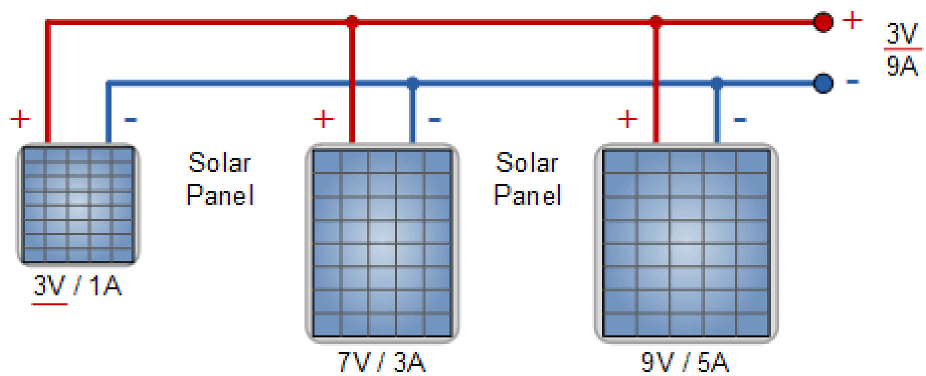

Figure 3: Solar panels connected in parallel with various ratings [1]

2.3 Algorithm I

1. Add up all the voltages of your panels. V_T
2. Add up all the currents of your panels. I_T
3. Find the smallest individual voltage of your panels.V_0, note the panel.
4. Find the smallest individual current of your panels.I_0, note the panel.
5. Multiply $V_T I_0$ and note the result, omit the panel with the lowest current I_0. Keep note of the omitted panel. Go back to 1 and repeat until the value of $V_T I_0$ becomes smaller than the last iteration. Use the iteration with the greatest value.
6. Multiply $I_T V_0$ and note the result, omit the panel with the lowest current V_0. Keep note of the omitted panel. Go back to 1 and repeat until the value of $I_T V_0$ becomes smaller than the last iteration. Use the iteration with the greatest value.
7. If $V_T I_0$ is the greater of the results from 4 and 5, you are done. Use a series circuit and do not use the omitted panels. Else go to 8.
8. If $I_T V_0$ is greater of the results from 4 and 5, use a parallel circuit and do not use the omitted panels.
9. If the results from 4 and 5 are equal, you can use either series or parallel.

3 Arranging panels over a rectangular area A

For identical panels, arranging them over a rectangular area A is trivial. Remember that identical panels can be placed either in a series circuit or parallel circuit. Use this algorithm, Algorithm II.

3.1 Algorithm II

1. Find the area A
2. Find the area of one of your panels, P
3. Divide A by P
4. If the result is a whole number, you are done. That is the exact number of panels that will fit into A. If it is not a whole number, go to 5.
5. The result is not a whole number, so round down and that is the number of panels you can fit into A.

Because of this simplicity, it is advisable to use identical solar panels whenever possible.

3.2 Arranging non-identical panels

The induced current in a solar panel (photovoltaic cell, PV cell) is directly proportional to the area of the panel. Therefore, I will be assuming that there are no differences in the efficiency between identical panels. That is to say, a smaller panel and a larger panel are comparatively the same (as in, the smaller panel if scaled to be the same size as the larger panel would yield exactly the same power output).

It is important to note that when using non-identical panels for an area A, less panels may actually be better than more panels. This is because squeezing a very small panel (which as previously stated, has directly proportional power output and therefore voltage/current rating) may restrict (bottleneck) the entire circuit and result in the power output of the larger panels being bottlenecked.

Therefore, I propose Algorithm III below.

3.3 Algorithm III

1. Use Algorithm I on page 4 to find your most efficient panel circuit.
2. Find the area A
3. Order your panels by identity, that is like for like.
4. Find the area of your largest identical panels P. Take note of these panels.
5. Subtract P from A, and replace the value for A used in 1 with this new value.
6. If A is negative, do not use the panels in this iteration and use all in previous iterations.
7. If A is positive, go back to 2.

4 Analysing the algorithms

It is clear by inspection that the algorithms will be very successful for very large solar farms (containing hundreds of large panels). If you have many identical panels, then *Algorithm I* will easily tell you how many panels will fit and you simply fit them.

Similarly, combining *Algorithm II* and *Algorithm III* will always resolve any non-identical dilemmas.

4.1 Example 1

If you have 100 solar panels with ratings 10V/5A connected in series, then you have a total power output of $(1000)(5) = 5000W$. If you additionally connect the 8V/4A in series, you then have $(1008)(4) = 4032W$, resulting in a nearly 20 percent power output loss.

If we make it 200 solar panels of the same rating, that the power output initially is $10000W$ which is reduced to $(2008)(4) = 8032W$

Now we can compare the efficiency loss:

$$4032/5000 = 0.8064 \tag{2}$$

$$8032/1000 = 0.8032 \tag{3}$$

So it is observed that as the number of panels increases, as well as their ratings, this differential in power output also increases. Therefore the algorithm works well for the large solar farms.

4.2 Problems with the algorithm

The algorithms are often not accurate for very small circuits. When tested with circuits involving circuits with only 4 panels, the algorithm does not produce the correct result. Average commercial solar panels have ratings around 12 volts and 9 amps. A single solar panel of this rating produces a power output of 108 watts. However, introducing a smaller panel with rating 8V/6A (direct proportions) produces a maximum power output of 120 watts.

Therefore, in such a case the algorithm would not work as it is better to connect the smaller panel. However, upon increasing this to two 12V/9A panels the power output is 216 watts. Adding the smaller 8V/6A returns only 192 watts of power.

Research shows that on average at least 4 solar panels are required for even a 1 person household [2]. Therefore, it is safe to assume that the algorithms will work for almost any situation.

5 Maximising energy production on a yearly scale

Due to the nature of the sun, the angles that solar panels stand at must be adjusted throughout the year to maximise power production. The angles at which the panels must be depends mostly on the location of the panels. For example, London has a latitude of 51.50 degrees and Bristol has a latitude of 51.45 degrees, which are both sufficiently close enough that they can be assumed the same.

As in Figure 4, we can determine the optimal angle for our panels in London or Bristol with a simple equation.

$$90 - L = \theta \tag{4}$$

Where L represents our latitude of 51 degrees and θ represents our optimum angle. So, we can plug in $L = 51$ to find that our value for θ is 39 degrees.

However, as in Figure 2, we can even optimise our power output further by adjusting our solar panel angle in the summer and winter. Since the sun is higher in the sky in summer, we might change our angle of incidence from 39 to something in the region of 62.4 degrees. In the winter, we could move our panel to an angle closer to 25.4 degrees.

The reason why the change of angle in summer and winter produces more power is that solar panels produce the most power when they are perpendicular to the direction of projected sunlight. That is to say, when they are at a 90 degree angle to the sun. By moving the panels in this way during summer and winter, we maximise the amount of time that the panel is at and close to perpendicular to the direction of projected sunlight.

$$P = VI = V^2/R \tag{5}$$

Recall this equation, when the panel is perpendicular to the direction of projected sunlight, the voltage produced by the panel is at a maximum therefore, since resistance can be considered constant, the power is also at a maximum.

5.1 How to angle the panels if on a slope

For panels on a slope, the most important factor is to ensure that they are facing perfectly South, or as close to South as we can get. That is, if we are in the Northern Hemisphere, which for the purposes of this report we are assuming (in cases of the Southern Hemisphere, we would face the panels perfectly south).

In some cases, the slope may help us. For a case in London with latitude 51 degrees, if the slope has an elevation angle like that in Figure 4, the solar panel will be rather well optimised simply laying on the slope. However, if the elevation angle of the slope was to increase or decrease, we would have to install the solar panel such that we could tilt it to receive more sunlight. As an example, if the angle of elevation is 10 degrees more than that in Figure 4, we would need to tilt it 10 degrees counter-clockwise to get back to that sweet spot of 39 degrees. Conversely, if it was 10 degrees less than that in Figure 4, we would need to tilt it 10 degrees clockwise to get back to 39 degrees.

Additionally we would want to place the solar panel(s) as high up the slope as possible to reduce the amount of shadowing that may occur once the sun moves beyond the slope.

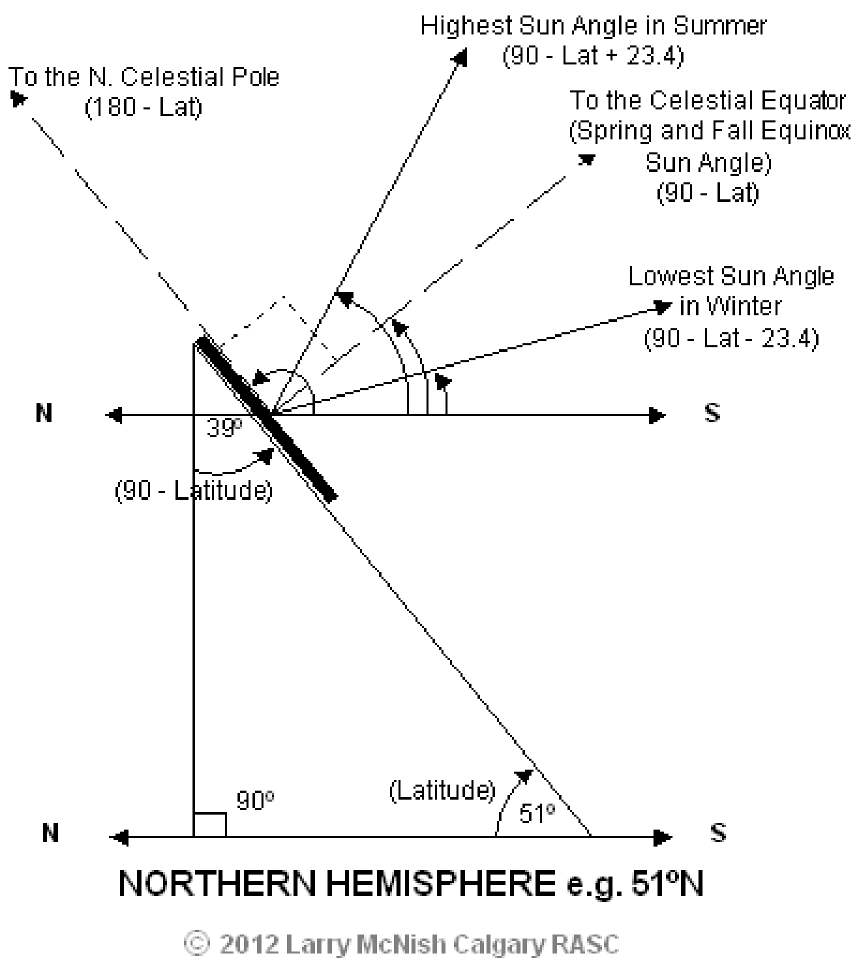

Figure 4: Optimal panel orientation for the latitude of London [3]

6 Conclusion

Orientation and arrangement is perhaps the most important part of solar panel efficiency. While technology is improving, we have to ensure that we are getting the most out of what we have now. Overall I am pleased with the methods and algorithms presented in this report, and I believe they are sufficient for many different situations regarding solar panels. The methods could be improved by testing them in the real world, particular against the methods of real companies and people who distribute and install solar panels. I was surprised to learn how the arrangement of solar panels in electrical circuits could have such a big effect on their productivity when connecting non-identical panels. Renewable energy is an obvious necessity given that non-renewable sources won't last forever; and since nuclear fusion had always been a topic of interest to me, discovering more about renewable energy was rewarding.

References

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[3] http://calgary.rasc.ca/solarpanels.htm